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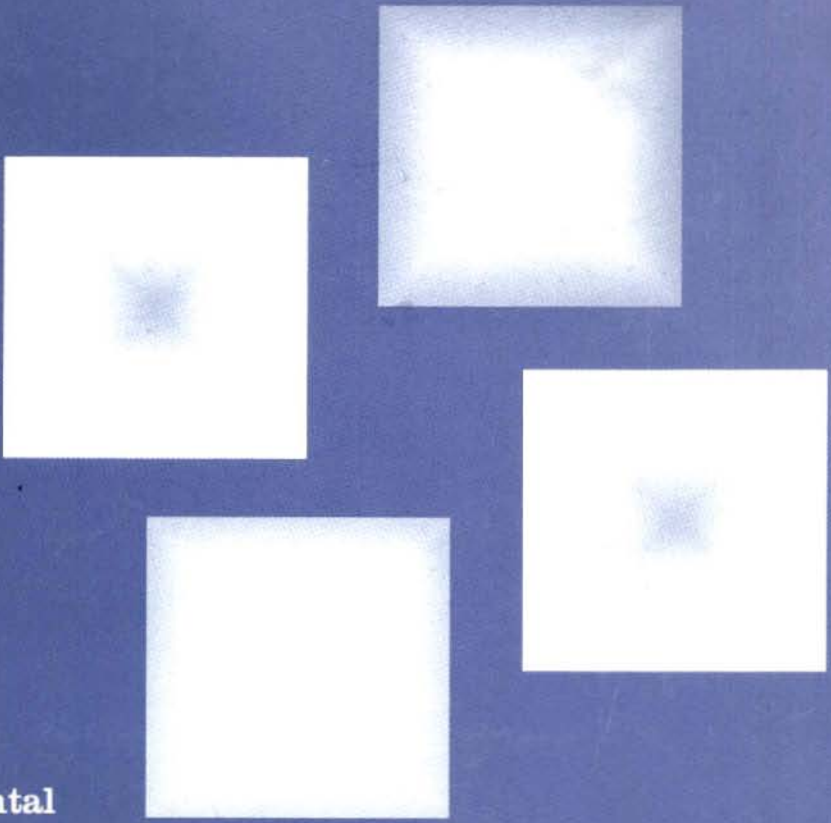
Management of solid wastes



Multimedia Postgraduate Course in Environmental Engineering

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IN ENGINEERING SCIENCES

Management of solid wastes

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COURSE TEAM

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PREFACE

In 1990, UNESCO conceived the Series of Learning Materials in Engineering Sciences (SLEMES) which was aimed at introducing new methods for teaching engineers. Within the SLEMES project, a number of teaching modules have been prepared for use at first degree level in African Universities. In the South-East Asian and Pacific Region, four such modules have been completed. This text module on Management of Solid Wastes is a product within the framework of the UNESCO SLEMES project. This project aims at preparing a Series of Multimedia Postgraduate Learning Materials in Environmental Engineering and is co-sponsored by the Commonwealth of Learning (COL), a Vancouver-based multi-national institution with an interest in distance education.

The global emphasis being placed on environmental protection in the past twenty years is justifiable. The immediate post-war decades of the 1950s and 1960s saw unprecedented advances in chemical technology which accentuated chemical and industrial pollution. The decades of the 1960s and 1970s saw the emergence of several politically independent states in Africa, Asia, Latin America and the Caribbean with the attendant rising population growth rates, rapid and unplanned urbanisation and industrialisation in these countries. All these "developments", coupled with the current global economic recession which started to manifest itself in the 1970s, have greatly accelerated global environmental degradation. Environmental problems range from the global types such as climate change and global warming, desertification and deforestation, ozone layer depletion, etc. to such local types as the provision of an adequate and wholesome water supply and hygienic basic sanitation, etc.

There is an increasing shortage of engineers and scientists with adequate education and training to tackle the ever increasing and emerging environmental problems of the last decade of the twentieth century and beyond. UNESCO has always demonstrated concern and leadership in the education and training of engineers as has been clearly exemplified by its widely circulated publication titled *The Environment in Engineering Education* (1980). The Commonwealth Secretariat's contribution titled *Sustainable Development: An Imperative for Environmental Protection* (1991), to the June 1992 Rio de Janeiro World Conference on Environment and Development is noteworthy for its concern on the problems of institutional development and technology transfer to small Island States. UNESCO and COL have further demonstrated their interest in the environmental education and training of engineers and scientists by agreeing at a June 1991 Port-of-Spain (Trinidad) consultation to develop a Series of Multimedia Postgraduate Learning Materials in the following selected environmental engineering topics:-

(i) Management of solid wastes;
(ii) Municipal water and wastewater treatment;
(iii) Groundwater and soil pollution from agricultural activities;
(iv) Selected topics in environmental management;
(v) Air pollution control.

A UNESCO/COL Advisory Board Meeting held in Leuven, Belgium, 6-8 February 1992, refined the syllabuses of the modules and selected six international teams and their co-ordinators. In keeping with the global nature of the porject, each UNESCO Regional Office for Science and Technology was assigned the task of producing one module. UNESCO Paris was reponsible for the preparation of this module on Management of Solid Wastes.

In this module the management of solid wastes is treated as a system comprised of a number of functional elements or operations linked together in a rational manner for the purpose of achieving specific objectives. The principal objective of the system is to collect and dispose of the solid wastes of a community at minimum cost while preserving public health and ensuring negligible impacts on the environment. Among the constraints to which this system is subject are : national and personal income, foreign exchange, level of social and economic development and the social customs of the community.

Chapter 1 introduces the subject through an overview of the entire module and establishes the concept of appropriate management methods having regard to widely differing circumstances from country to country and especially between the developed and deloping countries. This more global treatment of the subject breaks new ground in that it is an approach not used in standard texts. Understandably these are pitched to the paticular conditions in the more affluent countries.

The material contained in Chapters 2-6 follows a logical course, reflecting the path of solid wastes from source to final disposal. The discussions essentially concern municipal solid waste, the management of which falls within the purview of government and quasi-government authority. Worked examples and case studies are included, where appropriate, to assist the student in his/her study of the module. An additional Chapter presents a series of self assessment questions.

UNESCO acknowledges with thanks the contributions made by the authors : Professor H. O. Phelps, Department of Environmental Engineering, University of the West Indies, Tridinad and Tobago, the text editor and co-ordinator, Professor G. W. Heinke, Department of Applied Science and Engineering, University of Toronto, Canada, Professor J. F. Jonker, Faculty of civil engineering, Delft University of Technology, the Netherlands, Dr. E. A. R. Ouano, Consulting Engineer, Makati, Philippines, and Professor C. Vandecasteele, Department of Chemical Engineering, University of Leuven, Belgium.

Further, UNESCO is grateful to Dr. M. A. Warith of G&S Ltd, Ottawa, Canada for undertaking the final review of the material presented in this module.

CONTENTS

AIMS AND OBJECTIVES

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The aims of this module are:

1. to provide, in the context of worldwide concern over environmental degradation, a suitable text for the post-graduate study of solid waste management (SWM), which takes account of the widely varying conditions: social, economic, cultural and climatic, among the countries of the world.

2. to demonstrate that the solutions to environmental and health problems caused by the inadequate management of solid wastes are not universal, but rather depend on the specific conditions that prevail in the area to which the management system applies.

3. to provide a guide to current practice and future trends in solid waste management.

After studying this text, working through the examples and self assessment questions (SAQ's) and consulting the references, the student should be able to:

Chapter 1

1. Discuss the principal factors that affect SWM solutions.

2. Describe the SWM system and its functional elements and sketch a flow diagram of the system.

3. Classify solid wastes according to type and source and define the various types of wastes.

Chapter 2

4. Describe qualitatively and quantitatively the current composition of municipal solid waste (MSW) in his country of origin and elsewhere, explaining the principal influences of national income, socio-economic status and social custom.

5. Describe the field investigations required for determining waste composition.

6. Describe the likely future composition of municipal solid waste, having regard to present trends, and the effects this could have on disposal, recycling and resource recovery.

7. Discuss the physical and chemical characteristics of MSW that are important in planning and designing a SWM system.

8. Discuss the possible effects on public health and the environment of poor waste management practice.

Chapter 3

9. Describe the collection system and its components and the factors affecting the efficiency of the system.

10. Describe the desirable characteristics of waste containers used for residential, commercial and communal storage, giving examples of various types of container.

11. Describe the types of vehicle used for the collection and haulage of MSW, stating the particular conditions suitable for each type.

12. Discuss the methods used for optimizing the collection operation, including the procedures and design methods used for determining the size and movements of the collection crew and the routes of collection vehicles.

13. Evaluate, in terms of capital, operational and maintenance costs, whether or not a transfer station should be included in the collection system.

14. Discuss the institutional arrangements necessary for the proper management of a collection system.

15. Describe the basic steps in planning, designing and implementing a collection system, stating the constraints to which this process is subjected. Also, sketch the flow diagram of this process.

16. Discuss the requirements for record keeping and inventory control in the operation of a collection system.

17. Discuss the interaction between the collection and disposal systems, showing the importance of integrating the two systems.

Chapter 4

18. Define what is meant by a Sanitary Landfill and describe the several phases of its life cycle.

19. Describe how a landfill site is selected and discuss other essential preliminary activities at the planning stage before commencement of design and construction.

20. Describe the physical, chemical and biological processes that take place in a landfill, distinguishing the five phases of these processes, taken in proper sequence.

21. Discuss the advantages and disadvantages of the co-disposal of MSW with hazardous wastes.

22. Describe how a landfill is designed, constructed and monitored to ensure that it has negligible impacts on the environment.

23. Estimate the quantity of leachate produced and its rate of production, and design the liner and drainage systems for the control of leachate pollution.

24. Describe qualitatively and quantitatively the composition of leachate, stating the ranges of values of its components.

25. Describe the processes used for treating leachate.

26. Describe qualitatively and quantitatively the composition of landfill gas, stating the ranges of values of its components.

27. Estimate the quantity of landfill gas produced and its rate of production, and design a landfill gas extraction system for control of the risk of fire, explosion and asphyxiation.

Chapter 5

28. Discuss the resource potential of MSW, with a special comment on differing situations in developed and developing countries.

29. Describe the techniques and equipment used in the preliminary conditioning of MSW prior to its use for resource recovery, product conversion and energy production.

30. Discuss the use of incineration as a means of waste reduction and energy recovery, identifying where environmental control measures must be taken to prevent pollution of land, water or air.

31. Sketch the flow diagram for a typical resource recovery plant and the energy diagram for an incineration plant.

32. Describe the characteristics of organic wastes used as resource material for composting and bio-gas production.

33. Describe the physical, chemical and biological processes that take place during composting and bio-gas production, stating the environmental conditions that favour and inhibit the processes in each case..

34. Sketch a flow diagram for the commercial production of compost from organic waste.

35. Discuss the advantages and disadvantages of bio-gas production and compare the operating conditions of this technology with those of composting.

36. Describe the methods employed in the recovery of paper and paper products, plastics, metals and glass, using case studies to illustrate the descriptions.

Chapter 6

37. Give a standard definition of hazardous waste and comment on the variation in definitions from one authority to another.

38. Describe the major uses of asbestos, the hazards it poses to public health and the methods used for the removal of asbestos-containing waste.

39. Describe the main classes of pesticides, their potential for damage to public health and the methods used for the disposal of pesticide-containing waste.

40 Describe the methods available for the physical and chemical treatment of hazardous wastes.

41. Give a detailed description of the solidification - stabilization technique for treating hazardous wastes, including the several variations in the technique according to the binders used, the containment mechanism or the type of process.

42. Discuss the essential components of a hazardous waste minimization programme, with descriptions of alternative processes, or modifications of existing processes, in the production of titanium oxide, chlorine and caustic soda, and in the metal plating, photofinishing and leather industries, to illustrate typical minimization techniques.

Concluding Remarks

43. Describe the crucial role of comprehensive legislation in the management of solid waste, citing the deficiencies, if any, in current legislation.

44. Explain the principles underlying the design of an organizational structure for a solid waste management authority and examine critically the structure of SWM authority in his district/country.

45. Explain the principles underlying the design of an organizational structure for a solid waste management authority and examine critically the structure of SWM authority in his district/country.

46. Discuss the role of education in conditioning the public, in respect of its knowledge, attitudes and behaviour, towards a more sympathetic acceptance of the need for environmental management in general and solid waste management in particular.

1. INTRODUCTION

1.1 MODULE OVERVIEW

Solid wastes are defined as the useless, unwanted or discarded materials, normally in the solid state, that arise from human activities. A particular waste product may be valued by someone, but if the producer seeks neither material nor monetary exchange for its removal it is still considered to be waste. A study of the generation, storage, collection and disposal of solid wastes is important to any community which recognizes the potentially harmful effects of such wastes on public health, on the environment and on its general welfare.

In this module: Management of Solid Wastes, the course material follows a logical sequence, reflecting the path of solid waste material from source to final disposal.

This first chapter establishes the context of solid waste management practice and makes a special point of distinguishing between prevailing conditions in developed and developing countries as a way of introducing the central concept of appropriate management methods.

With increasing awareness worldwide of the problems arising from poor waste management practices, there is a tendency for developing countries to adopt the methods and technology of the prosperous industrialized countries. Experience has shown, however, that such a policy more often than not leads to disastrous consequences. A good example is the case of a developing country with a tropical climate which has had to abandon an incinerator of sophisticated design, constructed at high capital cost. The characteristics of the waste would in any case have been unsuitable but, in the event, the country had neither the financial resources to meet the high operational and maintenance costs of the facility nor the technical personnel for its efficient operation. Likewise, fleets of high cost compaction vehicles have been purchased for use in communities where the prevailing wastes are already of high density and many of the collection routes are inaccessible to these vehicles.

In the second chapter, attention is drawn to the data which is necessary for the planning, design and operation of a solid waste management system, namely, the quantities, sources, composition and characteristics of solid wastes.

The discussions and material presented focus principally on municipal wastes which include domestic, commercial and institutional wastes as well as waste from municipal services. These are the wastes of urban areas: villages, towns and large cities, where the problems of waste management are most acute.

Industrial wastes and agricultural wastes are not addressed except in so far as they impinge on the stream of municipal wastes. The problems associated with these wastes are unique for each industry and agricultural activity and, with the sole exception of hazardous wastes, lie outside the scope of this module.

Chapter 2 also looks at the ways in which solid wastes can affect public health and cause environmental damage. It is these aspects of solid wastes management which command our attention because of the exponential growth of waste quantities, their further concentration due to increasing urbanisation and the coming on stream, at an ever increasing rate, of new and more complex materials.

With a knowledge of the nature of solid wastes and their adverse affects on health and the environment, the methods of storage, collection, transport and disposal can better be examined in detail. A limiting factor in the improvement of methods and technology applied to the management of solid wastes is cost. It follows that a justification of improved techniques should take full account of the social costs of health and environmental degradation in the absence of such improvements.

In Chapter 3, storage and the collection and transport of solid waste are considered together, as integral parts of the collection system. This is the most politically sensitive component of the solid waste management system since its operation impinges directly on the community. The overriding concern of citizens is not disposal. Rather, it is the removal of wastes from their immediate neighbourhood. Not surprisingly, therefore, the major portion of municipal budgets for solid waste management - up to eighty percent in some developing countries - is allocated to the collection system. Because of the many variables, most especially national income, cultural practices and climate, great care must be taken by a solid waste management authority in providing collection systems that are appropriate for its particular conditions - social economic and technological.

Ultimately, even with the best efforts of a country to minimise the waste it generates, there is always a residue which must be disposed of. In this regard disposal at a sanitary landfill remains, and will remain for the foreseeable future, the most commonly used method of disposal worldwide. However the mere act of covering solid waste with a layer of soil in itself provides no guarantee that the potential for environmental degradation is eliminated. The physical chemical and biological processes which take place within the waste matrix are very complex and require careful investigation and study. Many of the products of these processes - solid, liquid and gas, can be harmful to humans and the environment and must therefore be carefully controlled. Several cases of serious groundwater pollution by toxic leachates and of fire and explosion due to the migration of landfill methane have been documented, so that the proper design, construction and operation of a landfill are matters of prime importance to the environmental engineer. The attention of the reader is drawn to the several aspects of waste disposal discussed in Chapter 4.

Waste recovery and recycling are receiving increasing attention in both developed and developing countries for the following reasons:

- the enormous increase in the quantities and diversity of solid wastes;
- failure of existing techniques to prevent serious environmental pollution;
- the realization that internal resources are not limitless and therefore need to be conserved as they become scarce and more expensive;

- the limited capacity of the land, waterways and the atmosphere to absorb increasing quantities of solid waste of even greater diversity without serious environmental and ecological consequences.

A thorough study of this aspect of waste management, considered in Chapter 5, is therefore essential, with proper emphasis placed on the economic dimension of the problem. Clearly there is no common solution. Each situation will yield a unique set of variables which require a unique solution having regard to the objective of minimizing costs.

Although a discussion on industrial wastes is outside the scope of this module, the problem of disposal of hazardous wastes is of such importance as to justify its inclusion in a separate chapter (Chapter 6). Such wastes are commonly transported to open dumps and sanitary landfills and therefore mixed with municipal wastes. They pose a serious threat to health and the environment by their potential to pollute land, water and atmosphere. In general these harmful effects can be minimised in two ways:

- by subjecting wastes to both physical and chemical treatment; this enables the characteristics to be altered so that the wastes are potentially less damaging;
- by preventing the discharge of such wastes into the stream of municipal wastes or any part of the environment where they maybe harmful.

Among the substances of greatest concern are those like PCB'S and some pesticides that are only slowly degraded and can accumulate in the food chain. Most have been banned in the developed countries while still enjoying a ready market in developing countries.

Finally we look at Public Education. There is little doubt that the best system of waste management for a particular community, carefully planned and executed, can fail if the public is not sufficiently educated to consider itself an integral part of the system. Moreover, looking ahead, the built-in flexibility of a system to cope with the changing characteristics of solid wastes is more likely to be effective if the general public, through education, is less frozen into traditional practices. Public Education, therefore, is an essential part of any forward looking programme for the general improvement of the management of solid waste systems. It should occur at all levels: primary, secondary and tertiary.

1.2 HISTORICAL PERSPECTIVE

The problems associated with solid wastes began at the dawn of civilization, when humans first congregated in settled communities - Priestley (1968). Prior to this momentous development, the wastes of primitive societies could readily be absorbed and dissipated by natural processes. Population densities were small and the available land relatively large. Moreover, being nomadic in habit, it was a simple matter for a tribe to move away from the wastes it generated. As villages grew into towns and then cities, it became common practice to throw wastes into access ways, waterways and vacant plots where they intermingled with the excrement of the community and of domesticated animals. The appalling conditions in the cities of the ancient civilizations of Europe, in Athens and Rome and later in the European cities and towns of the Middle Ages are well documented. Such conditions gave rise to epidemics like the Black Plague which in the fourteenth century destroyed half the population of Europe. Similar conditions prevailed in the ancient cities of the Middle East, Africa and Asia as well as those of the Americas. It is important to note that in the contemporary world, conditions in many of the towns and cities of the poorest countries are essentially similar to those that afflicted Europe and North America from ancient times until well into the nineteenth century.

Events which occurred in Europe in the nineteenth century mark a turning point in the evolution of solid waste management. First, the Industrial Revolution which took place in England between the eighteenth and nineteenth centuries and rapidly spread to Europe and North America, led to a surge in urbanisation as families, attracted by the prospect of greater job opportunities, left the rural areas for towns and cities. The resulting concentration of wastes in the streets, waterways and dumps reached such alarming proportions that governments of the day resolved to effect improvements through the passage of legislation. However, progress was not satisfactory until the establishment of positive links between the vermin infested dumps and the spread of diseases. It was the discovery of the role of pathogens as the agents of the diseases which for centuries had been the scourge of mankind, that laid the foundation for the sciences of bacteriology and epidemiology and paved the way for the development of modern sanitary practice. More recently a study by the United States Public Health Service has demonstrated the relationship of 22 human diseases to improper solid waste management.

It is, of course, true that the basic methods of disposal by open dumping, incineration, composting and burial were known and practised by ancient civilizations but these practices were haphazard and specific to particular cultures. The systematic storage, collection and disposal of solid wastes is without doubt a relatively recent phenomenon which dates back to no earlier than the middle of the 19th century and has its roots in Europe. To be more specific, the first system of collection and disposal of solid wastes by a local government authority derives from the Public Health Act of 1875 of the United Kingdom. This act made provisions for the removal by the sanitary authority, on appointed days, of accumulations of solid wastes from premises. Each occupier was obliged to place the wastes in a removable receptacle - the first legal recognition of the dustbin. The subsequent rapid evolution of the management of solid wastes to what is common practice today in the developed countries and the more affluent areas of the developing countries was made possible by technological advances and the economic wealth created through industrialization - Erhard (1964). These achievements which are the envy of the less developed countries lie at the heart of the problem of the transfer of inappropriate equipment and methods from developed to developing countries.

1.3 APPROPRIATE MANAGEMENT SYSTEMS

1.3.1 Developed and Developing Countries

In pursuance of the concept of 'appropriate management' it is of benefit to examine both the commonalities and the differences between developed and developing countries as they relate to the management of solid wastes. In itself this differentiation is far from satisfactory, for the differences and variations among the so called developing countries in terms of wealth, degree of industrialisation, social development and quality of life are greater than those between the developed countries and countries at the upper end of the scale of those classified as developing. However because of the universal use and understanding of these terms and for want of a better means of differentiation, it is appropriate to use this classification here.

Accepting the blurring of distinctions at the boundaries between developed and developing countries, the following factors are used as indices for such distinctions:

- Per capita income;
- Degree of social development - education, literacy, health care, dare for the aged;
- The ratio of wealth created by the production of primary products to that derived from manufactured goods.

In general, the people of countries classified as 'developing', are significantly poorer than those in developed countries, social development is not as advanced, and most of the working population are engaged in economic activity relating to primary products rather than the products of manufacturing industries. Solid waste management is heavily influenced by these difference, so that appropriate solutions to management problems may be expected to vary widely from country to country.

1.3.2 Factors Influencing Management Solutions

Quantities and Characteristics of Wastes

The quantities of wastes generated in municipalities range from about 0.25 - 2.3 kg per person per day, the higher figure being that of the United States whose production of wastes is the highest in the world. Low figures are typical of developing countries, there being a strong correlation between waste production and per capita income. A measure of waste composition and characteristics is density. In developing countries density is high, as much as 600 kg/m^3 compared with a figure of 150 kg/m^3 for the USA and Europe. The differences are largely accounted for by the proportion of paper and packaging in the waste stream. When this proportion is high, the density is low and vice versa. The wastes of high density found in the developing countries reflect a relatively high proportion of organic matter and moisture and lower levels of recycling.

Climate and Seasonal Variations

Most of the developed countries lie in the temperate regions of the world while the majority of developing countries have a tropical, sub-tropical or desert/steppe climate. In addition, there are the countries of the extreme north and south (> 70° N Lat, > 60° S Lat) where temperatures are very low for most of the year. Tropical countries are subject to sharp seasonal variations from wet to dry season. This causes significant changes of moisture content of solid waste, varying from less than 50% in the dry season to greater than 65% in the wet months. Collection and disposal of wastes in the wet months are often problematic. High temperatures and humidity cause solid wastes to decompose far more rapidly than they do in colder climates. The frequency of waste collection under these climatic conditions should therefore be higher than it is in countries with lower prevailing temperatures.

The very low rainfall in countries with a desert climate means that there is no significant variation in moisture content of wastes and low production of leachate from sanitary landfills. High winds and wind blown sand and dust cause special problems at landfill sites. In cold climates, drifting snow and frozen ground interfere with operations of a landfill. Trenches must be dug in the summer months and cover material stockpiled for winter use. Landfill sites located on permafrost can affect groundwater by altering the thermal properties of the soil and temperature inversions can cause airborne pollutants to be trapped near ground level.

Physical Characteristics of Urban Centres

In the villages, towns and cities of the developed countries, the layout of streets and houses is such that access by vehicles is possible to the majority. For this reason door to door collection of solid wastes is the accepted norm whether by large compaction vehicle or smaller satellite vehicle. This is also the case in the more affluent sections of the towns and cities of developing countries.

The picture is, however, quite different in the poorer parts of the latter, where the inner and usually older city areas have narrow access ways which make service by vehicles problematic and often impossible. Added to this is the problem of urban squatting on the outskirts of the cities where urban populations are growing at an alarming rate. Access ways are narrow, unpaved and tortuous and therefore not accessible to collection vehicles. Problems of solid waste storage and collection are most acute in such areas.

Financial and Foreign Exchange Constraints

Solid waste management accounts for sizeable proportions of the budgets of cities in both developed and developing countries. The proportion is however much greater in the latter, where there is a chronic shortage of funds, than in the former. This is because capital resources which go towards the purchase of equipment, vehicles and fuel are virtually the same for all countries. Labour costs are much lower in developing countries but the work force, generally speaking, is less productive. Typically between 10% and 40% of the revenues of cities in developing countries are allocated to solid waste management. In the affluent industrialized countries where prevailing wage rates are high, a major objective in selecting appropriate management systems is to optimise labour productivity. In the developing countries where wage rates are low, the position is reversed and the aim is to optimise vehicle productivity.

The unfavourable financial situation of most developing countries is further exacerbated by the acute shortage of foreign exchange which must be used for the purchase overseas of equipment and vehicles. This means that the balance between the degree of mechanization and the size of the labour force becomes a critical issue in arriving at the most cost-effective solution.

Cultural Constraints

The social mores of a community are not to be ignored, for they often over-ride what many may consider rational solutions. In some countries long standing traditions preclude the intrusion of waste collection on the precincts of households and therefore influence the collection system. In others, where the tradition of religious caste persists, recruits to the labour force for street cleaning and the handling of waste must be drawn from certain sections of the population. Others still will not countenance the placing of storage bins immediately outside the household. The wise engineering consultant or waste manager, sensitive to such local patterns of living, will take this factor into account in the planning, design and operation of a solid waste management system.

Management and Technical Resources

Solid waste management is complex and multi-disciplinary, and if it is to be successful requires a wide spectrum of manpower of high quality in keeping with the demands of the system. In general, the developed countries are adequately supplied with expertise and skills, from the skills of professionals to those of technicians and craftsmen. Management, and technical resources are not problematic in the highly industrialized countries. Indeed, it is commonplace that these resources are placed at the disposal of developing countries where they are in short supply. Unfortunately, the system provided through such arrangements do not always live up to expectations because they fail to take proper account of the quality and quantity of available manpower. The best system for a country is one which makes full use of indigenous crafts and professional skills or else ensures that training programmes are put in place to provide a self-sustaining supply or trained manpower.

SAQ 1.1

What factors underlie the concept of appropriate management as it applies to the management of municipal solid waste systems?

1.4 THE SOLID WASTE MANAGEMENT SYSTEM

1.4.1 The System Defined

Like any other system, a solid waste management system consists of a number of operations linked together in a rational manner in order to achieve a specific objective(s). In this case the principal objective is to collect and dispose of the solid wastes of a community at minimal cost while preserving public health and ensuring negligible impact on the environment. This objective is subject to the constraints discussed in section 1.3.2.

Figure 1-1 is a representation of the system in its most general form, so that it applies to all countries whatever their state of development. This does not mean that all the elements and linkages shown will always be present. What it does imply is that the elements and linkages of any system are expressed in the diagram. The operations highlighted in boxes are the functional elements of the system.

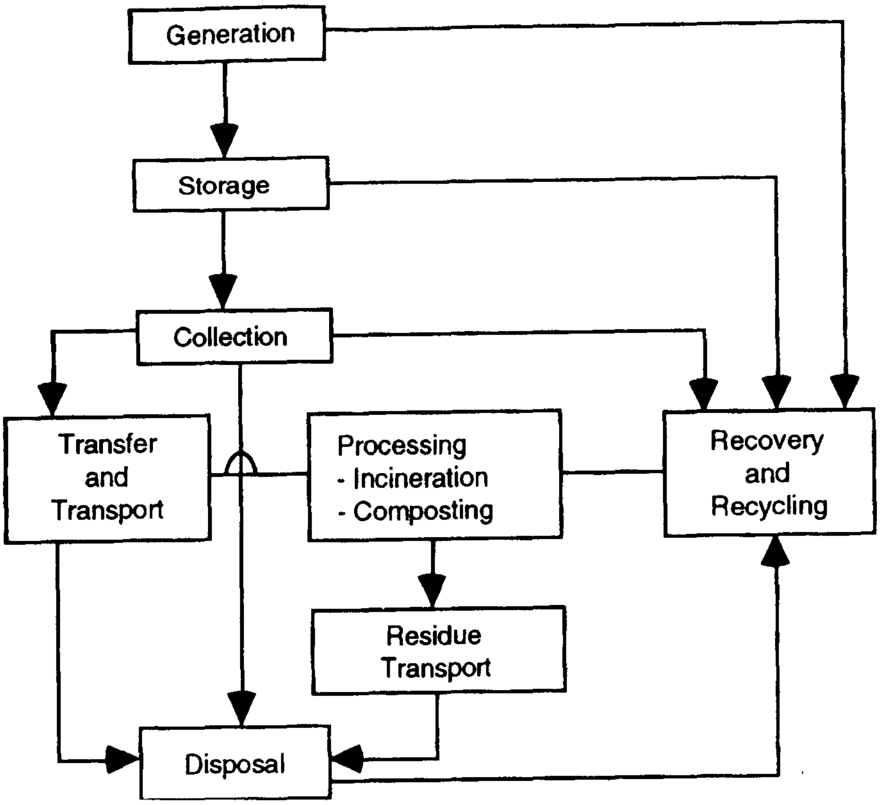

Figure 1-1 Functional Elements of a Municipal Solid Waste Management System

1.4.2 Functional Elements

Waste Generation

Solid wastes here refer to municipal wastes which are generated by households, commercial areas, industry, institutions, street cleaning and other municipal services. The quantity and composition of these wastes are determined by the characteristics of the source.

Storage

Storage is an essential functional element because, invariably, collection of wastes never takes place at the point in time of their generation. Containers vary greatly in size, material and form. They may be disposable plastic bags, the conventional dustbins of households, oil drums, large storage bins of institutions and commercial areas or depots servicing urban slums.

Collection

The methods of collection are also wide ranging. In the developed countries where door to door collection is normal practice in residential areas and the system highly mechanised, collection is by specialized vehicle loaded manually or mechanically. Most of these vehicles have the facility for compacting the waste to make full use of the carrying capacity of the vehicle. Apartment blocks, institutions and commercial areas deposit wastes in large containers which of necessity require mechanical loading of the collection vehicle. In some cases the storage container is itself taken away for discharge of the wastes stored at the disposal site, and replaced by an empty container. Such methods are common in the affluent areas of towns and cities of developing countries. Areas not accessible to the larger vehicles are serviced by small satellite vehicles which operate in narrow streets and alley ways and empty their loads in a mother vehicle. In the poorer sections of towns and cities in developing countries, collection is quite different in character. The stored contents of communal bins and depots are emptied by manual labour into vehicles which exhibit a wide variety of size and design - from open tray trucks to agricultural tractors hauling trailers to bullock carts. Collection from areas with limited access may be by handcarts or wheelbarrows. After wastes are collected they must be transported either directly to the disposal site, to a processing facility or to a transfer station.

Transfer and Transport

In large systems, especially those in which the disposal site is remote from the area of waste generation, it is often found that a more efficient means of transporting collected material is first to transfer the waste to larger vehicles, barges or rail cars at a transfer station. From there it is transported to the disposal site, to a processing facility or to a facility for recovery and recycling.

Processing

The processing element serves the purpose of changing the physical and chemical characteristics of the waste. Incineration and composting are the most common processes, both of which entail separation and recovery of specific waste components for recycling. The organic portion of the waste is incinerated, often to generate steam for electricity. This fraction can also be subjected to anaerobic decomposition to produce methane (bio-gas) or a residue useful as a soil conditioner. Both incineration and composting represent practical methods of energy recovery.

Recovery and Recycling

Recovery and recycling of solid wastes offer tremendous potential for reduction of quantities reaching the disposal site. In section 1.1 some of the reasons for increasing attention to these activities were identified.

As indicated in Figure1.1, there are several linkages of this functional element to other elements of the system. In this regard it is of interest to note the differences in practice between the most affluent countries and the poorest. In North America, Europe and the wealthy countries of Asia, the thrust is towards the separation of waste components at source by the producer, each being stored and collected separately. Glass, paper, plastics and aluminium have been identified as most suitable for re-use. This is a significant change from the traditional mixed nature of domestic wastes collected from households, institutions and commercial areas. On the other hand, economic survival is the over-riding imperative which motivates these activities in poor countries. Scavenging is one of the few avenues of self-help open to the very poor and is widely practised at all stages of the waste stream - from generation to final disposal.

Recovery of materials at processing plants is also significant, being a necessary concomitant of the need to separate components which are neither suitable for combustion nor bio-degradable but have value as recycled materials.

Residue Transport

This element represents the conveyance of rejected material that remains after processing such as the ash and non-combustible material from an incinerator or non-bio-degradable material from a composter. Such material is generally transported to a landfill site. Incinerator residue is sometimes used in road construction.

Disposal

A landfill site for final disposal of material wastes either in their original form as collected from the producer, or the residue from processing, is a necessity. It is the ultimate functional element of the system.

SAQ 1.2

In what ways do the operations: Recovery and Recycling illustrate how practices that are widely different may be equally acceptable in different parts of the world?

References

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ANSWERS TO SELF ASSESSMENT QUESTIONS

SAQ 1.1

The principal objective of a SWM system is to store, collect and dispose of the solid wastes of a community at minimal cost, while preserving public health and ensuring negligible impact on the environment. Because of differences within a given country, and from country to country, in respect of:

- quantities and characteristics of wastes
- climate
- physical characteristics of municipal areas
- per capita income
- foreign exchange control
- cultural and social mores
- technical man power

the fulfillment of this objective is necessarily achieved by methods which are appropriate to prevailing conditions. The diversity of management solutions is an embodiment of the concept of appropriate management.

SAQ 1.2

In the affluent countries of North America, Europe and Asia, where unemployment rates are characteristically low, solid wastes are not valued by householders. Nevertheless, communities have been persuaded, through education and coercion, that it is in their interest to separate waste components at source for storage and collection. Glass, paper, plastics and aluminum are the most common materials targeted in this way for re-use and recycling.

Very significant reductions in the quantities of waste reaching disposal sites are possible. Furthermore, the re-use and recycling of materials reduce the demand for their primary production and conserve energy. For example, paper recycling reduces the felling of forest trees, while glass recycling reduces the mining of silica sands. However, the economics of re-use and recycling are not always favourable because of market saturation and low prices. This has led some countries to seek to export their separated wastes in the face of mounting financial losses and severe environmental problems. The export of paper waste by the USA to Europe is an example.

The situation in the poorest countries of the developing world is quite different. Unemployment rates are high and per capita income low. Wastes are valued both by householders and workers within the management system. In these circumstances, re-use and recycling are automatic and self-sustaining, albeit in a disorganised and inefficient manner, conducive to health and environmental problems. Motivated by the imperative of economic survival, householders, waste collectors and scavengers at disposal sites all take part in the separation, re-use and re-cycling of wastes, for direct economic benefit. Although such practices are rarely officially permitted by SWM authorities they are often tolerated because they provide financial incentives to low-paid workers as well as avenues of employment for the pariahs of the society.

The benefits of re-use and re-cycling are similar in both cases. Refer also to Chapter 5.

2. COMPOSITION, CHARACTERISTICS, QUANTITIES AND ENVIRONMENTAL EFFECTS

2.1 INTRODUCTION

This chapter considers two aspects of solid wastes. The first relates to the nature of wastes - their sources, composition, physical and chemical characteristics - and to the quantities generated. Such information should be seen as basic to the planning phase of a solid waste management system. The second aspect refers to the adverse impacts of solid wastes on health and the environment. As noted in Chapter 1, mitigation of dangers to public health was, historically, the primary motivation for the development of modern solid waste management systems. However, in recent years the impacts of solid wastes on the environment are being viewed with growing concern and are receiving much greater attention.

Terminology and Classification

The student will find, on perusal of the literature on this subject, that there is some confusion in the terminology used to describe the nature of wastes. In this text, 'composition' refers to the limited list of components or constituents, such as paper, glass, metal, plastic and garbage, into which an aggregate of municipal waste may conveniently be separated. 'Characteristics' on the other hand, refers to those physical and chemical properties which are relevant to the storage, collection, treatment and disposal of waste, such as density, moisture content, heating value and chemical composition.

In addition to these general terms, there are a number of more specific terms which, for greater clarity, must also be defined. A comprehensive list of definitions is therefore presented in section 2.2. Some terms, like 'domestic wastes' and 'municipal wastes' refer to the sources of the wastes, while others, such as 'garbage', 'street wastes' and 'hazardous waste', indicate the types of wastes.

Both systems of classification are useful and have been conveniently combined in a tabulated classification proposed by the Institute of Solid wastes of the American Public Works Association (1966).

Worldwide variations in Composition and Characteristics

An examination of the composition and characteristics of wastes in different countries underscores the profound influences of national income, degree of economic and social development and cultural practices, and thereby focuses attention on the importance of obtaining data locally. Nowhere are such considerations more important than in developing countries where there is a tendency for authorities to take ill-considered advice from foreign consultants, especially with respect to equipment used for the collection, treatment and disposal of solid wastes. Several tables of waste composition in different parts of the world are presented in Section 2.3 to illustrate this point.

Since solid waste management systems are designed for the future as well as the present, careful consideration should also be given to changes that may occur during the design life of a system. Changes are inevitable and occur at an increasingly rapid rate in response to the increasing pace of social and technological development. No one can predict with accuracy the full nature and extent of such changes, so that a built-in flexibility in the waste management system becomes essential. Nevertheless, it is possible to identify some of the factors that are likely to cause changes in waste composition and characteristics and, by this means, to enable planners to make reasonable judgments about the future.

Waste Quantities

Knowledge of the quantities of waste generated is an obvious requirement for the design of all elements of the solid waste management system. Average quantities are not sufficient because of significant variations with seasons of the year (garden waste) and at times of special events and festivals (Christmas, Divali ,Eid-ul-fitr, Carnival). At such times there are surges in specific types of waste which must be accommodated by the storage, collection and disposal systems. Other variations result from differences of income and life-style within a given community, and differences in regional climate within the borders of larger countries. Proper attention must also be given to long term trends. Increasing levels of income tend to increase waste generation, while recycling promises dramatic reductions in waste quantities, especially in the developed countries.

Health and Environment Effects

In section 2.4, we look at the ways in which solid wastes can affect health and the environment. Inadequate management of solid waste has caused and continues to cause many public health disasters, principally relating to the spread of disease by insect and animal vectors and to the physical and chemical hazards resulting from waste constituents. Added to these effects are a number of secondary nuisances commonly found at open dumps such as smoke, dust and wind-blown litter. Workers in the solid waste management system are particularly at risk. Areivala (1971) has shown that the incidence of parasitic infection in a group of workers in India was 94% compared with slightly more than 4% in a controlled group not subjected to this exposure. Data presented by Hanks (1967) also confirms that solid waste workers run a greater risk of accident than industrial workers.

Objectives

The objectives of this chapter are:

- to clarify the terminology used to describe solid wastes and to present a comprehensive system of waste classification
- to indicate the major constituents of municipal solid waste and to demonstrate the wide variation in the proportions of constituents from one community to another
- to introduce some representative techniques for obtaining basic data on the composition and characteristics of solid wastes, in the field and in the laboratory
- to identify the factors which cause short-term and long-term changes in the composition, characteristics and quantities of solid wastes
- to outline the principal effects of poor waste management on public health and the environment and explain why some wastes should be restricted at source.

2.2 DEFINITIONS AND CLASSIFICATION OF SOLID WASTES

In order to plan, design and operate a solid waste management system, a thorough knowledge of the quantities generated, the composition of wastes and their characteristics is essential. This requires as a first step, a proper definition of the terms most widely used to describe wastes within a system of classification. Furthermore, definitions are necessary in order to avoid the general confusion that is common in the usage of these terms.

2.2.1 Definitions

Our Introduction - Chapter 1, began with a definition of solid wastes which needs no further elaboration. However, there are many other terms which relate to the types and sources of wastes and these too must be defined.

Domestic/Residential Wastes

This category of wastes comprises the solid wastes that originate from single and multi-family household units. They are a consequence of household activities such as cooking, cleaning, repairs, hobbies and redecoration and contain empty containers, packaging, clothing, books and writing paper, and old furnishings. Households also discard bulky wastes such as furniture and large appliances.

Municipal Wastes

Municipal wastes include wastes resulting from municipal functions and services such as street wastes, dead animals and abandoned vehicles. However, in contemporary management practice, the term is applied in a wider sense to incorporate domestic wastes, institutional wastes and commercial wastes.

Commercial Wastes

Included in this category are solid wastes that originate in offices, wholesale and retail stores, restaurants, hotels, markets, warehouses and other commercial establishments. Some of these wastes are further classified as garbage and others as rubbish.

Institutional Wastes

Institutional wastes are those arising from institutions such as schools, universities, hospitals and research institutes. They include wastes which are classified as garbage and rubbish as well as wastes which are considered to be hazardous to public health and to the environment.

Garbage

Garbage is the term applied to animal and vegetable wastes resulting from the handling, storage, sale, preparation, cooking and serving of food. Since such wastes contain putrescible organic matter which produces strong odours and therefore attract rats, flies and other vermin, they require special attention in their storage, handling and disposal.

Rubbish

Rubbish is a general term applied to solid wastes originating in households, commercial establishments and institutions, excluding garbage and ashes.

Ashes

Ashes are the residue from the burning of wood, coal, charcoal, coke and other combustible materials, for cooking and heating in houses, institutions and small industrial establishments. When produced in large quantities at power generating plants and factories these wastes are classified as industrial wastes. Ashes consist of a fine powdery residue, cinders and clinker often mixed with small pieces of metal and glass. It is valuable in landfills because it is almost entirely inorganic.

Bulky Wastes

In this category are bulky household wastes which cannot be accommodated in the normal storage containers of households. For this reason they require special collection. Included among bulky wastes are large household appliances such as cookers, refrigerators and washing machines as well as furniture, crates, vehicle parts, tyres, wood, trees and branches. Metallic bulky wastes are sold as scrap metal but the greater portion is disposed of at sanitary landfills.

Street Wastes

This term applies to wastes that are collected from streets, walkways, alleys, parks and vacant lots. In the more affluent countries manual street sweeping has virtually disappeared but it is still commonplace in developing countries where littering of public places is a far more widespread and acute problem. Mechanised street sweeping is the dominant practice in the developed countries. Street wastes include paper, cardboard, plastics, dirt, leaves and other vegetable matter.

Dead Animals

As a term applied to municipal wastes, dead animals are those that die naturally or are accidentally killed. This category does not include carcass and animals parts from slaughterhouses which are regarded as industrial wastes. Dead animals are divided into two groups, large and small. Among the large animals are horses, cows, goats, sheep, hogs and the like. Small animals include dogs, cats, rabbits and rats. The reason for this differentiation is that large animals require special equipment for lifting and handling when they are removed. If not collected promptly, dead animals are a threat to public health because they attract flies and other vermin as they putrefy. Their presence in public places is particularly offensive from the aesthetic point of view.

Abandoned Vehicles

In this category are automobiles, trucks and trailers that are abandoned on streets and other public places. Responsibility for their removal varies from country to country but is more commonly that of the municipal authority. Their value to collectors is also highly variable. In some countries where new cars are a luxury but which have the necessary skills and technical expertise and therefore a vested interest in keeping old vehicles serviceable, they are greatly valued for their parts. On the other hand, the wealthy countries find it more economical to abandon vehicles to the grave yards, after relatively short lives, in favour of new purchases. Abandoned vehicles have significant scrap value for their metal and are sold to scrap merchants. However the equipment and machinery used for scrapping, transport and processing of the vehicles for the scrap market are expensive requiring a large capital investment. The economics of such an enterprise dictates that only a large operation is feasible. At present (1994) about 10% of abandoned vehicles are recycled in industrialised countries.

Construction and Demolition Wastes

Construction and demolition wastes are the waste materials generated by the construction, refurbishment, repair and demolition of houses, commercial buildings and other structures. They consist mainly of earth, stones, concrete, bricks, lumber, roofing materials, plumbing materials, heating systems and electrical wires and parts of the general municipal waste stream, but when generated in large amounts at building and demolition sites are generally removed by contractors and disposed of at landfills.

Industrial Wastes

In this category are the discarded solid material of manufacturing processes and industrial operations. They cover a vast range of substances which are unique to each industry. For this reason they are considered separately from municipal wastes. It should be noted, however, that solid wastes from small industrial plants and ash from power plants are frequently disposed of at municipal landfills.

Hazardous Wastes

Hazardous wastes may be defined as wastes of industrial, institutional or consumer origin which, because of their physical, chemical or biological characteristics are potentially dangerous to humans and the environment. In some cases although the active agents may be liquid or gaseous, they are nevertheless classified as solid wastes because they are confined in solid containers. Typical examples are: solvents, paints and pesticides whose spent containers are frequently mixed with municipal wastes and become part of the urban waste stream. Certain hazardous wastes cause explosions in incinerators and fires at landfill sites. Others, such as pathological wastes from hospitals and radioactive wastes, require special handling at all times. Good management practice should ensure that hazardous wastes are stored, collected, transported and disposed of separately, preferably after suitable treatment to render them innocuous.

Sewage Wastes

The solid by-products of sewage treatment are classified as sewage wastes. They are mostly organic and derive from the treatment of organic sludges separated from both the raw and treated sewage. The inorganic faction of raw sewage such as grit and egg shells is separated at the preliminary stage of treatment, but because it entrains putrescible organic matter which may contain pathogens, must be buried without delay. The bulk of treated, dewatered sludge is useful as a soil conditioner but invariably its use for this purpose is uneconomic. The solid sludge therefore enters the stream of municipal wastes unless special arrangements are made for its disposal.

2.2.2 Classification

Because of the imprecise nature of solid wastes, no single method of classification is entirely satisfactory. In some cases it is more important for the solid waste specialist to know the source of waste, so that classifying wastes as domestic, institutional or commercial, for example, is particularly useful. For other situations, the type of waste: garbage, rubbish, ashes, street wastes and the like, is of greater significance because it gives a better indication of the physical and chemical characteristics of the waste. We have chosen here to use the latter as the principal classification - Table 2.1, which was first proposed by the Institute for Solid Wastes of the American Public Works Association (1966). The first three types, garbage, rubbish and ashes are those which make up the bulk of municipal wastes, derived principally from households, institutions and commercial areas. These wastes account for the most urgent problems in urban areas.

2.3 COMPOSITION, CHARACTERISTICS AND QUANTITIES

2.3.1 Rationale For Analysis

An analysis of the composition, characteristics and quantities of solid wastes is essential for the following reasons:

- it provides the basic data on which the management system is planned, designed and operated
- by comparison of analyses over time, the waste manager is able to detect changes in composition, characteristics and quantities and the rates at which these changes take place; such knowledge facilitates forward planing.
- it provides the information for the selection of equipment and appropriate technology
- it indicates the amount and type of material suitable for processing, recovery and recycling
- the forecast trends assist designers and manufacturers in the production of vehicles and equipment suitable for future needs.

For such information to be of the widest possible benefit it must be collated by a responsible national, regional or local authority and made available to all who require it.

Table 2.1 Classification of Solid Wastes

TYPE		DESCRIPTION	SOURCES
Solid wastes	Garbage	Wastes from the preparation, cooking, and serving of food. Market refuse, waste from the handling, storage, and sale of produce and meats	From households institutions, and commercial concerns such as: hotels, stores, restaurants markets, etc.
	Rubbish	Combustible (primary organic) Paper, Cardboard, cartons Wood, boxes, excelsior Plastics Rags, cloth, bedding Leather, rubber Grass, leaves, yard trimmings	
		Noncombustible (primary inorganic) Metals, tin cans, metal foils Dirt Stones, bricks, ceramics, crockery Glass bottles Other mineral refuse	
	Ashes	Residue from fires used for cooking and for heating buildings, cinders	
	Bulky wastes	Large auto parts, tyres Stoves, refrigerators, other large appliances Furniture, large crates Trees, branches, palm fronds, stumps, flotage	From: streets, sidewalks alleys, vacant lots, etc.
	Street wastes	Street sweepings, dirt Leaves Catch basin dirt Contents of litter receptacles	
	Dead animals	Small animals: cat, dogs, poultry, etc. Large animals: horses, cows etc.	
	Abandoned vehicles	Automobiles, trucks	
	Construction & demolition wastes	Lumber, roofing, and sheathing scraps Rubble, broken concrete, plaster, etc. Conduct, pipe, wire, insulation, etc.	From: construction and demolition sites
	Industrial wastes	Solid wastes resulting from industry processes and manufacturing operations, such as: food processing wastes, boiler house cinders, wood, plastic and metal scraps and shavings, etc	From: factories, power plants, etc
	Special wastes	Hazardous wastes: pathological wastes, explosives, radioactive materials Security wastes: confidential documents, negotiable papers, etc	Households, hospitals, institutions, stores, industry, etc.
	Animal and agricultural	Manures, crop residues	Farms, feed lots
	Sewage treatment residues	Coarse screening, grit, septic tank sludge, dewatered sludge	Sewage treatment plants, septic tanks

2.3.2 Field Investigations

Field investigations are necessary for providing the basic data on solid wastes and are carried out in three ways:

- vehicle weighing at disposal sites
- sorting of wastes at disposal sites into predetermined components for weighing and sampling in order to determine the percentage of each component and the physical and chemical characteristic of the wastes
- visiting institutional and industrial sites to identify wastes being generated and disposal methods.

The weighing of loaded and unloaded vehicles is accomplished with a weighing scale or weighbridge. An electronic portable axle scale, with a capacity of 20,000 kg is suitable. This scale is made up of two load-cell platforms and an electronic control and display unit. The vehicle's front wheels are weighed first, followed by the rear wheels, the sum of the two giving the total weight. Vehicles are weighed when they enter the disposal site loaded, and when they leave the site empty. Weighing is carried out each day of the weighing period in order to determine the average. Ideally the weighing scale should be operated during the entire daily period of operation of the landfill site, around the clock if necessary. A shift system should be employed, the weighing team comprising four workers for each scale - a supervisor, assistant and two helpers, who move the scale platform to the desired spacing for each vehicle.

The quantities of waste measured at disposal sites more correctly reflect a disposal factor rather than a generation factor, since the measurements do not include:

- waste salvaged at the site, of generation
- waste disposed of in unauthorised places-empty lots alleys, ditches
- waste salvaged by collectors
- waste salvaged at the disposal site.

Differences between the two are insignificant with well-managed collection systems, enlightened public attitudes and strict enforcement of legislation. This is frequently not the case, particularly in developing countries, and it is then necessary to measure waste quantities at source. Flintoff (1984) describes a method for collecting samples with the active co-operation of householders; containers or plastic bags are filled by a representative number of householders and labelled before being taken to the depot where the contents are weighed and the volume measured.

Sorting is carried out manually, each sample size being about 100 - 150 kg for satisfactory accuracy of analysis. This process separates the waste into pre-determined components, each component being separately weighed. Equipment used includes:

- a sorting table, 3m long x 1.5 m wide
- a measuring box 1m long x 0.5 m wide x 1m high
- bins or boxes of about 60 liters capacity to contain sorted materials
- a platform weighing machine - 500 kg

Samples collected for physical and chemical analysis are double bagged in plastic bags, sealed and sent to the laboratory for analysis, each sample being in the range 1.5 to 5 kg. Wastes from industry and institutions are usually investigated by visiting the facility, viewing the waste handling system and completing a questionnaire with the assistance of the plant manager or senior technical personnel.

2.3.3 Composition and Characteristics

The composition and characteristics of municipal solid wastes vary throughout the world because they are determined by social customs and living standards. A typical solid waste does not exist. Municipal wastes are heterogeneous, that is, they comprise an enormous variety of materials derived from the diverse activities which produce them. Nevertheless it is possible to make some general observations about their composition that make the picture somewhat less confusing:

- the major constituents are paper and putrescible organic matter
- metal, glass, ceramics, plastics, textiles, dirt and wood are generally present although not always so, the relative proportions depending on local factors
- The average proportions of constituents reaching a disposal site(s) for a particular urban area are fairly constant although subject to long-term changes; however they may be significant seasonal variations within a year.

For these reasons an analysis of the composition of solid waste, for rich and poor countries alike, is expressed in terms of a limited number of constituents. Apart from the intrinsic benefit of such information, it is useful in illustrating the variations from one urban centre to another and from country to country. Data for different geographical regions are presented in Table 2.2 and for different degrees of national wealth (annual per-capital income) in Table 2.3. Wastes composition also varies with socio-economic status within a particular community, since income determines life-style, consumption patterns and cultural behavior, - Table 2.4.

Several conclusions may be drawn from this comparative data:

- the proportion of paper generated increases with increasing national income
- the proportion of putrescible organic matter (food and garden waste) is greater in countries of low income than those of high income
- national income is more indicative of waste composition than geographical region, although the latter is also significant
- waste density is a function of national income, being two to three times higher in the low-income countries than in countries of high income
- moisture content is also higher in low-income countries
- the composition of wastes within a given urban centre varies significantly with socio-economic status (household income).

Table 2.2 Composition of Municipal Waste by Country

COUTRY	COMPOSITION (% by weight)										
	Metal	Glass/ Ceramics	Food Garden	Paper	Textiles	Plastic/ Rubber	Misc. Combust	Misc. Incombust	Inert	Other	Information Source
ASIA India, Calcutta	1	8	36	3	4	-	5		4.2		Holmes (ed) (1984)
Taiwan	1.1	2.8	24.6	7.5	3.7	2.3	-	56.0	-	0.8	Lohani & Thanh (1978)
Singapore	3.0	1.3	4.6	43.1	9.3	6.1	3.9	-	6.4	22.3	ibid
Japan	5.9	15.0	11.7	38.5	4.1	11.9	3.8	-	9.1	-	Recycling Berlin (1979)
Thailand, Bangkok	1.0	1.0	44.0	24.6	3.0	7.0	-	3.5	4.8	-	Flintoff (1978)
MIDDLE EAST Iran, Shiraz	2.3	1.5	60.0	26.4	-	2.3	4.0		3.5		Holmes (1984)
TURKEY Istanbul	1.4	0.7	60.8	10.2	3.2	3.1		16.2		6.4	Recycling in Dev Count. (1982)
Tunisia, Tripoli	10.2	3.0	52.2	21.4	4.2	3.9	2.5	-	2.6		ibid
Egypt, Port Said	3.0	1.3	36.9	24.0	2.2	3.4	9.3	9.6	10.0	0.3 (bones)	ibid
AFRICA Nigeria, Lagos	4	3	60	14	-	-	-	-	10		Holmes (1984)
Ghana, Accra	2.6	0.7	8701	5.7	1.2	1.3	-	-	-	1.4	Recycling in Dev. Count (1982)
LATIN AMERICA Columbia, Medellin	1	2	56	22	4	5	-		10	-	Seldmantal WldBk (1979)
Brazil, Sao Paulo	4	2	47.5	26	4	4.5	1.9		9	6.1	Acurior Ruiz (1979)
Mexico, Acapulco	3.6	11.8	33.3	17.2	-	3.4					Holmes (ed) (1984)
CARIBBEAN Barbados	9.6	9.6	47.4	10.5	1.7	1.0	7.4	11.1	8.4	2.7	Archer, PAHO, (1987)
Trinidad & Tobago	7.9	9.1	46.0	26.4	2.0	4.5	1.0	-	2.9	-	Stanley Ass. (1979)
EUROPE UK	9	9	28	37	3	3	1	1	9	-	Flintoff (1978)
Spain, Madrid	4	3(glass)	50	18	2	4			6	13	Pfeffer (1992)
Sweden	5-6	6-8	30-38	32-36	2	6-7	-	-	-	8-9	Recycling Int. (1982)
N. AMERICA USA (urban)	12	12	31	33	4	3	-	-	2	3	Pfeffer (1992)

Source : Holmes(ed) (1984). Lohani & Thanh (1978). Ibid Recycling berlin (1979). Flintoff (1978). Recycling in Dev. Count. (1982) ibid. Seldmanetal WldBk. (1979). Acurior Ruiz (1979). Stanely Ass (1979). Flintoff (1978). Leffer (1992). Pfeffer (1992).

Table 2.3 Patterns of Composition, Characteristics and Quantities

	Low Income Countries (1)	Middle Income Countries (2)	High Income Countries (3)
Composition: (% by weight)			
Metal	1 - 5	1 - 5	3 - 13
Glass, Ceramics	1 - 10	1 - 10	4 - 10
Food and Garden	40 - 85	20 - 65	20 - 50
Paper	1 - 10	15 - 40	15 - 40
Taxtiles	1 - 5	2 - 10	2 - 10
Plastics/Rubber	1 - 5	2 - 6	2 - 10
Misc . Combustible	1 - 5		
Misc . Incombustible			
Inert .	1 - 40	1 - 30	1 - 20
Characteristics			
Densities (kg,m^3)	250 - 500	170 - 330	100 - 170
Moisture Content (% by wt)	40 - 80	40 - 60	20 - 30
Quantities			
Waste Generation (kg/cap/day)	0.4 - 0.6	0.5 - 0.9	0.7 - 1.8

(1) Countries having a per capita income less than US$360 (1978 prices)
(2) Countries having a per capita income US$360-3500 (1978 prices)
(3) Countries having a per capita income greater than US$3500 (1978 prices)

Source : Holmes, J ; Managing Solid Waste in Developing Countries .

Table 2.4 Variation of Composition with Socio-economic status

Waste Component	**COUNTRY**							
	Lima, Peru		Cairo, Egypt		Columbo, Sri Lanka		Shiraz, Iran	
	High	Low	High	Low	High	Low	High	Low
Metals	5	4	3	0	5	3	2.3	2.4
Glass, Ceramics	2	2	3	1	3	2	1.5	1.6
Food, Garden	39	21	75	27	57	78	60	56
Paper	21	20	16	10	12	7	26.4	22.4
Textiles, Bones, Rubber, Wood	2	6	2	2	8	2		
Plastics	3	2	1	0	3	1	2.3	2.0
Inert	28	45	1	60	11	7	3.5	7.2

Source : Holmes , J , Managing Solid Wastes in Developing Countries , Wiley (1984)

SAQ 2.1

Why is it important that a SWM authority should carry out its own investigations and analysis of the composition, characteristics and quantities of solid wastes generated in its area of jurisdiction?

SAQ 2.2

A SWM authority in a Central American country collects 250 000 tonnes of municipal solid waste per year. It can separate and sell 75% of the paper collected for recycling and fuel. Because it has neglected to update its waste analysis, it proposes to use the figures given in Table 2.2 for Acapulco, Mexico, to arrive at an estimate of the quantity of paper available for sale. On this basis, estimate the savings in waste disposal costs if the cost at the landfill site is US$22 per tonne. Comment on the limitations of this simple approach to paper handling.

Factors causing long-term change in waste composition

Fuels for Heating and Cooking

Improvements in standard of living and·the advent of cheap oil and gas have favoured shifts from solid fuels for space heating and cooking, to liquid and gas fuels. This results from the convenience of automatic burners using liquid and gas and the absence of residue(ash). In the developed countries the shift has been most noticeable in respect of space heating, and the trend is continuing. For example, the proportion of ash and cinder in municipal waste streams in the USA decreased from 60% at the turn of the century to a negligible 2% in the 1990's. This factor accounts for the difference in the ash component (inert) in waste streams between the USA and the United Kingdom, where it stands at about 9% (1990). For many of the developing countries where warm climates make space heating unnecessary, the shift is in respect of the replacement of firewood for cooking, by kerosene or bottled gas, especially in places like Nigeria, Indonesia, Trinidad and Tobago and Venezuela where oil and gas are indigenous. A further incentive for this shift arises from global concern over the harmful effects of the destruction of forests in low income countries.

Packaging and Marketing of Food and Consumer Goods

Technological advances are having profound effects on the packaging and containerisation of food, beverages and consumer goods, as levels of economic prosperity increase. The major contributors to this revolution are:

- the development of new materials - plastic film and metal foil
- the perfection of processes for the preservation of food eg. freeze-drying, dehydration, freezing.

- change in cultural practices eg. prepared foods replacing home cooking
- the development of the pop-top aluminum can and the non-returnable bottle for beverages
- the development of plastic containers in large sizes for beverages
- increased packaging of consumer goods, in response to the development of self-service stores and super-markets, for the protection of merchandise on display, for reasons of security, and for accommodating pricing and other information.

Expansion of the food processing industry means that the waste formerly generated in the home from food preparation becomes industrial waste at the processing plant, while the processed products must be packaged for the market. This readily explains the increase of the paper and packaging components and the reduction of the food component.

Table 2.5 Effect of Technology on Beverage Container use (USA)

Container	**Containers used (million units)**		
	1958	1965	1976
Non-returnable			
Bottles	1931	7011	22100
Can	8746	18559	36000
	10177	25570	58100
Returnable bottles	1628	2499	1660
Total containers	11805	28069	59760
Total Filings	52921	65213	79500
Containers/Fillings	1:4.5	1:2.3	1:1.3

Source: Midwest Research Institute. The Role of Packaging in Solid Waste Management - 1966 to 1976, Bureau of Solid Waste Management, Washington DC, 1969.

SAQ 2.3

Referring to Table 2.5, what would you say are the principal effects on the stream of solid wastes which resulted from changes in beverage containerisation?

The effect of new materials on the composition of municipal wastes is also evident from statistics relating to the beverage container industry in the USA where aluminum cans and plastic containers have rapidly replaced steel cans and glass bottles. Table 2.5

These trends are already evident in both middle and low-income countries and can be expected to take a similar course and have similar impacts on the composition of solid wastes as in the United States. Aluminium cans, which dominate the US market for disposable beverage containers, increasing from about 1% in 1964 to over 90% of all can containers in 1984 - Pfeffer (1992) are now common in many developing countries. However, increasing concern in the USA, Europe and Japan over the excessive quantities of packaging and containers has, in recent years, sparked a movement towards a reversal of this trend, through public education, covenants between Government and industry and the implementation of laws which make recycling mandatory. Indeed recycling, which through force of circumstance has always played a significant part in waste reduction in the poorest countries, has now taken centre stage in the developed world and is being pursued with great vigour - Chapter 4.

SAQ 2.4

What changes would you expect to take place in the composition and characteristics of municipal solid wastes in the future? Comment on the reasons for these changes and on the implications for landfill operations.

2.3.4 Quantities

The quantity of solid waste generated by a community is a key determinant in developing a cost-effective collection system, as well as in planning a disposal facility. As shown by the information on waste generation in Table 2.3, the weight of municipal solid waste generated in low-income countries is about 30-50% of that in a major industrialised country. Added to this are the much lower densities in the latter, so that the volume of waste per capita in low-income countries is 10-20% of that in a high-income country.

While per capita waste generation is a statistic that is necessary for indicating trends in consumption and production, the total weight and volume of wastes generated by the community served by the management system are of greater importance in planning and design. As in all other aspects of data collection for the planning and design phases, data on waste generation, - weight and volume - should be collected by each authority for application in its own area of operation.

In general, waste generated has increased in most countries between 1970 and 1990, both in total weight and per capita generation. The figures for the United States - Pfeffer (1992), for example, show an increase of 35% in total waste generated and 12% per capita.

Forecasting waste quantities in the future is as difficult as it is in predicting changes of waste composition. The factors promoting change in waste composition, adduced in Section 2.3.3, are equally relevant to changes in waste generation. An additional point, worthy of note, is the change of density as the waste moves through the management system, from the source of generation to the point of ultimate disposal. Storage methods, salvaging activities, exposure to the weather, handling methods and decomposition, all have their effects on changes in waste density. As a general rule, the lower the level of economic development, the greater the change between generation and disposal. Increases in density of 100% are common in developing countries, which means that the volume of wastes decreases by half.

Seasonal Variations

Short-term variations in waste quantities must be accommodated by the management system. They arise from seasonal factors with respect to both climate and cultural events. Climate affects the generation of vegetative waste (yard and garden) as plant growth responds to favourable temperatures and soil moisture. In temperate climates the growth season is from spring to autumn while in tropical areas, where temperatures are always favourable, maximum growth is in the season of rainfall. At the end of the growth season (autumn and the dry season) leaves may comprise a significant proportion of the solid wastes.

Consumer purchasing patterns are a function of prevailing social customs. In Christian communities, for example, increases in the quantities of paper and plastic occur during the Christmas holidays, while similar surges in these and other waste components take place in Muslim, Hindu and Jewish communities at different times of the year. Carnivals (Mardi Gras) in the Americas, the Caribbean and Europe are examples of national festivals which have significant impacts on waste generation. Muttamara and Fude (1979) have presented data which shows a 10% variation between minimum and maximum monthly weights of generated waste.

Variations resulting from residents per household

When the collection system is being designed a knowledge of the waste generated in residential areas, within the same community, is essential. Attention has already been drawn to the influence of household income on waste composition and quantity-section 2.3. Added to the factor of income is the number of residents per household. Studies conducted in the USA have shown that this is also a primary factor (Waste AGE, April 1976, USA). Measurements of waste generation indicated a fall in per capita values from 1.25 kg/day for two residents to 0.4 kg/day for ten residents. These results are explained by reason of economies of scale in the purchase of food and beverages and the common use of certain consumer items. The relationship further shows that the rate of reduction is most rapid between two and five residents, after which the rate decreases and is virtually independent of the number of residents when this number exceeds ten. Clearly, such relationships would be expected to be culture-dependent, but this factor should be borne in mind in view of its potential significance in the design process.

2.3.5 Physical Characteristics

Density

A knowledge of the density of a waste, that is, its mass per unit volume (kg/m^3), is essential for the design of all elements of the solid waste management system. For example, in high-income countries, considerable benefit is derived through the use of compaction vehicles on collection routes, because the waste is typically of low density. A reduction of volume of 75% is frequently achieved with normal compaction equipment, so that an initial density of 100 kg/m^3 may readily be increased to 400 kg/m3. Put in another way, the vehicle would haul four times the weight of waste in the compacted state than when the waste is uncompacted. The situation in low-income countries is quite different: a high initial density of waste precludes the achievement of a high compaction ratio. Consequently, compaction vehicles offer little or no advantage and are not cost-effective. Cointreau (1984) has reported that rear-loading compaction vehicles tested in Bangkok, Thailand, Columbo, Sri-Lanka, and Jakarta, Indonesia, all low-income countries, achieved compaction ratios no greater than $1\frac{1}{2}$:1.

Significant changes in density occur spontaneously as the waste moves from source to disposal, as a result of scavenging, handling, wetting and drying by the weather, vibration in the collection vehicle and decomposition. Generally the lower the level of economic development of a community the greater the likelihood of significant density change. Measurements in several cities amply demonstrate this observation - Cointreau (1984).

- Kampur, India: Wastes in open communal containers exhibited densities of 400-500 kg/m^3, while measurement at the source indicated densities of 200-300 kg/m^3.

- Metro Manila, Philippines: The densities of samples of residential and market waste which were 209 kg/m^3 at the collection point increased to 275 kg/m^3 and 365 kg/m^3 respectively in open trucks.

- Rio de Janeiro, Brazil: Waste at source averaged 230 kg/m^3; in the storage container it was 280 kg/m3 and in the compaction vehicle, about 400 kg/m^3.

- Kano, Nigeria: Waste at the source averaged 250 kg/m^3; after storage in stationary communal containers and loading, it measured about 600 kg/m^3 in non-compaction open trucks.

Density is as critical in the design of a sanitary landfill as it is for the storage, collection and transport of waste. Efficient operation of a landfill requires compaction of the waste to optimum density after it is placed - Chapter 4. Data presented by Pfeffer (1992) taken from compaction tests on domestic waste at a landfill, using a Caterpillar D-9 crawler tractor for spreading and compaction, led to the following conclusions:

- the effect of increasing the moisture content of the waste is detrimental - dry density decreases at higher moisture levels.

- Soil cover (0.6 m) plays an important role in containing the waste.

- There is an upper limit to the density - in this case about 770 kg/m^3.

- a conservative estimate of in-place density for waste in a sanitary landfill is about 600 kg/m^3.

Moisture Content

Moisture content is defined as the ratio of the weight of water to the total weight of the wet waste.

$$\text{Moisture content (\%)} = \frac{\text{wet weight - dry weight}}{\text{wet weight}} \times 100$$

A typical range of moisture contents is 20-40%, representing the extremes of wastes in an arid climate and in the wet season of a region of high precipitation. Values greater than 40% are, however, not uncommon. Moisture increases the weight of solid waste and, therefore, the cost of collection and transport. Consequently, waste should be insulated from rainfall or other extraneous water.

Moisture content is a critical determinant in the economic feasibility of waste treatment by incineration, since energy must be supplied for evaporation of water and in raising the temperature of the water vapour.

Climatic conditions apart, moisture content is generally higher in low-income countries because of the higher proportion of food and yard waste - Table 2.3.

Size

The measurement of the size distribution of particles in the waste stream is important because of its significance in the design of mechinical seperators and shredders. The results of the analysis are expressed in the manner used for the particle analysis of soils, namely, a plot of particle size (mm) against % less than a given value.

2.3.6 Chemical Characteristics

Classification

A knowledge of the classes of chemical compounds and their characteristics is essential for the proper understanding of the behaviour of waste as it moves through the waste management system. The products of decomposition and heating values are two examples of the importance of chemical characteristics. Analysis identifies the compounds and the per cent dry weight of each class.

Lipids

Included in this class of compounds are fats, oils and grease. The principal sources of lipids are garbage, cooking oils and fats. Lipids have high heating values, about 38000 kJ/kg, which makes waste with a high lipid content suitable for energy recovery processes. Since lipids in the solid state become liquid at temperatures slightly above ambient, they add to the liquid content during waste decomposition. They are biodegradable but because they have a low solubility in water, the rate of biodegradation is relatively slow.

Carbohydrates

Carbohydrates are found primarily in food and yard waste. They include sugars and polymers of sugars such as starch and cellulose, and have the general formula $(CH_2O)_x$. Carbohydrates are readily biodegraded to products such as carbon dioxide, water and methane. Decomposing carbohydrates are particularly attractive for flies and rats and for this reason should not be left exposed for longer than is necessary.

Proteins

Proteins are compounds containing carbon, hydrogen, oxygen and nitrogen and consist of an organic acid with a substituted amine group (NH_2). They are found mainly in food and garden wastes and comprise 5-10% of the dry solids in solid waste. Proteins decompose to form amino acids but partial decomposition can result in the production of amines which have intensely unpleasant odours.

Natural Fibres

This class includes the natural compounds, cellulose and lignin, both of which are resistant to biodegradation. They are found in paper and paper products and in food and yard waste. Cellulose is a larger polymer of glucose while lignin is composed of a group of monomers of which benzene is the primary member. Paper is almost 100% cellulose, cotton over 95% and wood products over 40%. Because they are highly combustible, solid waste having a high proportion of paper and wood products, are suitable for incineration. The heating values of oven-dried paper products are in the range 12000 - 18000 kJ/kg and of wood about 20000 kJ/kg, which compare with 44200 kJ/kg for fuel oil.

Synthetic Organic Materials (Plastics)

In recent years, plastics have become a significant component of solid waste, accounting for 1-10%. They are highly resistant to biodegradation which is the property that makes them popular in use but objectionable and of special concern in solid waste management. Much attention is, therefore, being given to the recycling of plastics to reduce the proportion of this waste component at disposal sites. Plastics have a high heating value, about 32 000 kJ/kg, which makes them very suitable for incineration. However, among the plastics is polyvinyl chloride (PVC) which when burnt produces dioxyn and acid gas. The latter increases corrosion in the combustion system and is a component of 'acid rain'.

Noncombustibles

In this class are materials considered to be non-combustible: glass, ceramics, metals, dust and ashes. Noncombustibles account for 12-25% of the dry solids.

Heating Value

An evaluation of the potential of a waste material for use as a fuel for incineration requires a determination of its heating value, expressed as kilo joules per kilogram (kJ/kg). The heating value is determined experimentally using the Bomb calorimeter test, in which the heat generated at a constant temperature of 25°C from the combustion of a dry sample is measured. Since the test temperature is below the boiling point of water, the combustion water remains in the liquid state. However, during combustion the temperature of the combustion gases remains above 100°C, so that the water resulting from combustion is in the vapour state.

Table 2.6 shows typical values of the inert residue and heating values for the components of municipal solid waste.

Table 2.6 Typical Heating Values and Values of Inert Residue of Municipal Solid Waste

Component	**Inert Residue %**		**Heating Value (kJ/kg)**	
Food wastes	2 - 8	5	3500 - 7000	4500
Paper	4 - 8	6	11500 - 18500	16500
Cardboard	3 - 6	5	14000 - 17500	16000
Plastics	6 - 20	10	28000 - 37000	32500
Textiles	2 - 4	2.5	15000 - 18500	
Rubber	8 - 20	10	21000 - 28000	18500
Leather	8 - 20	10	15000 - 20000	17500
Garden trimmings	2 - 6	4.5	2300 - 18500	6500
Wood	0.6 - 2	1.5	17500 - 20000	18500
Glass	96 - 99	98	120 - 240	140
Tin cans	96 - 99	96	-	-
Nonferrous metals	90 - 99	96	240 - 1200	700
Ferrous metals	94 - 99	98	240 - 1200	700
Dirt, ashes, brick, etc.	60 - 80	70	2300 - 11500	7000
Municipal solid waste			9500 - 13000	10500

Source: Lohani, Todina, Jindal, Recycling of Solid Wastes. Env. San. No 13/14 Sept. 1984.

The following should be borne in mind when evaluating incineration as a means of disposal or energy recovery:

- organic material yields energy only when dry
- the moisture contained as free water in the waste reduces the dry organic material per kilogram of waste and requires a significant amount of energy for evaporation.
- the ash content of the waste reduces the proportion of dry organic material per kilogram of waste and retains some heat when removed from the furnace.

SAQ 2.5

Using Table 2.2 and typical heating values in Table 2.6 compare the average heating value (kJ/kg) of municipal wastes in Accra, Ghana with that of the national average for Japan. How do these values compare with the heating value of fuel oil?

Ultimate Analysis

In order to make mass balance calculations for a chemical or thermal process, an analysis of waste must be carried out to determine the proportions of carbon, hydrogen, oxygen, nitrogen and sulphur. This is known as ultimate analysis. The ash fraction should also be determined because of its potentially harmful environmental effects, brought about by the presence of toxic metals - cadmium, chromium, mercury, nickel, lead, tin and zinc. Other metals, such as iron, manganese, calcium, magnesium and sodium, are also present but because they are not toxic, do not present a serious problem.

The results of ultimate analysis of municipal wastes in the USA have been reported by Pfeffer (1992) - Table 2.7.

Table 2.7 Ultimate Analysis of Solid Waste (USA data)

Element	**Range (% dry weight)**
Carbon	25 - 35
Hydrogen	2.5 - 6.0
Oxygen	15 - 30
Nitrogen	0.25 - 1.2
Sulphur	0.02 - 0.12
Ash	12.30

Proximate Analysis

A second analysis, known as a proximate analysis, is important in evaluating the combustion properties of a waste or a waste derived fuel (refuse derived fuel). The fractions of greatest interest are: moisture content, ash, volatile matter and fixed carbon. Moisture adds weight to the waste fuel without increasing its heating value and the evaporation of water reduces the heat release from the fuel. Ash also adds weight without generating any heat during combustion.

Volatile matter is that portion of the waste that is converted to gases before and during combustion. The gases are conducted to a secondary combustion chamber where rapid combusting occurs. Fixed carbon represents the carbon remaining on the surface grates as charcoal. A waste or fuel with a high proportion of fixed carbon requires a longer retention time on the furnace grates to achieve complete combustion than does a waste/fuel with a low proportion of fixed carbon.

Table 2.8 presents data for the United States - Pfeffer (1992)

Table 2.8 Proximate Analysis of Solid Waste
Proportion by weight (%)

	Range	Typical
Moisture	15 - 40	20
Volatile matter	40 - 60	53
Fixed carbon	5 - 12	7
Ash	15 - 30	20

2.4 HEALTH AND ENVIRONMENT EFFECTS

2.4.1 The Concept of Integrated Management

In 1971 a WHO committee on solid waste disposal and control, WHO (1971), made the following statement:

The disposal of waste must take place within a closed environment comprising only earth, air and water. When the liquid, solid or gaseous residues from waste treatment are disposed of, they must be discharged into one of these phases of the environment. Any or all of the phases may be polluted, and any solution to the general problem of the disposal of waste therefore involves a decision as to which part of the environment can accept residues with least damage to the whole. In other words, in deciding on a site for the disposal of residues, their total effect on the environment must be studied. Waste must no longer be transferred from one environmental phase to another without adequate study. This is particularly important in view of the fact that some residues persist permanently.

Implicit in this statement is the concept of waste management in an integrated environment, which is a major step forward from the tendency, all over the world, to solve solid waste problems individually. Thus in solving the public health problems created by open dumps through sanitary landfilling, water pollution may be caused by leachates; incineration may solve the problem of waste reduction, but it introduces pollutants to the atmosphere in the form of noxious substances like hydrochloric acid, oxides of nitrogen and heavy metals particulates. Even if flue gases are cleaned by scrubbers, the pollution problem is transferred from the air to water. The question therefore arises: What combination of management methods would minimise harmful effects on health and the environment while also minimising costs and negative impacts on the economy ?

The mere statement of this concept in no way reduces the difficulty of arriving at an optimal solution from a network of complex relationships. A great deal more research is needed in order to quantify the cost of negative impacts in a country, before pragmatic mathematical models can be developed. Nevertheless this is the way forward.

2.4.2 Public Health

The World Health Organization has defined health as a state of complete physical, mental and social well being and not merely the absence of disease or infirmity. This means that there are may dimensions to the problem of maintaining a healthy community. Solid waste management is but one of them. Apart from its direct and indirect effects through accidents, exposure and the spread of disease, one must also include the effects of visual pollution caused by litter and the nuisances created by smoke and dust at disposal sites.

Disease Vectors and Pathways

Solid wastes dumped indiscriminately provide the food and environment for thriving populations of vermin which are the agents of disease. The pathways of pathogen transmission from waste to humans are mostly indirect through insects - flies, mosquitoes and roaches, and animals - rodents, pigs. The discussion which follows considers the role of the most important of these vectors in the spread of disease. In general, two conditions are necessary for diseases to become a public health problem.

- the disease must be present in the human and animal population of the surrounding communities.
- there must be a carrier to transmit the etiological agent from the host to the receptor.

Flies

The most important of the flies is the housefly which transmits over twenty diseases, among which are: typhoid fever, salmonellosis, gastroenteritis and dysentery. Flies have a flight range of about 10km so that they are able to spread their influence over a relatively wide area. There are four stages in their life cycle:

egg, larva, pupa and adult.

Eggs are deposited in the warm, moist environment of decomposing food wastes. When they hatch, the larvae feed on the organic material until a certain maturity is reached, at which time they migrate from the waste to the soil or other dry loose material before being transformed into pupae. The pupae are inactive until the adult fly emerges. The migration of larvae within 4 to 10 days provides the clue to an effective control measure, which is that the waste should be moved before migration occurs. Consequently, in warm weather, municipal waste should be collected twice weekly, at least, for effective control. In addition, the quality of household and commercial storage containers is very significant. The guiding principle here is restriction of access by flies to the stored waste. Clearly, the use of sound storage containers and general cleanliness at the sites of their location, as well as frequent collection of waste, are measures which greatly reduce the population of flies. Control is also necessary at transfer stations, composting facilities and disposal sites to prevent them becoming breeding grounds for flies. Covering solid wastes with a layer of earth at landfill sites at the end of every day arrests the problem of fly breeding at the final stage of waste management.

Mosquitoes

Mosquitoes infect humans through attack by the female which transmits diseases like malaria fever, yellow fever and dengue fever. Since they breed in water, control measures centre around the elimination of breeding places such as tin cans and tyres that are so much a feature of open dumps. Proper sanitary landfill practices - Chapter 4, and general cleanliness in the community eliminate the mosquito problems caused by solid waste.

Roaches

Roaches cause infection by physical contact and can transmit typhoid fever, cholera and amoebiasis. The roach problem is associated with the poor storage of solid waste in households and commercial establishments. If containers are kept properly closed and inaccessible, the problem can be eliminated.

Rodents

Rodents, notably rats, proliferate in uncontrolled deposits of solid waste which provide a convenient source of food and shelter. They are responsible for the spread of 22 diseases including, murine typhus, leptospirosis, histoplasmosis, rat bite fever, salmonellosis and trichinosis. Many diseases are also caused by the fleas which rats carry. The problem is not only one of open dumping but also of poor sanitation in surrounding households which are invaded only if they provide suitable breeding grounds and food supplies. A properly operated sanitary landfill should have no rats.

Accidents

Workers handling solid waste are at risk of accidents related to handling operations, the nature of material handling and the safety precautions employed. They suffer skin wounds by contact with the sharp edges of glass and metals and of poorly constructed storage containers. It is good practice for waste handlers to wear gloves and to be vaccinated against tetanus. Data presented by Van Beek (1973) indicate that accidents of waste collection personnel are among the most numerous in the United Sates and that the lost time injury frequency rates for waste collection and disposal lead the list as the most hazardous occupation in the United States.

Animals

Apart from rodents, the pig is the most notable animal involved in the spread of diseases, especially in low-income countries. Diseases like trichinosis, cysticerosis and toxoplasmosis are transmitted through infected pork eaten in an underdone or raw state when the animal is improperly fed raw solid waste. This practice was banned in the United States as long ago as 1952 but continues in many countries of the developing world. If solid waste must be fed to pigs it should be cooked at 100°C for at least 50 minutes with proper equipment.

Other Factors

- muscular strain in collection workers as a result of the strenuous and asymmetric physical effort of handling containers; these complaints are directly related to the weight of containers and the loading heights of vehicles, which should be limited to 20 kg and 1 metre respectively.

- dust at disposal sites; this can cause lung and eye diseases as well as creating a nuisance; protection against dust means the provision of suitable masks and airtight cabins for the use of workers; dust reduces visibility along access routes thus creating greater risk of accident.

- transmission of disease by birds: the vulture harbours the pathogen of toxoplasmosis.

- explosive hazards of solvents and fuels (gasoline); it is common practice to dispose of containers used for such liquids at landfill sites for municipal wastes; sufficient quantities of the contents may remain to create explosive mixtures.

- toxic chemicals used as pesticides, cleaning solutions and solvents in households and commercial establishments; although the quantities of these liquid residues are small, they may be very toxic if ingested or absorbed through the skin.

- the careless dumping of lead-acid, nickel-cadmium and mercuric oxide batteries is a serious health hazard, particularily for children; battery manufacturers can assist by providing collection services.

2.4.3 Environmental Effects

Air Pollution

Burning of solid wastes in open dumps or in improperly designed incinerators represents a significant source of air pollution and should be prohibited. Several countries, both developed and developing, for example, the USA and Brazil, already have such restrictions. Studies in the United States before existing regulations were instituted show that the effects of open burning were greater than incinerators, especially in respect of aldehydes and particulates. Emissions from an uncontrolled incinerator system include: particulates, sulphur oxides, nitrogen oxides, hydrogen chloride, carbon monoxide, lead and mercury. Indeed all metals present in solid wastes can be discharged as particulates. Arsenic, cadmium and selenium are included in the list and since they are toxic at relatively low exposure levels, their discharge should be controlled. Recently formulated standards by the European Economic Community (EEC) introduce a new pollutant, dioxin, which is one of two general classes of organic compounds that are of concern because of their toxicity, carcinogenecity and possibly mutagenicity. These classes are: polychlorinated dibenzofurans (PCDFs), commonly called dioxins and furans. Five dioxins and seven furans are considered to be the most toxic. The establishment of standards for the emissions from solid waste incineration systems is still in the evolutionary stage as new analytical techniques are developed for detecting a greater number of compounds of high toxicity.

Water and Land Pollution

Water pollution results from open dumping and the improper design, construction and/or operation of a sanitary landfill. Control of infiltration from rainfall and surface runoff is essential in order to minimise the production of leachate - see Chapter 4. Pollution of groundwater can occur in the following ways: Engracia de Oliveira (1978).

- by direct horizontal contact when groundwater flows through deposits of solid waste.
- through the vertical flow of percolating water from rainfall or irrigation, or from the solid wastes themselves down to the water table.
- through the transfer, by diffusion and collection of gases generated by the decomposition of solid wastes.

The interaction between leachate contaminants and the soil depends on the characteristics of the soil. BOD is stabilized by soil bacteria if toxic substances are in low concentration, by anaerobic action. The carbon dioxide produced keeps the pH level low causing the water to dissolve minerals in the aquifers. Consequently the change in groundwater quality may be significant depending on the characteristics of the aquifer. Increases in hardness and iron and manganese compounds are common. Contamination can spread over considerable distances from the landfill if the aquifers are of sand or gravel. In clay soils the rate of movement is greatly reduced. The capacity of clays to exchange ions restricts the movement of metal ions by capturing them in the soil matrix.

Visual Pollution

The aesthetic sensibility of concerned citizens of all countries is offended by the unsightliness of piles of waste, in general disorder, that are to be found in both developed and developing countries. Chief among such eyesores is the open dump which unfortunately has not yet been laid to rest. In both middle and low-income countries, the situation is made worse by the presence of scavengers rummaging in the waste. While one must concede that such activities are difficult to eliminate in conditions of poverty and high unemployment, the more enterprising of low-income countries have shown that salvaging of materials can be organised at sanitary landfills by providing relatively simple and inexpensive facilities, such as a portable conveyor belt, for sorting and separation of waste components.

Other examples are: waste carelessly and irresponsibly discarded in public thoroughfares, along roads and highways and around communal bins; makeshift containers, without lids, used for the storage of residential commercial and institutional wastes, giving easy access to animals scavenging for food; waste deliberately thrown into open drains. In some cases, the solid waste management authority is culpable by not providing containers in sufficient number, but there is little doubt that the irresponsible attitude of certain members of the public is at the heart of the problem. The solution of this social problem undoubtedly lies in the implementation of vigorous programmes of public education at all levels - primary, secondary, tertiary and adult, both short-term and long-term, and in raising the status of workers and managers in the solid waste industry. This is the lesson of Singapore.

Noise Pollution

Undesirable noise is a nuisance associated with operations at landfills, at sites of incinerators, at transfer stations and at sites used for recycling. This is due to the movements of vehicles, the operation of large machines and the diverse operations at an incinerator site. The impacts of noise pollution may be reduced by careful siting of SWM operations and by use of noise barriers.

Odour Pollution

Foul odours are a feature of open dumps because of the presence of decaying organic matter. They arise from anaerobic decomposition processes some of whose products are particularily offensive. Proper landfill covering eliminates this nusiance.

Explosion Hazard

Landfill gas, which is released in anaerobic decomposition processes, contains a high proportion of methane (35-73%) - see Chapter 4 - and is therefore potentially explosive. It can migrate through the soil over a considerable distance, so that buildings in the vacinity of sanitary landfill sites are at risk even after their closure. Such an explosion occured in Loscoe, Derbyshire, England in 1986, destroying a house, after the gas had entered the building and was ignited by a boiler. Several methods are available for control of landfill gas, such as venting, flaring, and the use of impermeable barriers.

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ANSWERS TO SELF ASSESSMENT QUESTIONS

SAQ 2.1

Accurate data on the composition, characteristics and quantities of solid wastes is essential for the design of the various elements of a SWM system - Section 2.3. Data collected from countries and districts around the world shows very clearly the profound influences of living standards, climate and socio-cultural factors. Refer to Tables 2.2, 2.3 and 2.4.

Taking three high income countries: Japan, UK and USA, as an example, differences are largely accounted for by socio-cultural factors. On the other hand, low proportions of paper, high proportions of food and garden wastes and waste characteristics such as high density and moisture content, are indicative of lower income status.

The investment of financial resources in accurate field and laboratory measurements and analysis pays rich dividends in minmising the overall cost of operation of the SWM system.

SAQ 2.2

Using Table 2.2 the proportion of paper, by weight, in the waste stream for Acapulco, Mexico is 17.2%.

Weight of paper available for sale per annum = 0.75 x 0.172 x 250 000
= 32250 tonnes
Annual saving in disposal cost = 32250 x $22
= US$ 709 500

Possible errors inherent in the use of data not obtained locally are implicit in the answer to SAQ 2.1. In addition, the estimated annual saving in disposal costs, though considerable, will be offset by the cost of collecting the paper waste and baling if for sale to the purchasers. If this cost is greater than the saving of US$22 per tonne, the scheme would not be worthwhile. As a greater number of SWM authorities venture into paper recycling and re-use, markets are becoming oversupplied and prices are falling.

SAQ 2.3

Between 1958 and 1976, the percentage of returnable bottles declined from 13.8% to 2.8% of the total number of containers, while the percentage of non-returnable bottles and cans increased from 86.2% to 97.2%. There was also a dramatic increase in the total number of containers from 11805 to 59760. This means that there was a considerable increase in both quantity and weight of containers in the waste stream due not only to an increase in total number of containers, but also to the higher proportion of non-returnable containers.

The nature of waste beverage containers also changed, as noted from a decline of cans from 85.9% of the non-returnable containers to 62.0%. A large proportion of the increase of non-returnable bottles was in respect of plastic bottles while the increase of cans, from 8796 to 36000, reflects the change from steel to aluminium.

SAQ 2.4

You should look particularly at conditions in your own country, since much depends on its stage of socio-economic development, on the climate, on its culture and income status. However, some general trends may be adduced. Most countries would expect to improve their standards of living, which, as a general rule, results in an increase in the quantities of waste per capita. Up to the 1990's, there was a distinct tendency for the changes that have taken place in the developed countries (USA, Europe, Japan) to be repeated in countries at earlier stages of development. Among the most important of such changes are:

- an increase in the proportion of paper
- a decrease in the proportion of ash
- a decrease in the proportion of food and garden wastes
- an increase in the proportions of plastic and aluminium container wastes as opposed to glass;

There are promising signs, however, that as a result of the growing influence of the global environmental movement and of the revolution in information technology, the changes mentioned above are not inevitable for developing countries. Optimism about a reversal of the more worrisome trends in the USA and Europe is now well founded, in the light of the introduction of new and more stringent legislation. Some of the new measures are:

- incentive to re-use and re-cycle materials by separation at source and collection either at the household or at special depots
- reduction of packaging
- mandatory re-cycling
- encouragement of a return to the use of returnable, refillable bottles.

Clearly there is no easy answer to the question. Much will hinge on the sensitivity of governments and manufacturers to the benefits of waste minimisation and the preservation of the environment. In the developed countries, it is reasonable to expect a per capita reduction in paper waste and non-returnable containers and an increase in recycling of materials. Waste flows to disposal sites will probably be reduced.

Developing countries, on the other hand, will find it somewhat more difficult to reverse trends due to a shortage of funds necessary for the implementation of suitable legislation. The principal effect on landfill operations will be, that as waste density decreases, compaction will become more time consuming.

SAQ 2.5

The percentages of each waste component taken from Table 2.2 are multiplied by the appropriate rating values in Table 2.6

Component	**Accra, Ghana**	**Japan**
Metal	.026 x 700 = 18.2	0.059 x 700 = 41.3
Glass/Ceramics	0.007 x 140 = 0.98	0.15 x 140 = 21.0
Food/Garden (1)	0.871 x 5500 = 4790.5	0.117 x 5500 = 643.5
Paper	0.057 x 16500 = 940.5	0.385 x 16500 = 6352.5
Textiles	0.012 x 17500 = 210.0	0.041 x 117500 = 717.5
Plastic	0.013 x 32500 = 422.5	0.119 x 32500 = 3867.5
(2) Misc. combustible	- -	0.038 x 18000 = 684.0
Inert/Other	.014 x 7000 = 100.8	0.091 x 7000 = 657.0
Total	6483.48kJ/kg	12964.3kJ/kg

(1) Average of Food Wastes and Garden Trimmings

(2) Average of Wood and Leather.

Thus, we see that the heating valve of MSW in Japan is about twice the value in Accra, Ghana.

The percentages of the heating value of fuel oil are 14.7% and 29.3% respectively.

3. WASTE STORAGE AND COLLECTION

3.1 INTRODUCTION

To most residents of a community the solid waste collection system is the solid waste management system. The collection system removes solid wastes from houses, neighbourhoods, commercial and industrial areas and waterways and removal is what matters most to the community. Very few residents care where or how the collected wastes are disposed of. Operation of the collection system is the most politically sensitive component of the solid wastes management system . In terms of cost, the collection system in developing countries accounts for 70-80% of the total budget for solid waste management, the remaining 20-30% going towards street sweeping and overheads. Very little is spent on disposal. Optimizing the operation of the collection system would result, therefore, in considerable savings and improvement in the level of service. In this regard, operations research and modern management techniques are powerful tools but the use of these techniques requires computers and skilled operators which are beyond the reach of many solid waste management authorities. While solid waste management may be the largest single item in a municipal budget, it often does not attract talented personnel. Managers tend to be conservative and resistant to departures from conventional practice. Another important factor for developing countries is the expenditure of scarce foreign exchange on the importation of trucks, spare parts, compactors, and other mechanical equipment. Record keeping, an inventory of spare parts and planning and upgrading of the system are all important aspects of operation which must be given close attention to ensure a successful solid waste collection system.

Sections 3.2 to 3.10 are developed for students with minimal practical experience in planning and the preparation of feasibility studies. The student is expected to possess basic mathematical skills up to the level of the calculus. Application of operations research techniques requires knowledge of computer programming, especially GWBASIC and FORTRAN languages, probability and statistics, linear algebra, and differential equations. While some of the basic concepts of operations research and management are discussed in this chapter, the reader is advised to consult standard texts on these subjects. Suggested references for further reading are given at the end of the chapter.

Section 3.2 starts with a brief description of the collection system and its components, the variables affecting the performance of the system, and the design, selection and upgrading of the components. Section 3.3 gives a detailed description of the components of the system, while the technical and non-technical factors which affect efficient performance and interactions of the components are discussed in Sections 3.4 to 3.6. The student will learn how to carry out motion and time studies, synthesise a new collection sequence, and evaluate suggested modifications to existing components of the system. After mastering these tasks, the student will learn how to integrate the components into a working system, to evaluate the resources at hand, develop the best practical system and plan the upgrading of the system to match future demands and available resources. In addition he will learn how to plan the collection route, match the equipment and personnel, and evaluate the usefulness of transfer stations. With limited resources and pressing solid wastes collection problems, the authority of a developing country may be forced to implement the best practical system although it may not meet the standard required in developed countries. The best practical system must be compatible with the planned future system to minimise wastage of resources. Record keeping, and the keeping of other important documentation required for monitoring and upgrading the collection system are discussed in Section 3.9. The interaction between the collection system and the disposal system is discussed in Section 3.10. Section 3.11 caters for the dedicated student with mathematical inclinations who may wish to use advanced mathematical techniques and explore their utilization in planning and improving the collection system. Where the observations presented contradict existing practices meticulous care has been taken to explain the rationale for these differences. The student should be aware that in actual practice he has to interact with his fellow engineers, planners and managers in order to develop the most practical system. While an attempt has been made to quantify variables as much as possible, it must be emphasised that, in practice, some of the variables are non-quantifiable. Full use should be made of group dynamics during meetings and the discussion and exploration of the advantages and disadvantages of alternative proposals. The collection system is after all only a sub-system of the total solid wastes management system and is interactive with the disposal system and the resource recovery and recycling system.

Objectives

The objectives of this chapter are:

- to describe in general terms, how solid wastes are stored and collected, emphasising the strong influences of living standards, climate and culture on the manner in which these operations are carried out;
- to describe the characteristics of waste containers relative to their use for residential, commercial and communal storage, and of the vehicles and equipment used for collecting and hauling wastes;
- to discuss the collection operation: the movements of a collection crew, the procedure for planning an optimal route for a collection vehicle and the interaction between crew and vehicle as a means of determining crew size;
- to discuss the purpose of a transfer station as a component of the collection system and the factors influencing a decision whether or not to use this facility;
- to illustrate through worked examples how various aspects of the design and operation of the collection system are quantitatively taken into account;
- to discuss the institutional arrangements that are necessary for the proper management of a collection system;
- to discuss how a collection system is planned, implemented and monitored in the light of the several constraints to which this process is subjected;

- to discuss the requirements for record keeping and inventory control for the operation of a collecting system;
- to discuss the importance of integrating the collection and disposal systems.

3.2 THE COLLECTION SYSTEM

3.2.1 Conditions at the point of Collection

The solid waste collection system starts at the point of waste generation. Solid wastes may be collected in small garbage containers and consolidated into larger containers such as plastic garbage bags, plastic collection containers, odd pieces of disposable boxes, cans, crates and steel drums. Alternatively recyclable components may be separated from other waste streams. Sometimes the recyclable materials are kept for itinerant buyers, or a number of containers may be left for the collection crew to collect these materials separately. The practice is highly dependent on the standard of living, the market for recyclable materials, and enforcement of solid waste collection policies. In countries with relatively high standards of living there is little financial incentive for the householder to sell recyclable materials to itinerant buyers, and he prefers the collection crew to remove the recyclable materials from his premises free of charge.

Solid waste collection containers of good quality are highly recyclable and command a good price. For this reason householders in developing countries are reluctant to leave such containers at the curbside for long periods of time and tend to use containers which have little value. As a consequence, the collection operation is hampered by the odd sizes of containers, health risks to the collection crew and spillage that takes place during the loading operation. Chief among the health risks are:

- hernia and muscular strain from lifting large, heavy containers such as 55 gallon drums.
- cuts and bruises suffered on sharp edges on boxes and metal cans used as containers.

Spillage is more likely to occur when containers are not secure or without covers, or are easily tipped over and ripped apart by stray animals. Collection efficiency at each stop is then greatly reduced because the litter must be swept up by the waste collectors before loading into the collection vehicle.

To mitigate the apprehension of the householder concerning the loss of his container and to avoid the low efficiency and high health risk on the part of the collection crew, most solid waste management authorities in developing countries have evolved a collection system wherein the householder carries his own wastes and containers to the collection vehicle, where he is assisted by the crew in loading the wastes into the vehicle. Punctuality is essential for the efficient operation of this system since the householder is reluctant to leave ongoing tasks at an unscheduled time. The consequence of unpunctuality is the indiscriminate dumping of the wastes.

Some authorities, such as in Bandung, Indonesia, have solved the problem by using push-carts to collect the wastes from the households. The householder takes the container to the collector who loads the wastes into the push cart. Although the householder may be engaged in other activities at the opportune time the collection worker with his pushcart moves so slowly that even after 30 minutes he is still in the vicinity and the opportunity is not lost. The process has the advantage of generating employment, it reduces the need for imported collection vehicles and fuel, and improves the recycling of waste materials. When the push cart is full the collector wheels it to a designated area where its load is transferred to the vehicle. In Manila the collector is encouraged to recover recycled materials. Unlike mechanized collection where salvaging activities by the collection crew must be discouraged due to the high cost of idle vehicle time and fuel wastage, in systems employing a push cart the incremental cost is merely the collector's labour cost which is normally very low in developing countries. Pushcarts are still being used in cities in developed countries such as Rome and Seoul due to technical constraints imposed by the narrow and winding streets which preclude the use of motorised vehicles. However, most solid waste management authorities in developing countries tend to rule out the use of pushcarts as they consider the system primitive and degrading to their organizations.

Frequency of Collection

Solid wastes may be collected daily or as infrequently as once a week. The quantity of waste generated tends to decrease with declining collection frequency, for example, the wastes generated in a collection area served once a week could be 10% lower than when the same area is served daily. While it is desirable to reduce the frequency of collection in order to reduce the quantity of solid wastes generated and reduce the fixed cost of moving in and out of the collection area, local climatic conditions often have a stronger influence in determining collection frequency. In hot and humid climates solid wastes must be collected at least twice a week, otherwise the presence of insects, bad odour and leachate from decomposing solid wastes will tempt the householder to indiscriminate dumping. The quality of solid wastes containers on site also affects the collection frequency. Sealed plastic bags allow infrequent collection, up to three days whereas open and unsealed containers may require daily collection especially during the rainy season.

The Collection Crew

The solid wastes collection vehicle may be a motorized vehicle, a pushcart or a trailer towed by a suitable prime mover such as a tractor. The number of collectors depends on the size and type of the collection vehicle used, spacing between houses, the solid wastes generation rate, frequency of collection and labour cost. Because of its size, a push cart is normally served by one collector. A trailer may have up to four collectors although the number is restricted to two. Non-compaction vehicles with capacities less than 5 m^3 are served by three to five collectors while a 10 m^3 vehicle may be served by four to six collectors. As the cost of labour increases, the number of collectors per vehicle is reduced. Normally, the driver does not participate in the loading of wastes. However, in countries with labour costs higher than U.S. $2/ hr (1987 prices), compaction vehicles served by one person are viable since the cost of idle collection equipment is lower than the cost of underutilised labour. As the solid waste generation rate increases or with less frequent collection, the quantity of wastes collected per stop increases. Hence, a bigger crew size is justified. Proper selection of crew size with respect to the collection equipment is a simple economic evaluation of the cost of equipment relative to the cost of labour for loading a given quantity of solid wastes in a given time. The principle is discussed in more detail in Section 3.4.

When the collection vehicle is full, the crew takes time off while the collected wastes are hauled to the disposal site or to the transfer station. Since the travel time between the service area and the disposal site or transfer station could be longer than the collection period, it is possible for the crew to spend more than 50% of the working day idle. To counteract this shortcoming, management could reduce the size of the collection crew to increase the proportion of the collection time with respect to hauling time or otherwise operate a relay of collection vehicles and crews. One collection crew could serve two collection vehicles or two collection crews three collection vehicles. While theoretically it is possible to adjust the ratio of collectors to collection vehicles such that the crew idle time is minimized it is difficult to implement this measure in practice because the travel time and collection period are stochastic in nature. Overlapping in crew collection and truck idle time could result. Fig. 3-1 illustrates the scheduling of collection vehicles and crew in a relay.

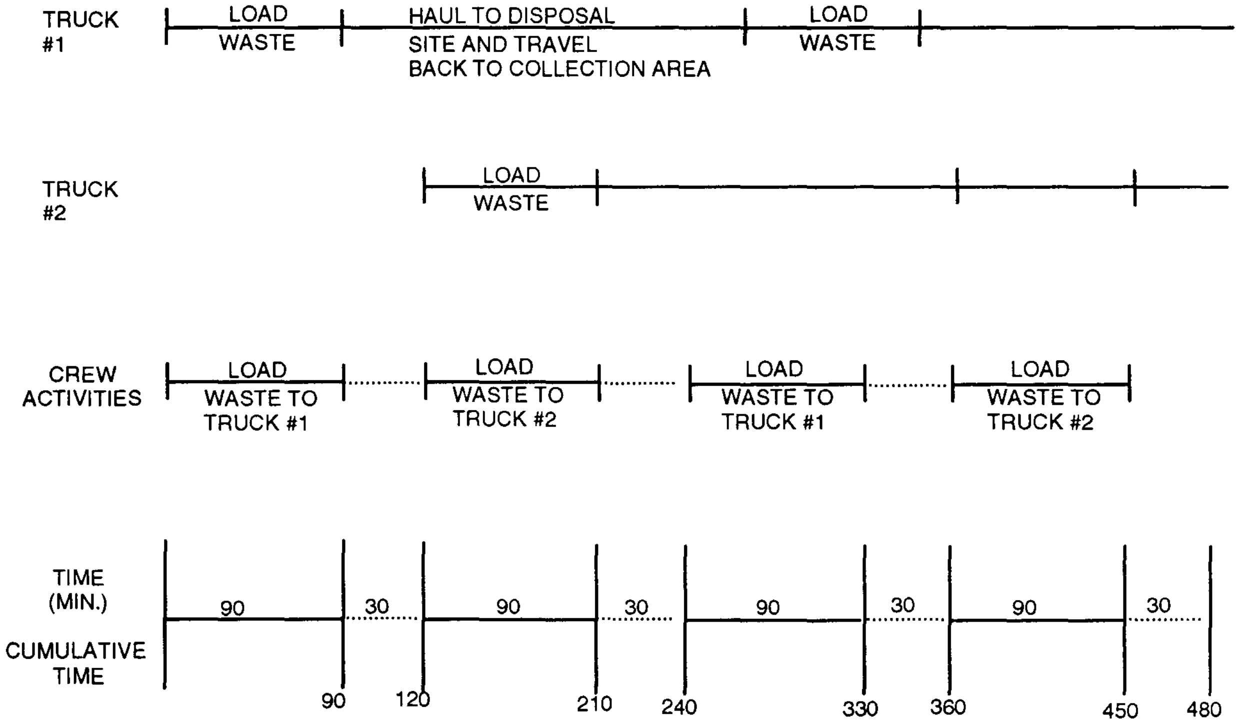


Fig. 3-1 Operation of A 2 Truck/One Collection Crew Relay System

In most developing countries, collectors of solid wastes supplement their meagre income from the sale of recyclable and reusable materials. This practice is discouraged by some authorities because it increases the cost of collection especially for fuel and vehicles. On the other hand some authorities encourage this practice since it allows them to retain crews in relative contentment with the salaries that the authorities can afford. Under these conditions the authorities tend to substitute compactor and mechanised vehicles with pushcarts as discussed earlier. Yet other authorities allow the collection crew to sort and bale the recyclable materials only during the hauling operation. However it is difficult to monitor compliance by the collection crew and more often than not salvaging interferes with the collection operation. The operation of a relay system is difficult since the collection crew will be busy sorting and salvaging recyclable materials when the collection vehicle is hauling the wastes to the disposal site or transfer station.

Haulage to the Disposal Site

The unit cost of hauling solid wastes from a collection area to a transfer station and disposal site decreases as the size of the collection vehicle increases for the following reasons:

- labour costs for the driver remain constant.
- the ratio of payload to vehicle load increases with vehicle size.
- the waiting time, unloading time, idle time at traffic lights, and driver rest period are constant, regardless of the collection vehicle size.

If the disposal site is remote from the collection area, a transfer station may be justified. Under this arrangement smaller collection vehicles transfer their loads at the transfer station to larger vehicles which haul the wastes long distances to the disposal sites. In some instances the transfer station serves merely as a convenient point for transferring loads between vehicles of different sizes, while in others the transfer station serves as a pre-processing point where wastes are dewatered, baled or compressed. Centralized sorting and recovery of recyclable materials may also be carried out at the transfer station.

3.3 CONTAINERS AND COLLECTION VEHICLES

3.3.1 Containers

Solid waste is generated continuously but collected intermittently. Consequently it is necessary to provide facilities, at the point of generation, for storage of the waste until it is collected. The design of an efficient collection system requires careful consideration of the type, size and location of containers used for storage. The smallest containers are used for single family households while multi-family residential housing units, commercial units, institutions (hospitals, universities, schools) and factories require larger containers. The latter type sometimes have built-in compactors for reduction of the volume of the waste if it is of low density. Containers used by single family households are usually handled manually whereas the larger, heavier containers require mechanical handling. A distinction is also made between containers which have their contents transferred to collection vehicles at the site of storage and those which are hauled directly to a processing plant, transfer station or disposal site for emptying before being returned to the storage site. The former are called stationary containers and the latter hauled containers.

The difference in practice between developed and developing countries, as far as solid waste containers are concerned, is striking. In the former, the type, size and location of containers are strictly regulated by ordinance and contract whereas the chronic shortage of funds in low-income countries makes regulation a difficult proposition. Among the desirable characteristics of a well-designed container are low cost and those characteristics which relate to size, weight, shape, resistance to corrosion, water tightness, strength, durability, resistance to penetration by disease vectors (rats, insects) and resistance to destruction by animals (dogs, cats, wild animals). Tchobanoglous, G. et al (1977).

A container designed for manual handling by one person should not weigh more than 20 kg when full in order to avoid the occupational health hazards of hernia and muscular strain. If a waste has a density of 250 kg/m^3 the container should have a capacity of 60 litres allowing 5 kg for the empty container. For low density wastes, 100-150 kg/m^3, the container's capacity may be as large as 90-140 litres. Containers which weigh more than 20 kg when full require two or more crew members to load the wastes into the collection vehicles, resulting in a lowering of collection efficiency.

A container should not have rough or sharp edges which could cause cuts and bruises when handled. It should have a handle and if possible be provided with a wheel to facilitate mobility. Containers should be covered to prevent rain water from entering since rain water increases the weight of the solid wastes, and makes them more difficult to load. Rain water also increases the rate of decomposition of organic materials in the solid wastes attract insects, rats and other disease vectors as well as generates foul odors. This lowers the efficiency of collection crews and exposes them to greater health risk.

For greater stability a container should have a low centre of gravity. A high centre of gravity facilitates spillage and overturning by stray animals. The container body must be strong enough to resist and discourage stray animals and scavengers from ripping it as well as to withstand rough handling by the collection crew. When used for mechanical loading of compactor vehicles, the container should be provided with a lifting bar compatible with the hoisting mechanism of the vehicle. The container must not absorb moisture, otherwise cleaning becomes more difficult and the growth of fungi and slimes is encouraged. Its surfaces must be smooth so that dirt is easily removed and when washed the rinse water easily drained. The material used should be resistant to corrosion, light, recyclable and easily molded. High density polyethylene and polybutylene meet most of the requirements mentioned above but are very expensive compared to alternative materials such as discarded 55-gallon steel drums, cans, bamboo baskets and plastic grocery bags. Black polyethylene plastic bags are used as disposable containers. The use of disposable containers facilitates the collection operation since members of the collection crew do not have to return the containers, nor do they have to open the containers. However, in developing countries where incomes are low the collectors often rip the plastic bags to sort out salvageable materials. In most cases the plastic bags are part of the salvageable materials.

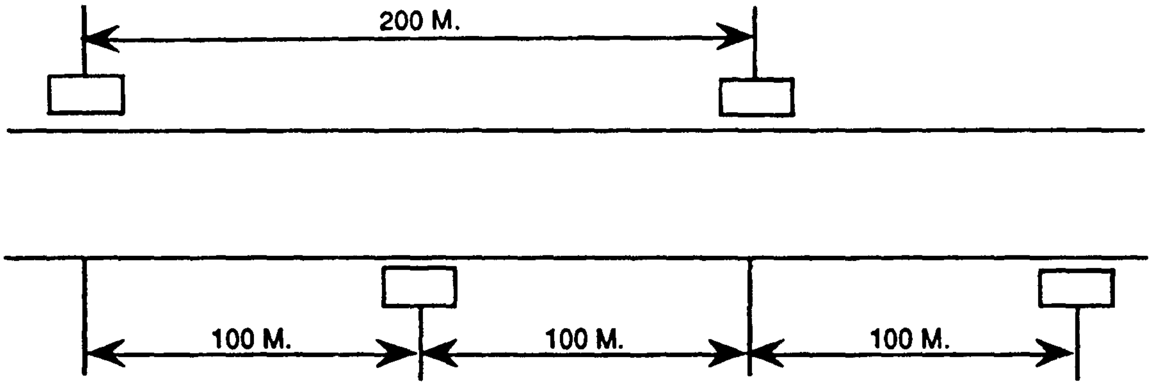
Steel and ferrous containers are subject to corrosion; the rust peels off exposing sharp edges which could be hazardous to the collection crew. Steel containers are also heavy and in some instances they weigh more than their contents. Wooden containers such as bamboo, rattan and wooden baskets readily absorb and retain moisture. The surfaces are rough, irregular and difficult to clean. Lint could also harm the collectors. However, in practice the solid waste management authority has little option but to collect solid wastes from containers of various makes, shapes and sizes if the standard of living is very low. In developed countries solid waste containers are often provided by the solid wastes management authorities and standardize them to facilitate the collection operation. Even if the average standard of living for the whole service area is low, there are always pockets of affluence which can afford standardized containers. In such areas, standardization of the containers should be enforced to improve the collection crew efficiency and also to reduce the quantity of wastes scattered and blown by the wind.

3.3.2 Communal Containers

When the collection vehicle stops frequently, every 50 m or so, it has to operate in low gear. The fuel consumption is much higher than if it were to travel 100-200 m distances using higher gears. The continuous stop and go operation of the collection vehicle results in rapid deterioration of the clutch and brakes while continuous operation in low gear results in faster depreciation of the engine. When a truck is used as a collection vehicle the use of communal containers may be advisable. The containers are placed 100-200 m apart. The longer distance is used in narrow streets with low traffic where the house owner could readily cross the street. The communal containers are staggered such that the effective distance is maintained at 100 m as shown in Figure 3-2. This means that the farthest distance the householder will have to walk is 50 meters or approximately four houses away. Spacing the communal containers farther apart tends to encourage the householder to throw his solid wastes in nearby creeks, vacant lots and more convenient areas. Communal containers are often used in tall buildings and high rise residences.

The use of communal containers is highly dependent on local culture, tradition and attitudes towards wastes. In some cultures, for example, it is considered demeaning to be seen carrying one's wastes across the street. The solid wastes management authority must therefore exercise strong political will and establish institutions to monitor, maintain and upgrade the communal containers.

Communal containers may be fixed on the ground or they may be movable. Moable containers are provided with hoists and rails compatible with the lifting mechanism of the collection vehicles. Communal containers are also placed under the solid wastes chutes of large buildings or if there is no chute, in a space close to the service elevator. Such containers have capacities of 1-4m^3 Fig. 3-3 shows a typical communal container which is lifted and emptied mechanically by a compactor collection vehicle.



LOCATION OF COMMUNAL CONTAINERS IN NARROW ROADS

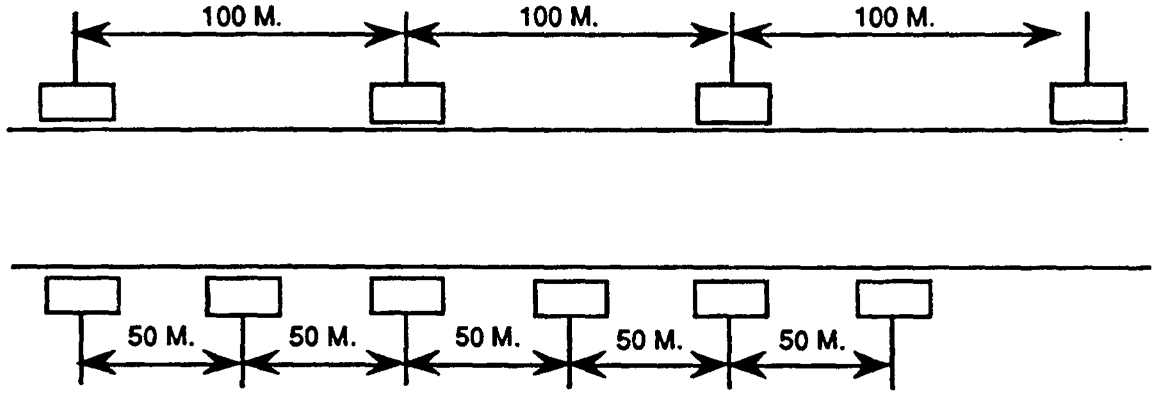


Fig. 3-2 Location of Communal Containers

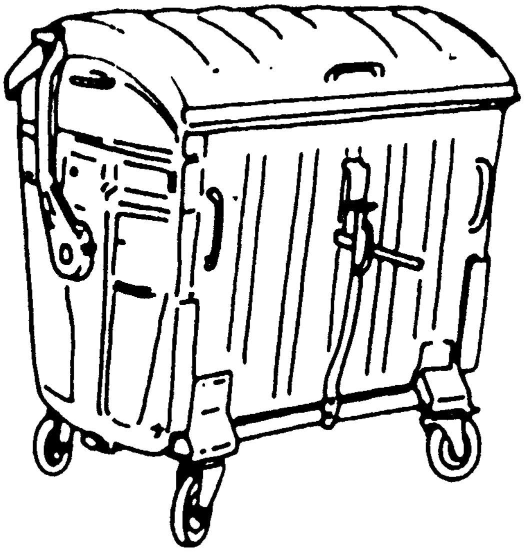


Fig. 3-3 Typical Communal Container used in conjunction with a lifting device fitted to a collection vehicle.

For areas with very high waste generation rates, like wet markets, large commercial centres and large business establishments where daily generation rates exceed two truck loads, roll on-roll off or hoisted communal containers are used. The containers have capacities of 12-20m^3 and a strong superstructure and may be provided with wheels. The communal container is lifted on to the platform of the collection vehicle which is provided with a hoist mechanism. The tenants or the building maintenance crew bring the wastes to the communal containers. The main problem with containers of this size is the lack of available space in buildings and service areas which must be sufficient to accommodate two containers. Normally the vehicle unloads an empty container as replacement before it loads the filled container. The container could weigh up to a ton and would be difficult to move manually. The lift mechanism in the vehicle could be used to move the empty container after it has lifted the filled container. Nevertheless, an extra space is needed while the vehicle is loading the filled container. Fig. 3-4 shows a communal container used at market sites in Manila in conjunction with a hoist vehicle with lifting chains.

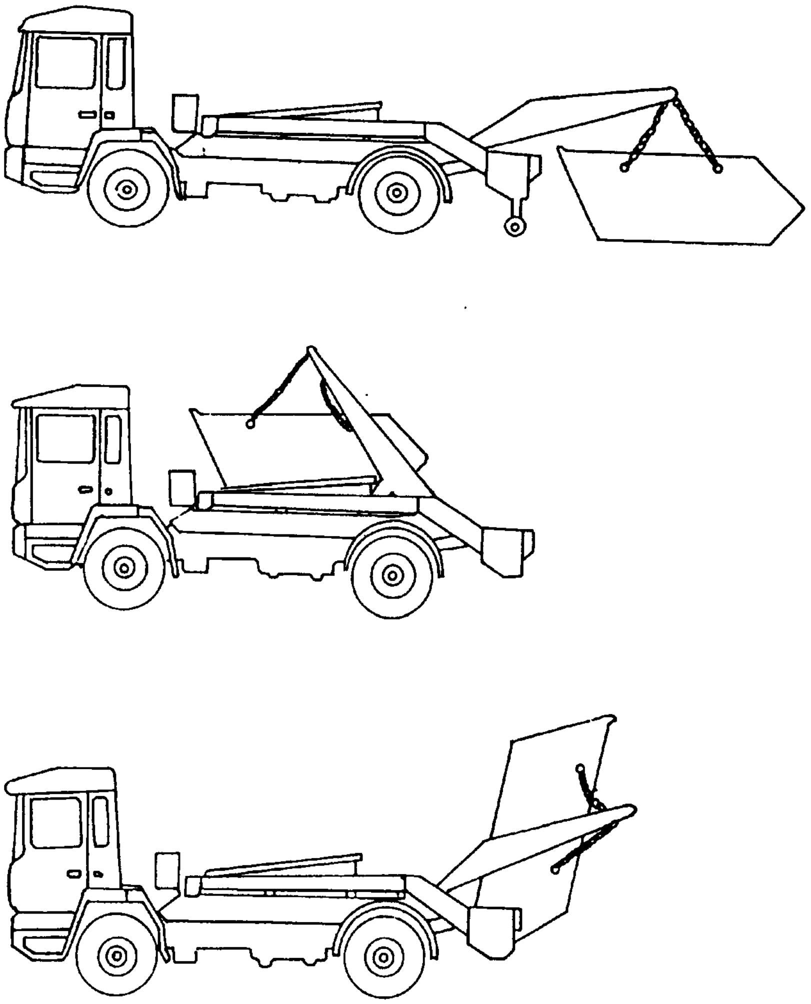


Fig. 3-4 Movable Communal Container and Hoist Vehicle.

Communal containers in buildings may be fixed and are made of steel or concrete. Normally the bottom of the container is at a higher elevation than the collection vehicle. The solid wastes are manually pushed into the truck. Steps are provided at the back to allow manual loading of solid wastes by the building tenants. In some cases the communal container is built immediately under the solid wastes chutes in the buildings.

In residential areas the communal containers are often made of concrete. Fig. 3-5 shows a typical communal container built on the ground for residential areas. In some cases the communal containers are built 0.5-0.75 m above the ground to prevent children from playing in the containers and to facilitate cleaning of residuals.

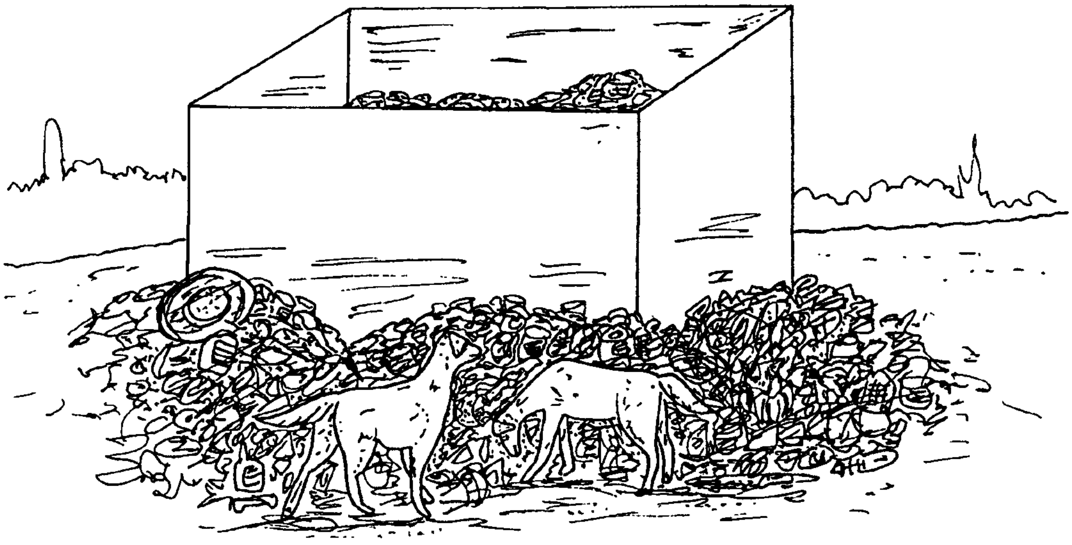


Fig. 3-5 A Fixed on Ground Communal Container where deterioration has set in.

The major disadvantage of communal containers is the lack of defined responsibility for their maintenance and upgrading. Once the solid wastes are scattered or residuals are not properly removed, deterioration of the communal containers sets in. The residuals and scattered solid wastes emit foul odors which discourage residents from using the containers properly. The user will then be more inclined to dump the solid wastes in the vicinity of the communal container rather than inside the container. This practice accelerates the deterioration of environmental conditions around the communal containers so that it is not unusual to find empty communal containers surrounded by large piles of solid wastes and a wide area full of litter. Fixed communal containers have consistantly failed and their use is not recommended. UNCHS Report (1988).

While communal containers may reduce vehicle down time, the potential cost savings may not be realized if they are not properly designed. Fixed containers built below the vehicle level require the collection crew to sweep and load the solid wastes into transfer containers before loading the wastes into the collection vehicle. Sweeping the communal containers and cleaning them of residuals takes a longer time than if the wastes were placed in smaller containers.

If communal containers are to be successful, the design of the containers, building chutes, loading and unloading areas, and collection vehicle accessories must be properly coordinated. It is not unusual to hear one group of experts recommending solid wastes chutes in tall buildings and at the same time another group of experts condemning the practice. Seoul, Republic of Korea, has had adverse experience with chutes and communal containers in high rise buildings to the extent that it has practically condemned the practice. On the other hand Singapore has found the practice satisfactory although with its warmer and more humid climate, more problems are expected there than in Seoul.

To overcome the problem of maintaining communal containers, individual residents should be required to maintain their individual containers and to locate them in one designated area. The communal area is provided with water and drains to facilitate the cleaning of the containers. This practice has the advantage of reducing the number of collection stops and at the same time maintaining the householder's responsibility for cleaning the containers. This practice is applicable in high rise buildings, town houses and high density development where the storage area for the containers can be properly planned in conjunction with the utilities. Nevertheless, the residents must be properly educated on the importance of good housekeeping as the containers in the communal area are subject to vandalism.

3.3.3 Collection Vehicles

In developing countries the most commonly used collection vehicle is the dump truck fitted with a hydraulic lifting mechanism. The truck may be covered and is built to contain 12-14 m^3 of solid wastes. In small towns the dump trucks used for solid wastes collection are old discarded trucks once used by the municipal engineer to haul sand and gravel. In modern cities compaction vehicles are more common. Compaction vehicles used in developing countries have capacities of 12-15 m^3 due to limitations imposed by narrow roads. Although the capacity of a compaction vehicle is similar to that of a dump truck the weight of solid wastes collected per trip is 2 to 2.5 times larger since the solid wastes are hydraulically compacted. If road width is not a limitation, compaction vehicles with capacities of up to 60 m^3 are available in the market.

In addition to diesel and gasoline driven vehicles, push carts, pedaled side carts, and animal drawn carts have been used effectively for solid wastes collection. As discussed earlier, these more primitive collection vehicles are effective if the labour cost is low and the distance traveled short. Pushcarts could serve a stretch of up to 10 km per day although a more common length served is 6-7 km. Pushcarts are suitable only for collection and must be supported by a fleet of motorized collection vehicles. ILO/UNCHS (Habitat)(1986); Flinthoff, F. (1976).

Tractor driven trailers are effective if the disposal site or transfer station is less than 2 km from the collection area. Otherwise, the trailer will have to be supplemented by a truck for longer distance hauling. The same holds true if animal drawn carts are used for collection. Non-compaction dump trucks with capacities from 10-12 m^3 are effective if the distance between the disposal site and the collection area is less than 15 km. If the distance is longer and if a potential transfer station site closer than 10 km from the collection area is available, then the use of a transfer station is often worth evaluating.

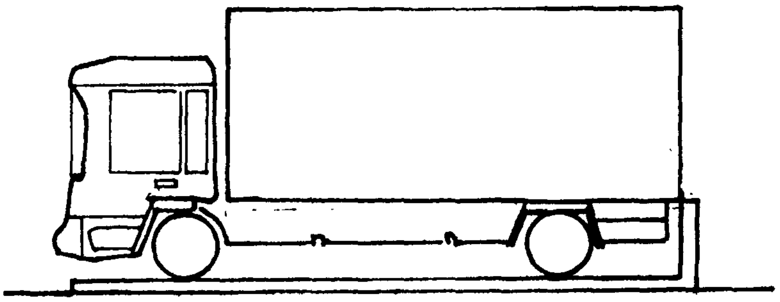
One of the common misconceptions in collection vehicle selection concerns the density of solid wastes. Solid wastes have a high density of 0.3 kg/litre in developing countries and a low of 0.15 kg/litre in most developed countries. The density of solid wastes is higher in developing countries due to extensive use of vegetable leaves for wrapping and packaging, and a higher proportion of food wastes in comparison to paper, plastic and rags in developed countries. In cold climates, the solid wastes density may reach 1.0 kg/litre if ashes from coal and wood burning are thrown in with the ordinary household refuse. Even in cold climates as the standard of living increases the use of coal and wood for household heating and cooking decreases in favour of gas and electricity resulting in a corresponding reduction in the solid wastes density. Due to differences in characteristics between former and other types of solid wastes, the ashes are collected separately. Since solid wastes collection is often the lowest category of solid handled by the municipal engineers office, worn out trucks are traditionally used for solid wastes collection. The old trucks have difficulty in moving their loads, hence the inference that solid wastes are heavy. Dump trucks used to hauling 10 m^3 of sand and gravel are specified for solid wastes collection. The density of sand and gravel is 3.6 kg/litre or approximately 14.5 times heavier than solid wastes. Ten cubic meters of sand and gravel weigh 36 tons or an equivalent of 145 m^3 of solid wastes.

Dump trucks with 36 tons payload when empty weigh 14 tons. The weight is due to the large engine and strong body built to accommodate the heavy load. Due to limitations in truck height and road width the dump trucks are designed to carry 14 m^3 of solid wastes which weighs 3.5 tons. Under this condition most of the fuel consumed in the collection system is utilized to move the truck body around and very little for the solid wastes. In fact, small trucks with body weight of 3.5 tons can be used to collect and haul the same volume of solid wastes. The initial capital cost of dump trucks with 36 tons payload is three times higher than the cost of dump trucks with 3.5-4.0 tons payload. By using large dump trucks the solid waste management authority wastes not only fuel but also scarce capital. In addition the heavy truck body causes rapid deterioration of the infrastructure at the disposal site especially the roads and bridges. Poor road conditions at the disposal site result in faster deterioration of the collection trucks.

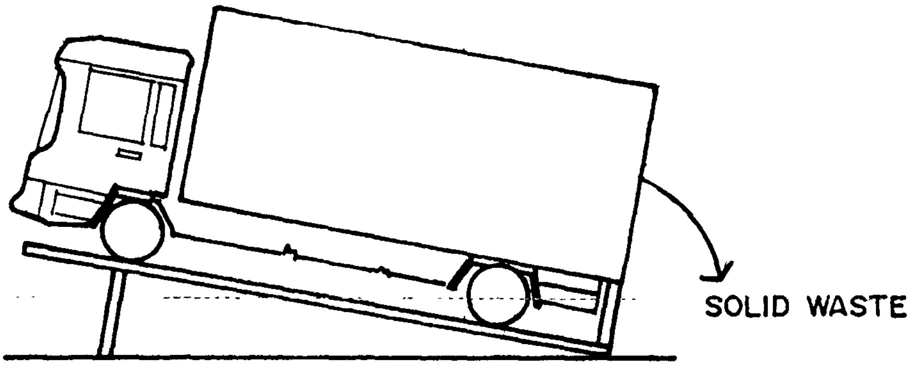
The dump trucks are provided with a hydraulic lifting mechanism which is placed under a 0.3 m high I-beam. The I-beam supports the bottom of the truck when it is lifted. The hydraulic lifting mechanism facilitates the unloading of solid wastes at the dump site. The use of a hydraulic lifting mechanism requires stringent control and monitoring of the truck driver's habit and work attitude since he is free to dump his load at any place and at any time he likes. Within the disposal site if he is tired of waiting in the queue, he could dump his load at the nearest convenient place. If the dump site is managed as a sanitary landfill it is important that the truck driver unloads the solid wastes at a pre designated area. Otherwise the sanitary landfill will fail and eventually deteriorate to an open dump.

Lastly, the 0.3m thick I-beam supporting the truck bottom and the hydraulic lifting mechanism raise the truck body 0.45-0.5 m higher than normal. The truck body must be flat and hence it should be higher than the wheel. The overall effect of the hydraulic lifting mechanism is to raise the truck body by at least 1.7m above the ground. The ideal loading height for the collection truck should be between the knee and shoulder of the collector. Loading heights lower than the knee will result in back pain while loading heights above the shoulder will result in shoulder and arm muscle strain. The use of a hydraulic lifting mechanism raises the truck body above shoulder height and hence causes rapid onset of fatigue during the collection operation.

To overcome this problem, the hydraulic mechanism is removed and a fixed platform with tilting mechanism is used at the disposal site as shown in Fig. 3-6. The truck enters the platform and the whole truck body is tilted with the platform. The platform is then towed to the working area of the sanitary landfill. While a stronger hydraulic mechanism is required for tilting the whole truck body, a smaller number of these devices is required. It takes 4 to 10 minutes to unload one truck so that one platform could serve up to five trucks in an hour. The absence of the hydraulic tilting mechanism in each truck allows the lowering of the truck body by constructing an enclosure around the wheel.



TRUCK MOVES TO THE PLATFORM



PLATFORM TILTS WITH TRUCK TO UNLOAD SOLID WASTE

Fig. 3-6 Unloading of Truck without individual Hydraulic Tilting Mechanism

Compaction vehicles have fewer problems than dump trucks since the vehicle body and mechanism are custom designed to suit the waste collection operation. The loading mechanism in compaction vehicles is located 1.0-1.2m above the ground and the solid wastes are lifted mechanically to the compaction chamber when the collector pushes the appropriate button. Compaction vehicles are provided with a lifting mechanism where the collection crew attaches the standard plastic containers. The lifting mechanism automatically performs a series of mechanical actions which lift, tilt and unload the contents of the container to the truck. After unloading, the container is returned to the curb for the householder to pick up.

The mechanism of a compaction vehicle is more complex and collectors require extensive training in its operation. Deaths have been reported at times when the collector crew tried to remove objects blocking the hydraulic rams. In such cases when the obstruction is removed the hydraulic ram jerks and compresses the collector together with the solid wastes. Since a compaction vehicle is custom-made for solid wastes collection, spare parts are not readily available in developing countries and must be ordered with the vehicles. Special training of mechanics for proper maintenance of the units is required. The Singapore experience has shown that an investment in a good workshop and repair facilities for compaction vehicles is necessary for reliable operation of the fleet. In Manila most of the compaction vehicles were out of commission within two to three years, or less than one half of their expected useful life. Well maintained compaction vehicles have a useful life of seven to eight years. However, authorities which can afford to change their fleet every five years do so to maintain punctuality and reliability of their level of service. The cost of a compaction vehicle is almost twice that of a dump truck of the same capacity. Considering that a compaction vehicle can carry up to 2.5 times more solid wastes than a dump truck it is cheaper than a badly selected dump truck but is more expensive than a properly sized and designed non-compaction flat bed truck.

Compaction vehicles compress cans, paper, plastic and glass. The quality of recyclable materials sorted out from compaction vehicles is generally poor. Sorting is more difficult since the various recyclable materials are mixed and compressed in lumps. Spoilt materials like fruits and vegetables destroy the value of paper and plastic materials. The collection crew normally separates the recyclable materials before loading the solid wastes in a compactor if allowed to do so. However, the cost of idle equipment is much higher than ordinary collection trucks.

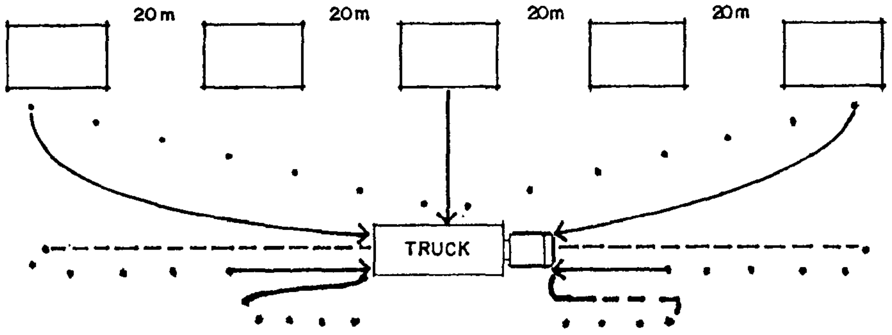
Animal drawn collection carts were extensively used in Japanese cities until the late 1950's. During this period the Japanese vehicle industry was already well established and was strongly competing in the foreign market. However, labour costs were low enough to justify the continued use of animal drawn carts. The quality of recycled and recovered materials is higher when using push-cart or horse-drawn carts than when compactors are used. Manually or mechanically powered side carts are extensively used in South East Asia for collection of recyclable materials separated at source. Fuel and trucks are often imported and if the country has a large unemployed or marginally employed labour force the use of pushcarts and animal-drawn carts would create employment and at the same time provide an effective means of solid wastes collection. As cities sprawl, the use of pushcarts must be supported by trucks for longer haul to the transfer station or to the disposal site. ILO/UNCHS (1986).

3.4 THE COLLECTION OPERATION

3.4.1 Movements of the Collection Crew

The collection crew and the collection vehicle driver work as a team. It is important to maintain team morale and a sense of social responsibility among these workers. In most cultures solid waste collection is assigned to the lowest social group. More often than not the collection crew member takes the job as a bridging position while looking for other jobs considered more respectable. The personnel turnover rate for solid wastes collectors is consequently very high. The problem is further compounded by the attitude most solid wastes management authorities take, that is, they provide no training for their collection crews since they believe solid wastes collection requires no skill. To most solid wastes management authorities strong arms and willingness to work under unsanitary conditions are the main qualifications of a collector. When a new collector starts working he is sent to the field without firm instruction concerning his duties, responsibilities, and required skills.

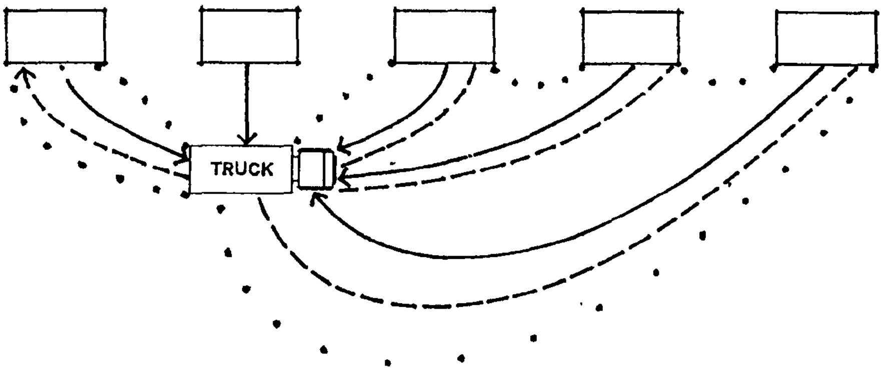
The driver and the collection crew are entrusted with expensive and complicated equipment. A non-compacting solid waste collection vehicle costs U.S. $75,000 and a compactor vehicle about U.S. $100,000. As mentioned earlier, if the collection crew is not properly trained they can destroy the mechanism of the compaction vehicle and at work run the risk of serious injury or death by accident. Even a simple flat bed vehicle requires systematic loading procedures in order to minimize fatigue, and muscular strains and maximize efficiency. For example upon arriving at a collection stop is it more efficient for the collection crew to serve the farthest point or vice versa? Consider the sketch shown in Fig. 3-7, calculate the distance the collection crew will have to walk if it were to serve the farthest point first or serve the point closest to the vehicle. Should the vehicle stop at the centre of the service stop or should it stop at some other point as shown in Fig. 3-7. The difference may be one or two minutes per collection stop, but how many stops will the crew take in a working shift? Multiply the few minutes by the total number of crews working in the whole city. Multiply it again by the labour cost. Is a two to three hour training program justified?



DISTANCE COVERED
PLAIN WALKING = 160 m.
WALKING WITH FILLED CONTAINER = 120 m.
WALKING WITH EMPTY CONTAINER = 120 m.

TOTAL DISTANCE COVERED BY CREW = 400 m.

(B)

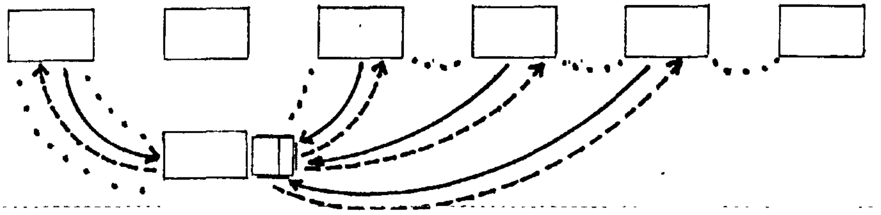


DISTANCE COVERED

PLAIN WALKING = 160 m.
WALKING WITH FILLED CONTAINER = 140 m.
WALKING WITH EMPTY CONTAINER = 140 m.

TOTAL DISTANCE COVERED BY CREW = 440 m.

(C) IF TRUCK IS MOVING TO THE RIGHT



DISTANCE COVERED

PLAIN WALKING = 100 m.
WALKING WITH FILLED CONTAINER = 140 m.
WALKING WITH EMPTY CONTAINER = 140 m.

TOTAL DISTANCE COVERED BY CREW = 380 m.

Fig. 3-7 Effect of Container Location and Vehicle Stopping point on Distance covered by Crew on Foot

Motion-Time-Measurement (MTM) Technique

The discipline of industrial engineering has developed a technique called Motion Time Measurement or MTM which tries to determine the best sequence of activities that workers must follow in order to complete a repetitive task in the shortest time possible, the best combination of equipment to maintain a desired level of output, reduce health problems related to the repetitive work sequence and predict the effects of changes in materials handled. MTM studies may be traced to the work of Taylor in the 1850's who found that a labourer could shovel more coal in a day when given a smaller spade with a capacity of 4 kg. than the standard spade which weighs 10 kg. when full. The labourer could sustain his output throughout an 8 hour working day with the smaller spade whereas his output dropped by more than 25% after the first hour with the standard spade and after four hours was less than 15% compared to the first hour.

MTM studies are now an integral part of the standard procedure in the development of solid waste collection systems. They could be simple estimates using two sets of stop watches. The movements of the collection crew are observed and timed and the results tabulated as shown in Table 3-1. More sophisticated MTM studies are carried out with video cameras hidden at different collection stops. With a video camera the operating sequence of the collection crew could be replayed and studied. If the crew is conscious of being observed it has a tendency to work faster, reduce time wastage in unauthorized salvaging and other non-scheduled activities. For this reason the first two hours or even three hours of observation are often neglected. After the crew is familiar with the person observing them and fatigue has set in the crew begins to perform more credibly. MTM studies are also carried out in laboratories. Mock vehicles and containers are built. Operation crew working sequences, team-spirit and the performance of added gadgets are observed. If a gadget is found to be beneficial it is installed in a few vehicles, a crew is trained and the system tested in the field.

In order to be successful the collection operation must observe a strict time schedule. Delays will result in lower cooperation from the wastes generator, and high potential for stray animals to ransack and scatter the solid wastes. It takes longer to collect scattered wastes which have to be swept, loaded into transfer containers and then loaded to vehicles. This starts the vicious cycle which ultimately disrupts the collection system. Testing of new routes, new gadgets and vehicles is best carried out first in the laboratory and later in a pilot area. Testing of a new sequence using the whole service area could result in chaos and break-down of the solid wastes collection system. As a rule of thumb it takes 2.0 hours to recover for every hour of a failed system.

At least thirty observations of the crew performance must be made to obtain a representative sample.

EXAMPLE 1

The existing sequence of waste collection for a residential area is to load the collection vehicle at defined stops 100m apart along the collection route. The houses are 10m apart and waste is collected from each house and delivered at the collection stop. Two collectors work along the route working in both directions from the collection stop. Walking speed is 50m/min.

Average loading time per container = 0.5 min

Average speed of collection
vehicle between collection points = 12 km/h

An alternative sequence considered is for the residents to load wastes directly to communal containers placed at each collection stop. In this case the loading time of the vehicle from the communal container is 3 minutes.

In both sequences the waste collected at each collection stop is 500 litres and the capacity of the non-compaction collection vehicle is $12m^3$. The round trip travel time of the vehicle to the disposal site, including unloading and driver rest period is 90 minutes. Compare the two sequences for full occupation of the driver over an 8 hour day, with overtime if necessary, so that a minimum number of trips is completed.

Table 3-1 MOTION- TIME-MEASUREMENT STUDY:
Determination of Time, Distance and Number of Containers on a Collection Route

	TIME		ODOMETER (Km)	NUMBER OF CONTAINERS	COLLECTIONS TIME	TRIP TIME TO NEXT STATION
	ARRIVAL	DEPARTURE				
Garage		: :	.			
1 Station	: :	: :	.		Min Sec	Min Sec
2 Station	: :	: :			Min Sec	Min Sec
3 Station	: :	: :			Min Sec	Min Sec
4 Station	: :	: :			Min Sec	Min Sec
5 Station	: :	: :			Min Sec	Min Sec
6 Station	: :	: :			Min Sec	Min Sec
7 Station	: :	: :			Min Sec	Min Sec
8 Station	: :	: :			Min Sec	Min Sec
9 Station	: :	: :			Min Sec	Min Sec
10 Station	: :	: :			Min Sec	Min Sec
11 Station	: :	: :			Min Sec	Min Sec
12 Station	: :	: :			Min Sec	Min Sec
13 Station	: :	: :			Min Sec	Min Sec
14 Station	: :	: :			Min Sec	Min Sec
15 Station	: :	: :			Min Sec	Min Sec
16 Station	: :	: :			Min Sec	Min Sec
17 Station	: :	: :			Min Sec	Min Sec
18 Station	: :	: :			Min Sec	Min Sec
19 Station	: :	: :			Min Sec	Min Sec
20 Station	: :	: :			Min Sec	Min Sec
Last Station	: :	: :			Min Sec	Min Sec
Disposal Site	: :	: :			Min Sec	Min Sec
Total	: :	: :			Min Sec	Min Sec
Weight	**With Load tonne**		**With Load tonne**		**With Load tonne**	

Sequence 1

Total walking distance for each collector at a given collection point
= 2(5+15+25+35+45)
= 250 m

Time spent on picking up and returning containers = 250/50
= 5 minutes

Loading time for containers at stop (5 containers/collector)
= 5 x 0.5
= 2.5 minutes

Working time of a collector at each collection stop = 5 + 2.5 = 7.5 minutes

Time of travel of vehicle between stops = f(100 x 60/12000)
= 0.5 minute

Time for collection at each stop = 0.5 + 7.5
= 8 minutes

Number of stops to fill vehicle = f(12 x 1000/500)
= 24

Time required to fill vehicle = 192 minutes

Total time per trip = 192 + 90
= 282 minutes

For an 8h day (480 minutes), two trips must be completed, requiring a total of 564 minutes, that is, with 84 minutes overtime. A total of 48 stops is serviced.

Sequence 2

Number of stops to fill vehicle = 24

Time required to load vehicle = 24 x 3
= 72 minutes

Travel Time = 0.5 x 24
= 12 minutes

Time required to fill vehicle = 84 minutes

Total time per trip = 84 + 90
= 174 minutes

For an 8h day, three trips must be completed requiring a total of 522 minutes, that is, with 42 minutes overtime. A total of 72 stops is serviced. On the basis of these calculations, the second sequence appears to offer very considerable advantages over the first.

It should be noted that calculations in the example above are based on average values. In practice the distances between the containers, the travel time between collection stops, hauling time, queuing at the disposal site, and loading time are stochastic variables. For more complex systems Monte Carlo simulation is carried out.

Notwithstanding the advantages of the second sequence, other non-tangible factors need to be taken into account. The morale of the crew and commitment to their work are important factors which are difficult to quantify. The collection crew may resist serving 72 collection stops per day instead of 48, for the same pay. The vehicle driver may drive slowly or take a longer time at the queue in order to recover the lost overtime. The collector's labour union may object to the changes in working routine. Moreover a third of the labour force may become redundant. To counter such adverse reactions, management could introduce bonuses and explain to the workers that they will have to walk shorter distances and consequently will be less fatigued at the end of the day. On the other hand management may require the collection vehicle to make four trips per day giving an automatic overtime of 216 minutes per day. However, half of the work force would then become redundant.

The new sequence may, at first glance, appear very attractive, but its reliability must be determined by a pilot study. In a repetitive operation a saving of 1 minute per cycle is an important factor in efficiency whose advantage is easily lost due to poor morale and other non-quantifiable conditions. As solid wastes collection is not a highly attractive occupation, the authority should make every effort to upgrade the morale of collectors, indoctrinate them on their social responsibility, and impose good discipline. A solid wastes collector protects the community and is of no less importance than any member of the protective services. A solid wastes management authority should also be sensitive to its own responsibility towards the work force. A corruption-ridden authority should not expect its work force to cooperate and render strong service to the community.

As a general rule, familiarity of the crew with the collection area improves efficiency. The driver becomes familiar with the traffic jams, the potholes, and other obstructions that he must avoid. The crew is aware of the vagaries of the containers, their locations and the vehicle stops. Familiarity also facilitates rapport with the residents and improves the crew's morale. For this reason it is important to assign to each crew specific areas of responsibility. Working together also establishes camaraderie, an understanding of the strong and weak points of the team members and efficient work sequences.

Assigning a specific collection area to a particular crew also facilitates the monitoring of collection efficiency, the award of bonuses and the imposition of discipline. Monitoring of crew efficiency should be made at the lowest level of government. Local residents' associations and councils are ideally suited to this purpose. A centralized monitoring and complaints centre deals with statistics and quantifiable factors whereas the local residents organizations are in a better position to evaluate the non-quantifiable aspects of waste collection. The solid waste authority should also emphasize to local councils the need to cooperate, should define the cooperative activities required and the level of service the collection crew is expected to render. If a higher level of service is required, additional costs and fees should be defined. Local residents may organize their own supplementary system for a higher level of service. It is important to define the level of service to the community, otherwise demands will be made which the authority cannot meet. In some instances failure of the solid waste management system is due to the lack of cooperation of the residents who, although wishing to do so, have no idea of how to cooperate.

3.4.2 Collection Vehicle Routing

The selection of a route for collection vehicles within a given collection area is a trial and error process. An inexperienced engineer may take a considerable time to plan and develop a collection route but as he gains experience he learns to adjust and refine a planned route within two hours. A number of decision variables are non-quantifiable. Hence it is important for the planner to visit the collection area, before commencement of planning, in order to gain insights into these variables. Among the most important non-quantifiable variables are: road conditions; movable and immovable obstructions; access to containers; community participation and attitudes; driving habits; terrain; the incidence of flooding; stray animals.

The following procedure is recommended for planning a collection route:

1. Define the boundary of the collection area so that it does not overlap an adjacent collection area; make a note of the collection vehicles serving adjacent areas for flexibility of operation in the event of a breakdown of the collecting vehicle.

2. Draw to scale the blocks to be served, noting the narrow streets/lanes and short blocks which could be served by the collectors without the vehicle moving into the lanes.

3. Determine the streets which would require the vehicle to stop on both sides; these are streets with centre lane fencing or islands, wide streets and busy streets.

4. Determine the one way streets.

5. Determine the entrance and exit points; at the start of the working day the entrance normally is at the point nearest to the garage while the exit is at the point nearest to the transfer station or disposal site; after the first trip, the entrance and exit are at points nearest to the hauling route, to the transfer station or to the disposal site.

6. On a diagram of the collection area, mark the one way streets, the streets requiring the vehicle to serve both sides, the entrance and exit points and major obstructions.

7. Simplify the block diagram by eliminating the small blocks and streets into which the vehicle would not be required to enter.(Fig. 3.8(a) is annotated to highlight important constraints while Fig. 3.8(b) illustrates the simplification of blocks).

8. Indicate on the diagram the sections of the route that are traversed more than once (retraced); although it is difficult and often impossible to avoid retracing a section or sections along the route, the number of such instances should be kept to a minimum. (Fig.3.8).

9. Whenever possible, plan the route such that those sections requiring the vehicle to service both sides as determined in (3) above are utilized for this purpose.

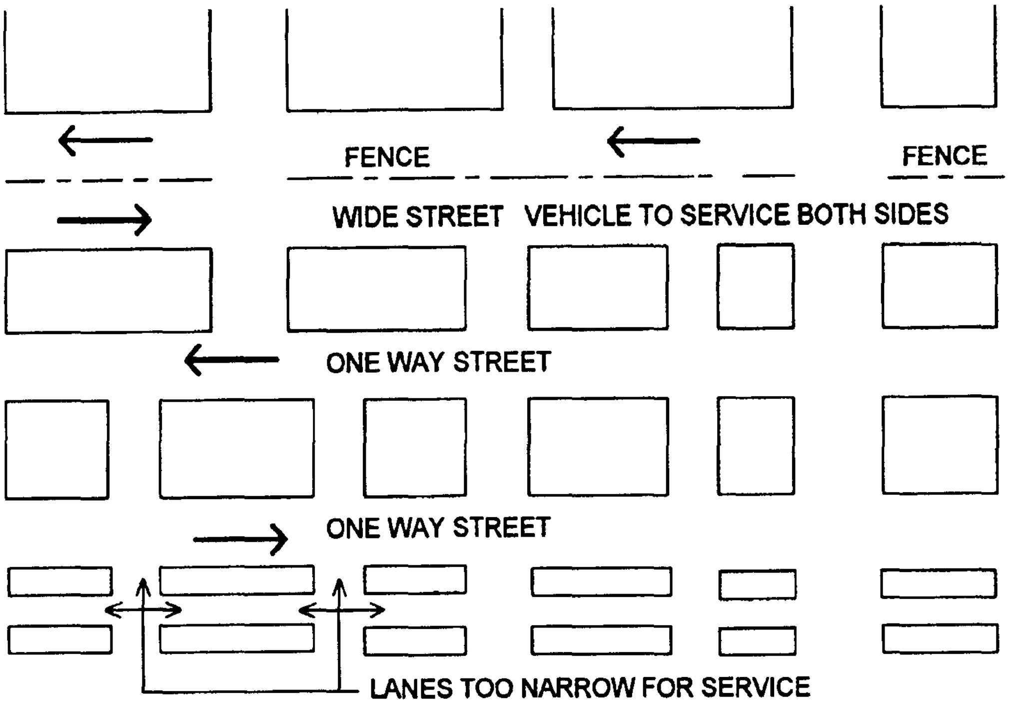
10. When traffic regulations stipulate driving on the right side of the carrageway, the collection vehicle should preferably turn right around the blocks to reduce traffic interference; conversely, for left side driving the vehicle should turn left around the blocks.

11. Plan the route in such a way that the vehicle moves downhill on steep streets, in order to reduce fuel consumption and clutch maintenance.

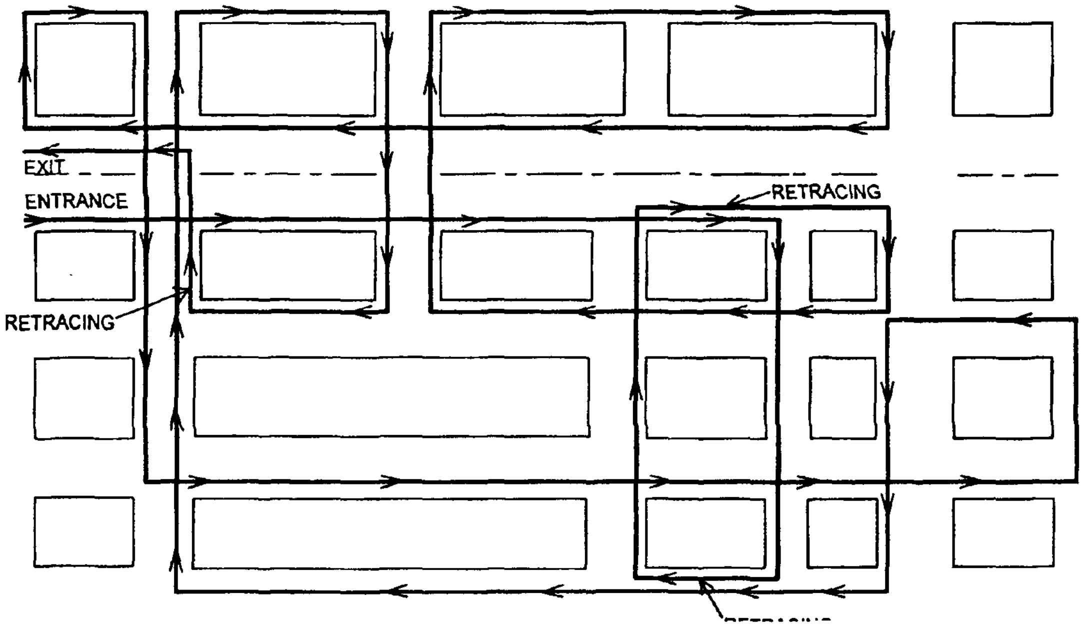
Planning of a vehicle route for the collection of solid wastes is a logistic problem which is similar in nature to that encountered in the collection and distribution of mail in the postal service. Topology and graph theory are branches of mathematics which may be applied to optimizing the collection operation by helping to find the shortest routes connecting various points or street intersections, as well as the fastest routes, given the prevailing traffic conditions, obstructions and other constraints. However, as previously discussed, many of the variables affecting the efficiency of collection cannot be quantified, so that familiarity with the collection area and experience are still the most important factors in the process of route selection. Computer programs are helpful in eliminating inefficient routes by trial and error, but selection of the optimal route will ultimately depend on sound engineering judgment.

3.5 COLLECTION CREW/ VEHICLE INTERACTION

An MTM study may also be carried out on a macro scale. The study would not be concerned with the mechanics of collecting a particular container but rather with the time spent by the crew for collection, resting, idle time, unauthorized activities, hauling and travel time. The main objectives of an MTM study of this nature are to determine whether the crew size per collection vehicle is appropriate, to explore the possibility of using relays, and to develop a system which could reduce dependence on collection vehicles if labour costs are very low. The study is carried out by following the collection crew and noting its activities. If idle time and unauthorized time are not considered, a tachometer installed in the vehicle will determine the time per collection stop, the traveling speed between collection stops, hauling time, and speed during hauling. It is advisable to install one tachometer with a chart recorder for every 50 vehicles in operation. The



(a)
Street Layout and Constraints in Service Area



(b)
Recommended Vehicle Route

Fig. 3-8 Collection Vehicle Route

use of this data is discussed further in Sec. 3.9 under record keeping. Typical results of MTM studies of this nature are shown in Fig. 3-9.

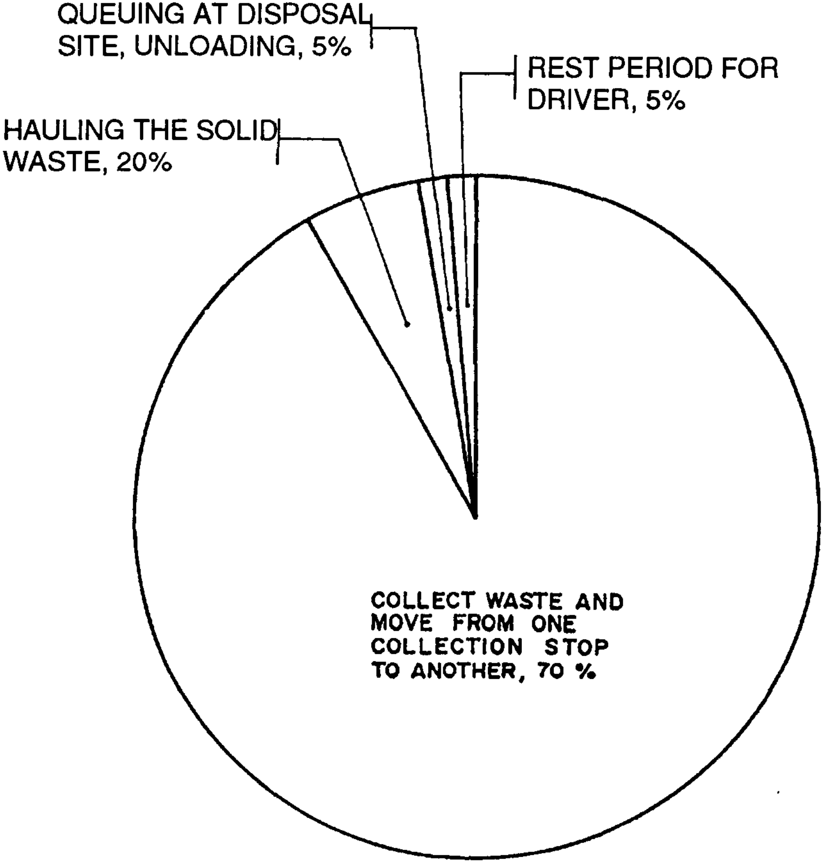


Fig. 3-9 Result of MTM Study on Macro Scale

Using Fig. 3-9 the areas where changes in the collection system are likely to improve performance may be identified. It is seen that the collection vehicle spends 70% of the working day moving from one collection stop to another with only 20% spent for hauling, 5% for queuing and unloading at the disposal site and 5% for rest periods for the driver. If the authority is short of vehicles, and the labour costs are very low, management may consider several options in an effort to reduce the period spent at the collection stops: the number of collectors could be increased, the viability of using centralized containers instead of house-to-house collections could be evaluated. The householders could be required to take their wastes to the vehicle instead of increasing the crew size, or push carts used to carry out the house to house collection, the collection vehicle serving only as a transfer station for the long haul, or unauthorized activities could be controlled in the collection area or a combination of these options employed. Management may also re-examine the truck design to improve the loading efficiency, such as lowering the loading ramps, providing a lifting mechanism and conveyor even for non-compaction vehicles. It is clear from Fig. 3-9 that there is no significant advantage in reducing the driver's rest period. For a 480 minute working day, the 5% driver's rest period accounts for only 24 minutes. If the vehicle is making two trips per day this is roughly only 12 minutes per trip. Neither would improving the queue at the disposal site lead to much overall improvement.

EXAMPLE 2

A financial analysis was carried out to determine the appropriate size of the collection crew size per vehicle. The average of the labour cost for the collector is US$ 0.01/minute and overtime is paid at 1.5 times the regular rate. A collection vehicle with a useful life of 7 years for a 16 hour operating time per day would cost US$ 100,000 and have a maintenance cost of US$10,000 per year. The truck driver is paid US$ 0.0125/minute. From the MTM study it was calculated that it takes 400 minutes for one man, 180 minutes for two men, 120 minutes for three men, 100 minutes for four men, 90 minutes for five men and 80 minutes for six men to fill a $12m^3$ vehicle, excluding travel time from one collection stop to another. When the vehicle is idling while it is being loaded, the fuel consumption is US$0.01/minute. The sum of the travel time between collection stops to load $12m^3$ of solid wastes is 20 minutes, and the time spent to haul to the disposal site, to queue, to unload, for the driver's rest period and to return is 60 minutes. The collection crew size is calculated as follows:

Step 1: The collection vehicle normally operates for 300 days per year. Using a straight line depreciation, the capital cost for the vehicle is calculated at 100,000/(7yrs x 300 days per yr x 17 hrs/day x 60 min/hr) or 0.0467 US$ per minute. As most solid waste management authorities are owned by the government no interest is added in calculating the capital cost per minute of the collection vehicle. For private contractors who borrow the capital from banks the capital recovery factor is used in calculating the capital cost per unit time. With overtime the actual working day may exceed 17 hours but in some instances the working day is also shorter than 17 hours. The average is used as discussed earlier.

Step 2: Calculate the maintenance cost of the vehicle. This is equal to US$ 10,000/(300 days x 17 hrs/dayx 60 min/hr) or US$ 0.033/min.

Step 3: Analyze for one load considering a one man crew. Note that the cost for the vehicle to travel from one collection stop to another, to haul, to queue, and to unload, is independent of the crew size. The labour cost of the driver for these activities is also constant. This cost may be estimated, but for purposes of this example it is denoted as "FC" or fixed cost. For a one-man crew the total time to fill one vehicle is as follows:

Loading	400 minutes
Travel from one stop to the next	20 minutes
Idle time while truck is hauling	60 minutes
Total Time per Collector	480 minutes
Driver's time	480 minutes
Truck Idle time while being loaded	400 minutes

Cost = 480min. x 1 man x 0.01 + 480 x 1driver x 0.0125 +
480min x (0.0467 + 0.033 + 0.01) + FC = US$53.86 + FC

For a 2 man crew the time is as follows:

Loading	180 minutes
Travel time from one stop to the next	20 minutes
Idle time while vehicle is hauling	60 minutes
Total time per collector	260 minutes
Driver's time	260 minutes
Vehicle Idle time while being loaded	180 minutes

Cost = 260min x 2men x 0.01 + 260min x 1 driver x 0.0125 +
260 min(0.0467 + 0.033 + 0.01) +FC = US$ 31.77 + FC

For a 3 man-crew the time is as follows:

Loading	120 minutes
Travel time from one stop to another	20 minutes
Idle time while truck is hauling	60 minutes
Total time per collector	200 minutes
Driver's time	200 minutes
Truck idle time while being loaded	120 minutes

Cost = 200 x 3 x 0.01 + 200 x 1 x .0125 + 200 x 0.09 + FC
= US$26 +FC

For a 4 man-crew the cost per haul is USD 25.6 + FC
For a 5 man-crew the cost is US$25.8 + FC
For a 6 man-crew the cost is US$ 25.9 + FC

Step 4: The ideal crew size is a complement of four. Since labour costs are quite low the use of a larger crew size, say 5 or 6, is still viable. In terms of economic analysis the solid wastes management authority may be required by the planning agency to use a factor lower than one for the solid wastes collector and a factor higher than 1 for the imported equipment to reflect the economic values of those components.

The reader may work through the same problem using a higher collector labour cost of US$ 0.10/minute or roughly US$ 48/day compared to US$ 4.80/day used in the above analysis. In this case it might even be worthwhile for the driver to get out of the vehicle to load the solid wastes rather than to hire an additional collector who will be idle during travel from one collection stop to another and during hauling. The same procedure could be used to evaluate the viability of using a gadget which reduces the loading time costing X dollars with a useful life of say Y years with the crew size constant.

It is important to note that, in developed countries, labour costs account for 70-80% of the total collection cost while in developing countries equipment and fuel account for 70-80% and labour only 20-30%. While it is theoretically possible to increase the collection crew size to above six per vehicle the physical dimensions of the vehicle limit the effective working area. In the above example it would take 400 minutes for a one man crew or 400 man minutes, and 180 minutes for a two-man crew or 360 man minutes to load $12m^3$. This means that the two man crew is more efficient. Considering a six man crew the time is 80 minutes or a total of 480 man minutes to load the $12m^3$ of solid waste as compared to 400 man minutes for a one man crew. In a collection stop where the number of containers is less than three some of the crew members in a six man crew will be idle. Even in a collection stop with a high concentration of wastes some of the crew members in a six man crew will be idle while queuing at the vehicle loading ramp.

The reader should also examine the effects of crew salvaging operations and other unauthorized activities. In developing countries the cost of time lost for these activities is not the labour cost but the idle time for the vehicle and fuel wastage. While the recycling and recovery of solid wastes are activities that must be encouraged, it is important to consider the effects of these activities on collection cost and efficiency.

As discussed in Section 3.3 one of the main problems of the relay system is the variability of the traffic condition during hauling. The collection vehicle may arrive earlier or later than the scheduled time. It will remain idle for some time while the crew is loading the other vehicle or otherwise is forced to take a rest between loading of vehicles. If the labour cost is low, the idle time for the vehicle could be much higher than the foregone labour cost without the relay system. In the above example even if the collection crew size were increased to six and the hauling time to 180 minutes, use of a relay system would not be justified.

If a pushcart, animal or tractor drawn collection vehicle is used it must be evaluated as an integral component of the whole collection system. The pushcart should not have a size larger than 0.75 m^3 which carries a weight of 190 kg of solid wastes and approximately 220 kg if the weight of the pushcart is included. It will be difficult to move the cart with more than 250 kg weight even over flat terrain. If the terrain is rough, hilly or muddy, the effective volume should be reduced as necessary. The system operates well when a meeting place and time are fixed for the pushcart collectors and the vehicle. Four to six pushcarts are normally assigned to a designated loading area. Too many pushcarts will create a traffic problem while one pushcart per loading point is not much better than the vehicle stopping at each collection point. Secondly, a lone collector will have difficulty loading the contents of his cart to the truck . Comparatively a pedal-driven collection vehicle could carry up to $1.2m^3$ of solid wastes. Pushcarts have a limited hauling range. A distance of 300m from the last collection stop is normally taken as the maximum although the travel distance within the collection area could be in the range of 6 to 9 km/day. The problem is more of perception. The pushcart operator is often reluctant to push the load a long distance considering that he does not get an additional load when the pushcart is already full. For pedal driven collection vehicles, the hauling distance could increase to 750m and the travel distance within the collection area to 12 to 16 km/day. Both push carts and pedal driven collection vehicles have a maximum of three loads per day. Labour cost is the major component. Normally a one-man collection crew is provided for every pushcart or pedal driven collection vehicle. However the value of recycled and recovered materials could be a high incentive for a family member of the collector to accompany him and assist in the sorting of recyclable materials as well as in the collection operation without extra cost to the solid wastes management authority.

An animal or tractor drawn collection vehicle can carry a larger volume of waste than a pushcart. ILO/Habitat 1986. The volume could vary from 2 to $3m^3$ for an animal drawn vehicle and from 5 to 8 m^3 for a tractor drawn collection vehicle. Animal and tractor drawn vehicles are not particularly sensitive to variations in terrain and road conditions. Nevertheless, changes in the load have to be considered when road conditions are extreme. For a tractor drawn collection vehicle, containers may be of the roll-on roll-off type. These containers are left in designated areas where they are picked up by larger vehicles. The lifting mechanism may be fixed at the site or it may be provided on the vehicle. Tractor drawn vehicles have an economical hauling distance of 2 to 3 km and an almost unlimited travel range within the collection area. Animal drawn vehicles on the other hand, have a hauling range of up to 2 km and a travel range of up to 20 km. An animal drawn vehicle will normally have a complement of two collectors including the driver who normally assists in the collection operation. The capital cost is slightly higher than for a pushcart or pedalled vehicle because the animal has to be acquired in addition to the cart. A tractor drawn vehicle can have a complement of three to four men depending on labour cost. The tractor driver seldom participates in the collection operation.

When the waste is of low density, compaction vehicles offer the distinct advantage of collecting a larger quantity of solid wastes per trip since the volume of wastes is reduced by 60-70% . Obstructions to traffic created by a $20m^3$ compactor are no worse for most streets than those caused by a $14m^3$ vehicle. However the $20m^3$ vehicle can collect $50m^3$ of uncompacted solid wastes per trip. The proportion of time spent by a compaction vehicle for hauling solid wastes from the collection area to the transfer station or disposal site is reduced. Fig. 3-10, shows that the use of a compaction vehicle could reduce hauling time from 20% to 7% of the working day or from 96 minutes/day to a mere 34 minutes/day. If the disposal site or transfer station is a considerable distance from the collection area or the traffic along the route congested, the use of compaction vehicles is particularly advantageous.

One of the main features of cities in developing countries is the poor condition of roads which are usually narrow and rough. There is no standardization of the solid waste containers and available land for transfer stations and disposal sites is limited. Under these conditions a labour intensive scheme for house-to-house collection is highly advantageous but the smaller non-compaction vehicles used for hauling are very inefficient as a result of traffic jams and long hauling distances. One system which has not been thoroughly evaluated is the combination of a pushcart for house-to-house collection and sophisticated compaction vehicles for hauling the solid wastes. Pushcarts may have to be modified to allow for mechanical loading into compaction vehicles. Experience has shown that solid wastes management authorities are not easily convinced of the advantages of this system although it is eminently suited to the technological and social conditions of most cities in developing countries. The system is used in ancient European cities like Rome where the streets are narrow and lined with historic buildings. Solid wastes are manually collected using pushcarts and are carried out to an area accessible by the compaction vehicles.

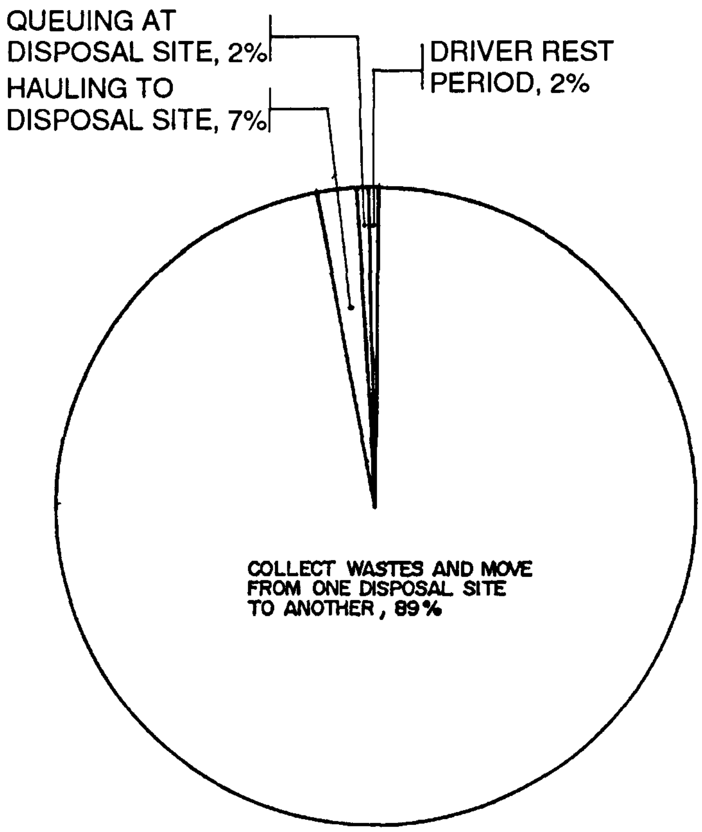


Fig. 3-10 MTM Results for Compactor Vehicle

SAQ 3.1

A city is served by 100 collections vehicles, each with a capacity of 15 m3. They operate for 16 hours per day, the remaining 8 hours being used for maintenance. The total volume of solid waste generated is 20,000 m3/day. An MTM study was conducted, the results of which are shown in Fig. 3.9. If it takes 30 minutes per trip to transfer and fill a vehicle with solid wastes, how will this alter the result of the MTM? How many vehicles will be needed with and without the push carts? How many trips could the vehicles make in a day using pushcarts as an auxiliary system?

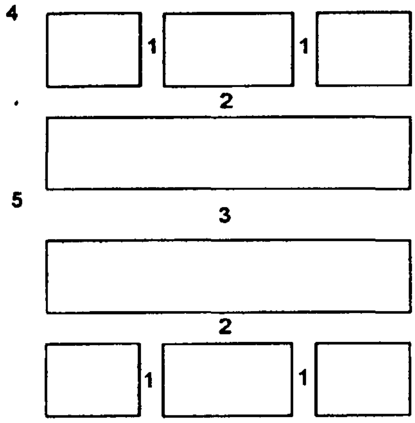
SAQ 3.2

The labour cost for collectors in a service area is $0.01/min, for the driver it is $.015/min, and for push cart boys is $.005/min. Depreciation, operation and maintenance cost for the collection vehicles during hauling is $0.10/min when travelling at 60 km/hr, $0.01/min when idling or queuing and $0.13/min when moving from one collection stop to another. One pushcart collector can collect 4 m3 of solid wastes in 480 min. The vehicle has a performance similar to those shown in Fig. 3-8 and is served by a collection crew of four men and one driver. a) Compare the collection cost when pushcarts are used with the vehicles, with the cost when the vehicles are used alone from one collection stop to another. b) If labour costs were to go up such that the collector recieves $0.10/min, driver $0.15/min and pushcart collectors $0.08/min how would the cost of the two systems compare?

SAQ 3.3

Develop a collection vehicle route, which is cost effective, for the city block shown below. Traffic flow is on the right side of the road. State the principles you used in determining the route.

1. Alley
2. Narrow Street
3. Wide street requires stops on both sides
4. Entrance
5. Exit



3.6. TRANSFER STATIONS

A transfer station is a place where solid wastes are transferred from small collection vehicles to larger vehicles for longer haul. A transfer station could be a small area along the street reserved exclusively for parking of solid waste collection vehicles, where collectors using pushcarts or pedaled collection vehicles could congregate, exchange salvaged materials and carry out further salvaging operations. For this type of transfer station the cost is a sign board worth US$20. A transfer station could also be a complex of structures with unloading ramps, conveyor belts, deodorizing mechanisms, compactors, washing facilities, magnetic separators for ferromagnetic materials, centrifugal separators for glass, a workshop for vehicle maintenance, facilities for manual segregation of recyclable materials and wastewater treatment facilities for the water squeezed out in the compaction process. Transfer stations of this type could cost up to US$50m and handle 2,000 tons of solid wastes per day. Between these two extremes are various types of transfer station with different levels of mechanical complexity, size, function and cost. A transfer station is needed because of the technical limitations of smaller collection vehicles, as discussed in the previous section and the lower cost of hauling the solid wastes using larger vehicles. These limitations in hauling solid wastes are the main factors to consider in evaluating the use of transfer stations. World Wastes (1984, 1985).

When pushcarts and pedal driven vehicles are used, the transfer station could vary from a simple place allocated for the purpose and marked with a sign board, to a permanent complex with a ramp inclined at 30 degrees to facilitate the transfer of the solid wastes to the vehicle. A $12m^3$ vehicle may have to stop at two or three simply marked transfer stations before being filled, while a $20m^3$ compaction vehicle may serve up to 15 transfer stations. The permanent buildings may provide temporary storage of the recycled and recovered materials so that when the collectors return to the collection area they do not have to bring with them the recovered materials. The transfer station should be provided with a small cleaning facility for pushcarts and pedal driven collection vehicles. Normally a $12m^3$ vehicle is filled at one transfer station with permanent structures. A $20m^3$ compaction vehicle could serve three or four transfer stations, with permanent structures, per trip.

The main problem in the establishment of a transfer station is securing a suitable site. In the vicinity of a transfer station the traffic and noise due to the smaller collection vehicles, collectors, drivers, and large vehicles moving in and out often create resentment by the community. Stored solid wastes and recyclable materials if not properly handled will attract flies and other insect vectors. Odours from the transferred solid wastes will be a nuisance if not properly controlled. The problem is less discernible in small transfer stations than in large stations. However, in large stations mechanical devices to control noise, odor, insects and rodents are economically viable and are easier to operate and maintain. Complaints are more common with medium-size transfer stations catering to communities with populations of 15,000 to 40,000.

The decision to provide a transfer station is based on economic analysis. The classical approach is to add the unit cost of the transfer station to the cost of hauling using large vehicles and to compare this cost with the cost of hauling directly to the disposal site using the smaller vehicles that service the collection area. The cost of hauling, using small vehicles, is the sum of the depreciation cost of the vehicle, driver's salary, salary of the collection crew if they are on standby waiting for the vehicle to return to the collection area, and fuel cost. The transfer station cost is the sum of the transfer station depreciation cost and the operating and maintenance costs divided by the capacity of the station. The cost of using the large vehicle is the sum of the vehicle depreciation, fuel and driver salary. The economic analysis is best illustrated by the following example.

EXAMPLE 3

The average travel speed during hauling is 60km/hr for both small and large vehicles. The fuel cost for small vehicles with a capacity of 12m^3 is US\$ 0.10/km, when traveling at this speed while for a large vehicle with 50m^3 capacity carrying compressed solid wastes equivalent to 150m^3, the cost is US\$ 0.50/km. The driver's salary is US\$ 0.0125/min. A transfer station with a capacity of 3000m^3 per day costs US\$2 million with 60% of this cost due to civil work items and the remaining 40% for electromechanical equipment for compressing and deodorizing wastes, weighbridge, ventilation, solids handling, lighting, etc. The civil work items have a useful life of 30 years while the electromechanical equipment has an average useful life of 10 years. The daily operating and maintenance cost is US\$1500. The collection vehicle is served by a crew of 4 receiving a salary of US\$ 0.01/minute. The driver takes a rest of 15 minutes at the disposal site. On the average the smaller vehicle takes 15 minutes to queue and unload while the larger vehicle takes 30 minutes to queue and unload. Depreciation cost for the 12m^3 vehicle is US\$ 0.20/min while for the 50m^3 vehicle it is US\$ 1/min. Investigate whether a transfer station is justified.

Step 1: Fixed Costs

Determine the depreciation cost of the transfer station using the straight line method:

$$\text{Cost of Civil works} = \frac{\text{US\$2 x } 10^6 \text{ x } 0.6}{\text{30 years x 365 days/yr x 3000 m}^3\text{/d}}$$

$$= \text{US\$ } 0.0365/\text{m}^3$$

Cost of Electrical/Mechanical Equipment

$$= \frac{\text{US\$2 x } 10^6 \text{ x } 0.4}{\text{10 years x 365 days/yr x 3000 m}^3\text{/d}}$$

$$= \text{US\$ } 0.073/\text{m}^3$$

Cost of operation and maintenance

$$= \frac{\text{US\$1500}}{3000\text{m}^3\text{/d}}$$

$$= \text{US\$ } 0.50/\text{m}^3$$

Total fixed Cost of the Transfer Station

$$= (0.0365 + 0.073 + 0.50)/\text{m}^3$$

$$= \text{US\$ } 0.6095/\text{m}^3$$

Step 2: Hauling Costs (Small Vehicle)

Let Xkm be the distance between the collection area and the disposal site.

$$\text{Time required for hauling (both ways)} = \frac{2X \text{ km x } 60}{60 \text{ km / h}}$$

$$= 2X \text{ minutes}$$

Rest period for driver = 15 minutes

Time for queuing and unloading = 15 minutes

Total time = 2X + 30 minutes

Labour Costs/minute

4 Crew - 4 x 0.01 = US\$ 0.04/minute

1 Driver - 1 x 0.0125 = 0.0125/minute

Total Labour Cost/minute US$ 0.0525/minute
Labour costs for Hauling Time of (2 x 30) minutes
= US$ 0.0525 (2X + 30)
Vehicle depreciation cost = US$ 0.2/minute x (2X + 30) minutes
= US$ O.2 (2x + 30)
Fuel Cost = 0.1 x 2X
= US$ 0.2x
Total Cost of hauling 12m^3 = US$ 0.0525 (2X + 30)
0.2 (2X + 30)
0.2X

0.7050X +7.575

Step 3: Hauling Costs (Large Vehicle)
Time required to hauling = 2X minutes
Rest period for driver = 15 minutes
Queuing and unloading time = 30 minutes
Total time = (2X + 45) minutes
Labour Costs/trip
= 1 x 0.0125 x (2X + 45)
= US$ 0.025X + 0.5625
Vehicle depreciation costs = US$ (2X + 45)
Fuel Cost = US$ 0.5 (2X)
Total Cost of hauling 150m^3 = US$ 0.025X + 0.5625
2X + 45

1.0X

3.025X + 45.5625
Total cost/m^3 0.0202X + 0.30375
Cost of transfer station/m^3 = US$ 0.6095
Total cost using transfer station and large vehicles
per m^3 of waste = 0.0202X + 0.30375
0.6095

US$ 0.0202X + 0.91325

Step 4. Cost of small vehicles at transfer station

A cost must be estimated for the small vehicles at the transfer station assuming it takes 15 minutes for queuing and another 15 minutes for unloading at the transfer station, then the fixed cost due to this cost must be added to the cost in step 3.

Step 5
The cost using the transfer station and large compactor vehicle for hauling to the disposal site is equated to the direct hauling cost using small vehicles.
This yields the equation:

$$0.0202X + 0.91325 + 0.63125 = 0.05825X + 0.63125$$

Solving for X, we get:

$$X = 23.7 \text{ km}$$

This means that if the distance between the disposal site and the collection area is greater than 23.7km the use of transfer station and large vehicles capable of carrying 150m^3 of solid wastes compacted to 50m^3 is viable. Note that the cost due to queuing, unloading and driver rest period cancels out if it is the same at the transfer station as at the disposal site. In some instances where the queuing and unloading time at the disposal site is longer than at the transfer station then the cost will have to be calculated as in Step 5. The graphs of the two cost functions are shown in Fig. 3-11.

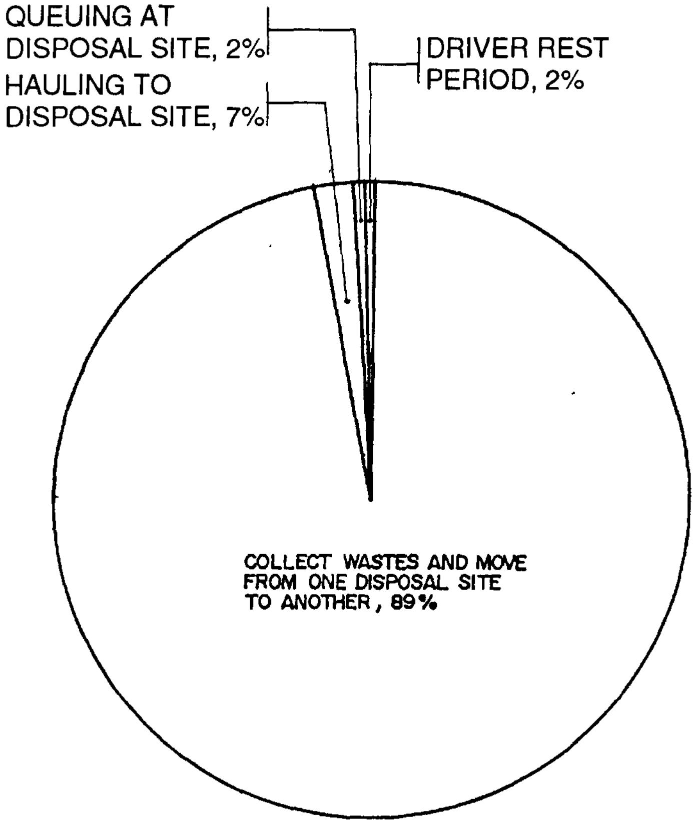


Fig. 3-11 Conventional Cost Analysis to Determine viability of Transfer Station

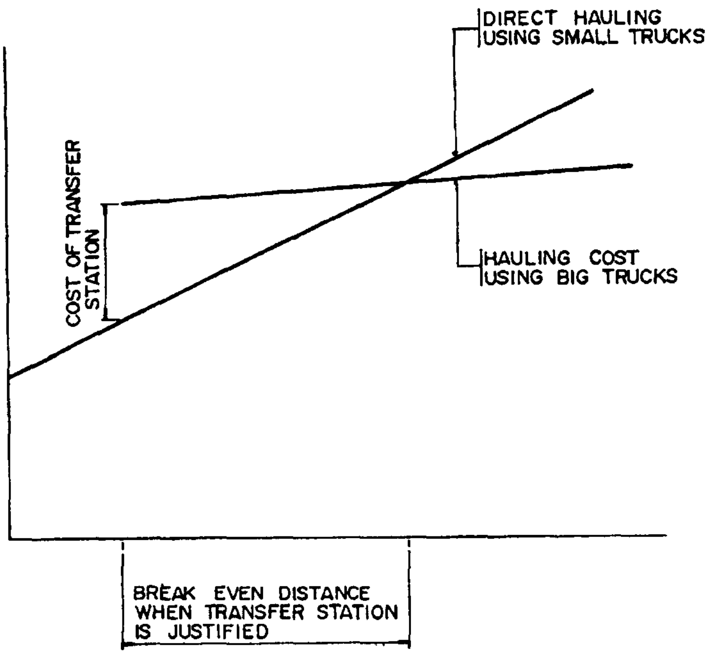


Fig. 3-12 More Accurate Cost Analysis to Determine Viability of Transfer Station

The distance between the disposal site and collection area is one of the principal variables in deciding whether to use a transfer station or to haul the solid wastes directly from the collection area to the disposal site. The effect of the hauling distance on the collection cost is shown in Fig. 3-12 .

Consider first the case where the transfer station is located directly along the hauling route between the disposal site and the collection area. If the unit cost of hauling using a small vehicle is $\$A/m^3 \cdot km$, the cost of operation, maintenance, depreciation, loading and unloading at the transfer station is $\$B/m^3$, the cost of hauling using large vehicles is $\$C/m^3 \cdot km$, X is the distance between the collection area and the transfer station in km, Y is the distance between the transfer station and the disposal site in km and X+Y is the distance between the collection area and the disposal site, then the total cost of hauling the solid wastes from the collection area to the disposal site using a transfer station is,

$$T = 2AX + B + 2CY$$

The factor 2 is added to account for the round trip which effectively doubles the distance travelled. The total cost of hauling without the transfer station is:

$$T_1 = 2A(X+Y)$$

The transfer station is justified if:

$$T < T1$$

that is the hauling cost using a transfer station is lower than the direct hauling cost between the collection area and the disposal site. Substituting the values of T and T1 yields :

$$2AX + B + 2CY < 2AX + 2AY$$

or

$$Y > B/(2A-2C)$$

It should be noted that X cancels out. The distance between the potential transfer station site and disposal site is the variable to consider. Statements such as: " the use of a transfer station is justified when the distance between the disposal site and the collection area exceeds ---- km" as commonly encountered in solid wastes management reports and literature have no meaning. The distance between the collection area and the disposal site is important in deciding the utilization of a transfer station if X is equal to zero in which case the transfer station is located right at the centroid of the collection area. In normal conditions the centroid of the collection area has a high land value and it would be impractical to locate a solid wastes transfer station in this area. Fig. 3-12 shows the effect of the distance between the potential transfer station site and the disposal site on the hauling cost.

Consider a general case where the transfer station is located away from the hauling route between the collection area and the disposal site. Let Z be the additional distance travelled by the vehicles. The cost T when using a transfer station is then equal to:

$$T = B + 2AX + 2AZ + 2CY + 2CZ$$

The cost for direct hauling from the collection area to the disposal site remains the same as previously defined. The use of a transfer station is justified if:

$$B + 2AX + 2AZ + 2CY + 2CZ < 2AX + 2AY$$

or

$$Y > (B + 2CZ + 2AZ)/(2A-2C)$$

Again the decision whether to use a transfer station is independent of the distance between the collection area and the proposed transfer station.

SAQ 3.4

The hauling cost using an 8 m^3 vehicle is \$0.03/km-tonne while for a 40 m^3 vehicle hauling compacted solid wastes it is \$0.01/km-ton. Cost is inclusive of the cost incurred by the returning empty vehicle using the same route. The cost of compaction, depreciation, operation and maintenance and transfer of the solid wastes from the smaller vehicle to large vechicles is \$0.40/ton. The distance between the collection area and the disposal site is 30km; the available transfer station site is 12 km from the collection area and 18km from the disposal site. a) Using the conventional method of transfer station analysis, determine the condition that would make a transfer station viable; b) compare the results of (a) with the results obtained by using the corrected cost analysis given in this text; c) compare the hauling costs with and without the transfer station.

SAQ 3.5

If the available transfer station site is 5 km off the main hauling route at a detour point 10 km from the disposal site, how will this affect the viability of using a transfer station using the same cost given in SAQ 3.4? The direct distance between the collection area and the collection site is 30km. a) Investigate whether a transfer station is justified; b) compare your results using the conventional cost analysis and the corrected cost analysis used in this text; c) calculate the hauling cost using the small and large vehicles.

3.7 INSTITUTIONAL ARRANGEMENTS

The management of the collection system calls for rapid response in terms of operation and maintenance, and purchasing of spare parts, additional vehicles, equipment and machinery. To prevent corruption most government bodies are controlled by strict regulations which require competitive tendering for purchases. Emergency purchases still require supplemental budgets. To maintain good discipline and recognition of meritorious achievements, financial incentives may be given to the collection crew but such incentives would be incompatible with their educational achievements. As discussed earlier the collection crew performs an important function almost equivalent to that of a medical doctor in protecting public health and welfare. While a medical doctor cures a sick person, the solid wastes collectors prevent healthy persons from falling ill. Yet solid wastes collectors lack education and are not accorded public recognition of their important social functions. To give the solid wastes collectors their due financial and social recognition would be impossible under most laws governing public service.

Privatization of solid wastes collection services has been heralded as a means of overcoming these deficiencies. Private corporations can pay their workers according to their productivity, free from civil service constraints on wage structures. Purchasing is faster and the capital procurement budget can be implemented from year to year to meet the future demand unlike the government where savings are lumped into general funds and are not available to the authority. Privatisation has been successfully applied to water supply and sewerage systems as well as to other public utilities like power, gas, and roads. However solid wastes management has some peculiarities which make privatization difficult. First the willingness to pay is much lower than the capability to pay. Unlike sewerage where the cost can be added to the water bill, in the case of solid wastes collection the cost cannot be added directly in a related commodity associated with a high willingness to pay. Studies have been carried out which show that the solid wastes generation rate is closely co-related with the electric power consumed. It would be reasonable therefore to add the solid wastes collection rate to the electricity bill. The solid wastes collection cost is estimated at 10-15% of the electricity bill. Bandung, Indonesia has successfully implemented this scheme, whereas in Cebu, Philippines, the electricity generating authority rejected the proposal since it would have increased the unaccounted for and unpaid electric bill. Direct billing to the household and business establishments is a common method of raising revenues for solid wastes management. However, if the billing is not related to a municipal permit, enforcement is difficult. If the billing is related to a municipal permit then the collection is subject to normal government disbursement regulations which negate the purpose of privatization.

Another scheme implemented was for the government to collect the fees or taxes and sign a contract with private contractors to provide the collection vehicles and crew for a fixed price and period. The practice could work well during the first three years of the contract. As the government collection vehicle inventory goes down it becomes more dependent on the private contractor. The contractor then asks for exorbitant fees. This was the experience of Manila, Philippines in the late 1970's. The problem was further aggravated because the contract was based on volume of solid wastes collected and the collection crew was assigned different collection areas every day. Some high-income residential areas contracted the same private contractors to supplement the government solid wastes collection service in their area. As the crew were assigned different areas every day it was difficult to pinpoint responsibility for uncollected solid wastes especially in low-income areas where complaints are received a week after failure of the contractor to collect the solid wastes. Some contractors collected the wastes from high-income residential areas and reported the collection to the government monitoring centre as wastes collected from their assigned area.

Monitoring is an important component for the success of the solid wastes collection system. Without an effective monitoring system the collection system will fail regardless of whether it is managed privately or publicly. The solid wastes management authority should establish a hierarchy for monitoring the collection crew efficiency and the level of service rendered. As mentioned earlier in Sec. 3.4, monitoring should be assigned to the lowest level of government or to an organization which is in direct contact with the population served. To make monitoring effective, the organization should be given enough power to document and withhold payment if necessary. Monitoring is more systematic and uniform if standard forms are developed as discussed in Sec. 3.8.

While solid wastes disposal may call for a centralized authority because of the regional nature of solid waste disposal facilities and the advantages of economies of scale, in the case of the collection system there is a need for decentralization of decision making and planning. The level of decision making should not be higher than the municipal government which should be involved with the operation of the transfer station, procurement of vehicles, fuel and collection equipment accessories. The hiring and firing of personnel should be delegated to the local organization or sub-structure of the municipal government which is in direct contact with the users. Maintenance of the vehicles and equipment should be headed by the municipal engineer or the municipal solid wastes management authority. The delegation and break down of responsibility prevents abuses from one level to another. Solid wastes collection vehicles, crew and equipment are often used for other purposes such as lining the streets to welcome foreign visitors, hauling of construction materials and even to engage ghost employees. The population served is the best judge of the quality of service rendered. If the community is happy with piles of uncollected solid wastes in their vicinity, this is a reflection of their health habits and attitudes. However should they want a better service and know the limitation of the government system they will be willing to raise the additional funds. Solid wastes collection calls for a high degree of unity in the community. A person who is reluctant to cooperate destroys the environment of the whole community.

3.8 PLANNING AND DESIGN OF THE COLLECTION SYSTEM

In the planning and design of a solid wastes collection system the engineer should remember that the service area is continuously changing. While he may have an ideal system in mind, the resources allocated to solid waste collection could be much less than those required to construct, operate and maintain an ideal system. He must first prove the effectiveness of a model and remember that failure breeds failure in the same way that success breeds success. Consequently a request for more resources is likely to be favourably considered if he has established a long record of successes rather than failures. Aside from a lack of resources he may have to face a number of quantifiable and non-quantifiable constraints, some of which occur by chance or are governed by the laws of probability. The system must be designed around the constraints as they exist and changes that lie ahead. For example, narrow streets cannot be widened, so that it may be wise to purchase one type and size of collection vehicle suitable for the conditions in order to facilitate an inventory of spare parts.

The planner must consider the project cycle. He plans, tests, modifies and implements the system and then plans its upgrading. While keeping the ideal system as an objective he should be sufficiently pragmatic to develop a less than ideal system in the first instance. An ideal system is never realized and if ever it is the service area would by then have changed and the system would no longer be ideal. Although the resources available may be limited, the planner should be very careful of accepting grant and foreign assistance which promise dramatically to increase funds at his disposal. It is important to evaluate the capability of an organization to maintain recurrent costs and to pay back capital and interest on additional resources if they are in the form of a loan. Loan repayments can drain an organization's resources and instead of upgrading the system in the future the authority might well be forced to downgrade it. In instances where the grant is limited to a particular component of the system the effects of this component on other parts of the system should be evaluated. While the designer seeks to develop the best system with the resources at hand, he should be aware of a number of variables that must be considered and the potential effects of these variables on the system. An adequate factor of safety should be provided for contingencies. It is better to develop a workable system rather than one that purports to be ideal but is likely to fail. Fig. 3-13 shows the planning and design cycle of a solid waste collection system.

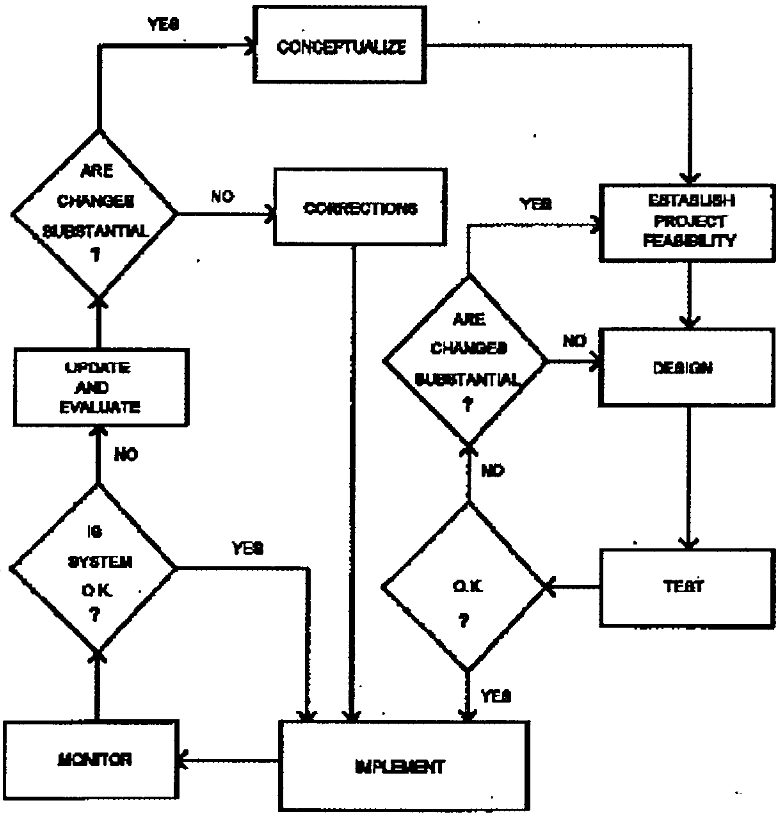


Fig 3-13 Project Planning, Design and Implementation Sequence

The service area is often very large with wide variation in physical conditions and characteristics of solid wastes. A number of collection sub-systems may be necessary to accommodate the characteristics of each area and these must be integrated to provide an effective collection system. For example, in slums and densely populated areas where access is limited, a pushcart system for house-to-house collection would be suitable, whereas in the central business district with heavy pedestrian and vehicular traffic and high generation rates, a compaction vehicle would be more appropriate. However, the slum and the main business district could well be adjacent to each other in which case they would share a common transfer station. The loading and unloading facilities at the transfer station would have to be designed to suit the compaction vehicles. Hence, the hauling vehicles supporting the pushcarts would also have to be compaction vehicles in order to utilize fully the facilities of the transfer station.

As mentioned earlier, one of the major problems faced by a solid waste management authority is finding convenient locations for its facilities. No one wishes to have these facilities in his neighbourhood. The planner may have identified a site only to find that at the stage of implementation it is no longer available. He must emphasize that the design of the facilities could be site dependent. For example a transfer station in Manila costing US$ 20 million was originally designed for a vacant area such that access was not a problem. After protest from land speculators who owned the surrounding vacant lots, the location was transferred to a narrow strip of land along the coastal road. Since the project was behind schedule, the authorities decided to use the original plans. The transfer station was completed in 1990 but it has never been used because the large hauling vehicles are unable to turn around in the narrow coastal road. These vehicles would have to travel 10 kilometers in either direction before finding a suitable space to turn around thus negating the advantages of the transfer station. When in doubt it is best for the designer to test the system using the appropriate vehicles. In the case of the Manila transfer station it was proposed to run container vehicles from the port area to test the configuration of the road. The idea was turned down by the authorities on grounds that it was unnecessary, considering that the roads in the area conform to standard design requirements of the Department of Public Works and Highways. A few tests costing no more than US$1000 could have saved the government and taxpayers US$ 20 million.

The solid waste planner and designer must be prepared to face all sorts of experts. In the eyes of most decision makers solid wastes management is a simple operation. For example, the decision to forego the test concerning the proposed Manila transfer station site was made by a well known structural engineer who held a very high government position. In spite of the US$ 20 million white elephant created he has nothing but contempt for solid wastes specialists. The solid waste system planner and designer has also to contend with equipment salesmen putting strong pressure on decision makers at various levels of government. Salesmen surprisingly are often more adept at tailoring their sales pitch to the needs and perceptions of the decision makers than the solid wastes system planner or designer. While they may have reservations about the system he is proposing and about quantifying restrictions and limitations on the applicability of the system, the salesman has no qualms in making exaggerated claims about the performance of his products. Too often the solid wastes system planner or designer looks incompetent and unsure of his proposals while the salesman emits an aura of confidence.

Lastly, solid waste management, especially the solid waste collection system, is open to abuse and corruption. Organized crime has been reported to have taken over private collection companies in both developed and developing countries. As long as the documentation is in order it is very difficult to check the actual performance of the collection crew. Nobody stores the solid wastes collected today for possible auditing a month ahead. The collection system is open to various abuses such as claims for trips which were never carried out, collection crew members who report only to collect their salaries, non- existent personnel, and the like. Such practices can be controlled to some extent by proper documentation, surprise inspection, instituting a strong monitoring programme, and establishing criteria for payment based on the cleanliness of the service area rather than on the quantity of wastes collected.

To facilitate the planning and design of a solid wastes collection system a checklist of the variables and potential solutions is shown in Table 3-2. As discussed earlier in this section, the variables and constraints affecting the solid wastes collection system are diverse and complicated. Table 3-2 is not an exhaustive listing of the criteria and possible solutions and the reader could well expand the checklist depending on conditions in the service area.

3.9 RECORD KEEPING, CONTROL AND INVENTORY

Records should be kept of: the quantities of wastes collected and their variation within the week, month and year; established long term trends in solid wastes generation rates and composition; sources of wastes, and the personnel collecting them. Information concerning variations in solid waste generation rates within the week, month or year is important in allocating the collection vehicles and crew. Long term trends in solid waste generation rates and composition form the basis for planning, especially in budgeting for future vehicle requirements, construction of transfer stations, strategic land acquisition and in determining the disposal options. Records of personnel time and quantities of wastes collected are used in determining the efficiency of the personnel and in correlating these quantities with conditions in the service area.

A weighbridge and time keeping system at the transfer or disposal site is a key element in improving the efficiency of the collection system and planning of an upgraded system. The Kuala Lumpur solid wastes collection system was improved and upgraded without substantial investment by installation of a weighbridge at each disposal site and proper analysis of the data gathered. Collection vehicles which arrived at the disposal sites partially filled were correlated with the cleanliness of the collection area. If the level of cleanliness was acceptable this meant that the theoretical quantity of wastes generated in the area was higher than the actual quantity generated. The collection area boundary was subsequently increased. On the other hand if complaints were received from the residents and the vehicles assigned were always full, further investigation of the causes was made. Most often additional vehicles and collection crew were assigned. If the crew were doing outside jobs for industries they could be easily detected. The timekeeping system also determined if the crew were taking long rest periods, spending time salvaging or carrying out unauthorized activities. The performance of a particular crew in terms of the quantity of solid wastes collected per day, could be compared with that of another collection crew working under similar conditions.

Table 3-2 Checklist of Variables Affecting the Selection of Solid Wastes Management Components

COMPONENTS	FACTORS TO CONSIDER
A. Crew Size	1. labour cost 2. distance between container 3. size and types of containers 4. loading accessories available with the truck 5. collection vehicle used
B. Container Type	1. solid wastes generation rate 2. density of wastes generation 3. street width 4. traffic volume 5. collection truch/crew configuration 6. standard of living
C. Collection Accessory	1. labour cost 2. protection of worker's health
D. Vehicle Size/type	1. street width, traffic volume 2. solid wastes generation rates 3. crew size 4. viability of a transfer station
6. Collection Route	1. street width, traffic volume 2. direction of traffic flow 3. solid wastes generation rates 4. spatial distribution of wastes 5. local topograpghy
7. Transfer Station	1. distance between disposal site and collection area 2. hauling cost for small and large trucks 3. cost of transferring the solid wastes from small to large trucks

Conditions in the service area are dynamic in nature. Generation rates increase with increasing numbers of residents in the area and a higher standard of living. Population shifts, the business cycle and accidents could, likewise, reduce waste generation rates in other areas. Collection data correlated with the cleanliness of the collection area serves as a basis for adjusting the boundary of the collection area in response to changes in generation rates.

The composition of solid wastes should be measured at least once a year for major districts and possibly once every two years in residential areas with stagnant growth rates and development. Changes in composition affect the collection equipment and configuration of the collection system and are also important in designing the disposal system. For example, the solid waste may contain a large quantity of ashes in which case the containers would be limited to 40 litres because of the high density of ashes. Ash density is in the range 1.5-2.0 tons per m^3 compared with 0.25 tons./m^3 for solid waste. Changes in an energy source, such as a shift to gas or electricity from wood or charcoal for cooking and heating, reduces the ash content of wastes, making the solid waste lighter in which case larger containers could be used. The same line of analysis holds true in specifying the collection vehicles.

One of the major objections to using a weighbridge at the transfer station or disposal site is the possible addition of sand and gravel to the solid waste by the collection crew to mask its inefficiency. Such a possibility is, however, remote since sand and gravel generally have a higher value as fill material or cover for sanitary landfill. Furthermore, sand and gravel are heavier and more difficult to load than solid wastes. Unless the collection crew has access to a quarry with a loader and a free supply of such material it is doubtful that they would resort to this form of cheating.

Comparison of the routes taken by various crews serving a particular area helps to identify the best hauling route. Although this route may be longer it could nevertheless be more economical in terms of hauling time. The best route often changes with the season. For example, parts of the road network may be impassable during the rainy season, so that vehicles using alternative routes during this period may increase traffic congestion. This development changes traffic patterns, and this requires changes in the collection vehicles, crew size and the need for transfer stations. All these decisions should be based on reliable data without which the solid waste collection system will inevitably be ineffective.

Table 3-3 is a sample form for monitoring the weight of wastes delivered at the disposal site, the time spent in collection, the number of trips made and the source of the wastes. The authority should develop a coding system for waste sources to facilitate the tabulation and comparison of crew performance. The results can then be coded into a database like DBASE IV or a LOTUS 123 program. The form should be concise enough to record as much data as needed at the time as well as data required for upgrading the system in the future. However, data gathering should not be tedious to the extent that a considerable portion of available resources are committed to it. It would be better for the authority to gather simple sets of data as shown in Table 3-3 and later on expand it as more experience is gained and more sophisticated equipment and personnel acquired for collation and analysis.

Monitoring is the link between reality and the assumptions made in planning and design. Proper interpretation of monitoring data allows the authority to adapt the proposed system to actual conditions. In some instances it also allows management to identify areas where the design is not realistic For example, monitoring data from one city showed that the crew were collecting 140% of the solid wastes generated, although piles of wastes were building up all around the collection area. Clearly, either the assumed generation rates were erroneous or the data on solid wastes collected were fabricated. In this particular instance it was later discovered that the collection crew were collecting the solid wastes from other areas where they had secured a private contract but were reporting the unauthorized collections as wastes collected from their assigned areas.

TABLE 3-3 Sample Form for Monitoring Collection
Efficiency at Disposal Site

VECHILE	AREA SERVED	TOTAL WEIGHT	TARE (Tonne)	WEIGHT OF SW (Tonne)	TIME STARTED	TIME COMPLTED	TIME FOR THIS TRIP (min)	TIME RQD/ TONNE (min/tonne)

3.10 INTEGRATING THE COLLECTION AND DISPOSAL SYSTEMS

The solid waste collection system and the disposal system are interactive. However, in a number of cases waste collection is managed separately from disposal as a result of the manner in which local institutions have evolved. This phenomenon is sometimes the natural result of the varying requirements of the collection and disposal systems. The disposal system is best operated on a regional basis and hence an administrative body in charge of regional planning and operation often develops this system while a more localized agency takes responsibility for the collection system. As the collection system is upgraded, and local institutions at the level of resident associations gain more experience in monitoring and interfacing with the solid wastes management authority, management of the collection system gravitates toward these institutions. The collection system generally is more effective and efficient as it becomes more responsive to the needs and intricacies of the users. On the other hand as solid waste generation rates increase and the degree of development in the service area rises, land for disposal sites becomes scarcer at the same time that requirements become greater. Disposal sites have to be sited farther from the service area and therefore require longer term planning. The development of disposal sites falls more appropriately within the purview of government institutions at a higher level. In fact the national or federal government may even have to interfere when solid wastes have to be transported across political boundaries outside the service area. In recent years there have even been instances where the transport of solid wastes has become an international issue.

Even within the same organization the orientation of personnel involved in the collection system and those servicing the disposal systems may diverge, resulting in loss of coordination. The personnel involved in the development of disposal sites encounter all sorts of problems from developers, land speculators, residents, environmentalists, bird lovers, politicians, and people in search of publicity, so that once a site has been selected they forget the implications of their decision on the components of the solid wastes management system. Sometimes the problem is biased towards a particular technology. For example, there is one group of international consultants who are strongly biased towards the recovery of methane gas from sanitary landfills for use in power generation. To make the system viable sanitary landfills are located in mountainous areas where the solid wastes must be piled high in order to reduce the cost of collection of the methane gas. This has resulted in the development of sanitary landfill sites that could not be used without causing the collection system to fail. In the Philippines alone some US$ 50 million has been wasted on this folly.

Of particular concern in the design of the collection system are the distance between the service area and the disposal site, the access route and the condition of the roads. The further away the disposal site is located from the service area the greater the cost of collection. Apart from the cost of collection, additional vehicles will be needed because the travel time between the collection area and the disposal site or transfer station is longer. As mentioned earlier, the solid wastes collection vehicles are often dilapidated dump trucks. If the disposal sites are located in mountainous areas, the collection vehicles or large hauling vehicles will have difficulty negotiating the routes. Even if they can negotiate the mountainous routes, depreciation will be higher. On the other hand improper selection of collection vehicles results in rapid depreciation and a high maintenance cost of the access road leading to the disposal sites. Solid wastes have low density.

Dump trucks previously used for hauling sand and gravel are very heavy not because of the solid waste load but as a result of the truck engine and chassis which could be ten times that of the load. Heavy dump trucks destroy the access road to the disposal site. Once the access road is destroyed personnel in charge of solid waste collection, noticing that the main failures in their trucks are in the chassis are likely to specify trucks with heavier chassis. The cycle starts once more with the heavier trucks destroying the access road faster than before. The authority ends up spending its fuel budget moving around the heavy trucks instead of the solid waste and wasting its budget for cover materials required at the sanitary landfill, on maintenance of the access road.

Even resource recovery and recycling have to be properly coordinated with the collection and disposal system. If the authority uses an incinerator for solid waste disposal, plastics, paper, and textiles are the main sources of heat. These materials also command a good price for recycling and recovery. The recycling and resource recovery programme must therefore be in phase with the operation of the incinerator, otherwise the incinerator may malfunction due to the low heating value of the reduced waste feed resulting from the diversion of materials to the resource recovery and recycling programme. It is important to test programmes on a pilot scale, and to perfect the system before implementation when management has control of the variables. Some programmes when scaled up will result in failure. For example, backyard composting of solid wastes could reduce the volume of wastes collected and ultimately the cost of collection and disposal. The programme may be viable at the household level where the labour cost for segregation, compost preparation and packaging is low or even free and the small volume scattered in the back yard will not create an intolerable nuisance. However, when it is applied to the entire production of a metropolis, quality control, marketing and inventory control make the project uneconomical.

3.11 OPERATIONS RESEARCH IN COLLECTION SYSTEMS

Operations research (OR) is that branch of systems engineering involved in the determination of optimal solutions to management problems subject to stochastic and deterministic constraints. Linear programming, queuing theory, Monte Carlo simulation, inventory theory, network theory and game theory are some of the OR techniques commonly used in solid wastes management especially in the design and operation of the collection system. Sasieni et al (1959); Churchman et al (1957). Linear programming is used in the allocation of collection vehicles to collection areas and establishing the disposal sites or transfer stations. Chance constrained linear programming considers the stochastic nature of variables like travel time, wastes generation rates, collection efficiency and their effects on the optimum allocation of vehicles to various collection areas. Dynamic programming is used to establish the optimal flow routes of solid wastes using various modes of collection such as: from push carts to collection vehicles to transfer station and ultimately to the disposal site.

Queuing theory is used in the design of transfer station ramps, collection crew size, and unloading facilities at the disposal site. Monte Carlo simulation predicts the efficiency and behaviour of the collection system considering the complex interaction of variables which are stochastic in nature, like travel time, solid wastes generation rates, service time and traffic conditions in the service area. Inventory theory is used in planning the stock of spare vehicles and spare parts, while network theory is used in planning the collection route which minimizes replication of coverage and in determining the shortest routes which effectively cover the collection area. Liebman et al (1975).

The application of these advanced mathematical techniques to the design and operation of a waste collection system is beyond the scope of this text. However, because of their great potential for developing optimal solutions and increasing operational efficiency, the student is strongly advised to acquire the necessary knowledge and skills in mathematics and computer programming in order to raise the level of his/her professional competence.

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ANSWERS TO SELF ASSESSMENT QUESTIONS

SAQ 3.1

a) Total Working Day = 16 hours/day x 60 mins/hr = 960 min/day

Activity	%	Time	Time/Trip
i) Rest period for driver	5	48	12
ii) Queuing at disposal site	5	48	12
iii) Hauling the wastes to disposal site	20	192	48
iv) Collecting wastes from one stop to another	70	672	168

(Note: Time is equal to 960 multiplied by the percentage, and time per trip is time divided by four)

With the use of a pushcart, item (iv) is eliminated and in its place is substituted the time to transfer the wastes from the pushcarts to the vehicle, which is 30 minutes per trip. The new MTM result is:

Activity	Time/Trip	%
i) Rest period for driver	12	11.8
ii) Queuing at disposal site	12	11.8
iii) Hauling the wastes to disposal site	48	47.1
iv) Transferring wastes from pushcarts to trucks	30	29.3

a) Number of vehicles required: 20,000/(4 trips/day x 15 cum/trip) = 334

The solid wastes management authority is short by 134 vehicles. With the pushcarts, the time consumed per trip as given at i, ii and iii of the above table plus the 30 minutes gives a total of 102 minutes. The average number of trips the vehicles could make in a day is 960/102 or 9.4 trips. (note: 9.4, the average number of trips, need not be a whole number.) The total number of vehicles needed is 20,000/(15 x 9.4) = 142. The solid wastes management authority has a surplus of 58 vehicles.

SAQ 3.2

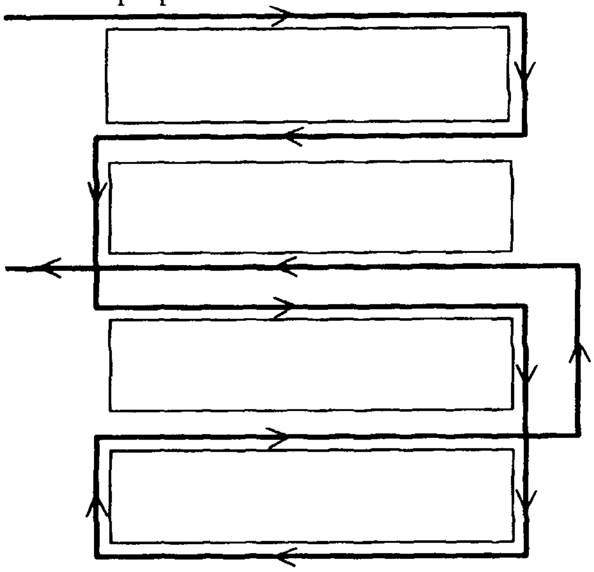
a) Consider the collection of one vehicle load using each system in turn. When the vehicle is used alone from one collection stop to another, the collection time is 240 mins with a 15 cu.m. load. Labour costs are:
4 men x .01 x 240 +1 driver x 0.015 x 240 + 48 x 0.10 + 168 x 0.13 + 12 x 0.01 = $39.96.
This is equal to a collection cost of $2.66/cu.m. The reader may note that labour costs account for $13.20 while vehicle depreciation, operation and maintenance, which are almost all foreign exchange costs, account for $26.64.

With the assistance of a pushcart the average collection time is only 102 min. The number of pushcart collectors needed to fill a 15cu.m. truck is 15/(4 x 102/480)= 18 collectors. The cost is equal to:-
18 x 0.005 x 102 + 102 x 0.015 + 48 x 0.10 + 30 x 0.01 + 12 x 0.01 = $15.93.
This is equal to a collection cost of $1.06/cu.m. Under this system, labour costs account for $10.71 while vehicle depreciation, operation and maintenance costs are only $5.22. The cost of pushcarts is neglected since it is very small.

b) The cost when using vehicles only will be
4 x 0.10 x 240 + 1 x 0.15 x 240 + 168 x 0.13 + 12 x 0.01 = $153.84
Under this condition labour costs account for $132.00 while vehicle depreciation, operation and maintenance costs are only $21.84. Investment to reduce the number in the crew such as provision of a mechanical lifting and loading mechanism on the vehicles would be attractive. The pushcart/vehicle system will cost
18 x 0.08 x 12 + 1 x 0.15 x 102 + 48 x 0.1 + 30 x 0.01 + 12 x 0.01 = $166.52.
In this case the system is not viable due to high labour costs.

SAQ 3.3

The route shown below is proposed.



There is no single, unique solution. Practice, experience and common sense are important in vehicle routing. The selected route should be verified before implementation.

The principles used are embodied in the procedure recommended in Section 3.4, namely:

- simplify the block diagram by eliminating the alleys;
- minimize left turns (traffic flow on right side);
- travel straight whenever possible;
- minimize street retracing;
- minimize vehicle travelling distance;
- serve both sides of the street simultaneously if it is not wide

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SAQ 3.4

a) Let X be the break even distance, then:
Cost of direct hauling using small vehicles is 0.05X
Cost using large vehicles is 0.01X + 0.40

At break even the cost of direct hauling is equal to the cost of using the transfer station. Then,

$$0.05X = 0.01X + 0.40$$
$$X = 20\text{ km}$$

The transfer station is viable if the distance between the collection area and the disposal site is greater than 20 km. Since this distance is 30 km, then the use of a transfer station is justified.

b) Let Y = the distance between the collection area and the transfer station
X = the distance between the transfer station and the disposal site.

Then the cost of direct hauling using small vehicles is:
$0.03Y + 0.03X$,

and the cost of hauling using the transfer station is:
$0.03Y + 0.40 + .01X$

For the transfer station to be viable the cost of direct hauling must be greater than the cost of using the transfer station. At break even,

$$0.03Y + 0.03X = 0.03 + 0.40 + 0.01X$$

$$X = 20\text{ km}$$

Since the disposal site is 18 km from the transfer station, which is less than 20 km, the use of a transfer station is not justified.

c) Cost of direct hauling = 0.03 (30) = \$0.90/ton
Cost using the transfer station = 0.03 (12) + 0.4 + 0.01 (18) = \$0.94/ton

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SAQ 3.5

a) Using the conventional break even cost analysis the use of the transfer station is justified if the distance between the collection area and the disposal site is greater than 20 km as shown in SAQ 3.4. This is the result of equating the cost of direct hauling using small vehicles of 0.03X and the cost of using the transfer station of 0.01X + 0.4. Since the distance between the disposal site and the collection area is 30 km, the use of the transfer station viable.

Using the corrected cost analysis:

Let Y = distance from the collection area to the detour point
Z = distance from the detour point to the transfer station
X = distance from the detour point to the disposal site

Then the cost of direct hauling = $0.03Y + 0.03X$
The cost using the transfer station = $0.03Y + 0.03Z + 0.01X + 0.40$. The use of the transfer station is justified if the cost is lower than the direct hauling cost. At break even,

$$0.03Y + 0.03X = 0.03Y + 0.03Z + 0.01Z + 0.01X + 0.40$$

If Z = 5 km, then

$$X = 30\text{ km}.$$

Since the distance between the disposal site and the transfer station is only 20 km, the use of the transfer station is not justified.

b) the cost of
direct hauling = 0.03 x 30 = 0.90/ton

the cost using the
transfer station = 0.03 x 10 + 0.03 x 5 + 0.01 x 5 + 0.01 x 20 + 0.4 = 1.10/km

4 WASTE DISPOSAL (SANITARY LANDFILLS)

4.1 INTRODUCTION

This chapter deals with the planning, design, operation and maintenance of sanitary landfills. The following will be discussed and/or described:

- activities in the planning phase of a sanitary landfill disposal system, taking into account social, political, aesthetic and environmental considerations (Section 4.2);
- the physical, chemical and biological processes which occur in landfills will be described (Section 4.3);
- the design, construction, operation and maintenance of a sanitary landfill disposal system will be described (Section 4.4);
- the quantities of leachate produced, the physical, chemical and biological characteristics of leachates and the facilities used for the treatment of leachates (Section 4.5);
- the quantities of landfill gas produced and the possibilities for landfill gas utilization. (Section 4.6).

Finally, examples of sanitary landfill designs will be given.

Definition of a Sanitary Landfill

A landfill is a disposal facility where solid wastes are placed and stored in or upon the soil. In the industrialized world, landfilling frequently is considered to be a technology of last resort to be used after every effort has been made to reduce or eliminate the hazards posed by the waste. Even so, in the U.S.A. 80% of all waste is still being disposed of in landfills. By comparison, in Japan the proportion is only 25%, 75% being either recycled or incinerated for energy recovery. A landfill is called a 'Sanitary Landfill' when the waste is compacted in layers and covered by soil at the end of each day's operation in order to minimize the threats to human health and the environment.

The purpose of landfilling is to bury or alter the wastes so that they are no longer environmental or public health hazards. Landfills are not homogeneous and are usually made up of cells in which a discrete volume of waste is kept isolated from adjacent waste cells by a suitable barrier. Barriers between cells commonly consist of a layer of natural soil (clay) which restricts downward or lateral escape of the waste constituents or leachate.

Landfilling relies on containment rather than treatment for control of wastes. Technologically, it is an unsophisticated disposal method. Yet properly executed, it is a safe and by far a cheaper method than incineration. The cross section of a completed and closed secure landfill is shown in Figure 4-1. Appropriate liners for protection of the groundwater from contaminated leachate, run-off control, leachate collection and treatment, monitoring wells and appropriate final cover design are integral components of an environmentally sound sanitary landfill.

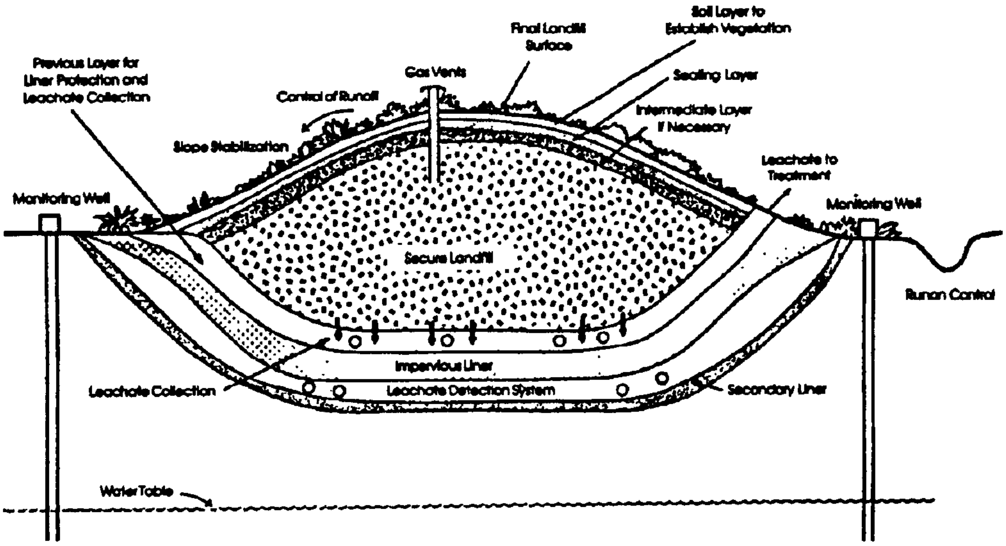


Figure 4-1: Schematic Cross-section of a Secure Landfill
(Source: U.S. Environmental Protection Agency, 1990)

Life Cycle of a Landfill

With respect to the environmental aspects of sanitary landfilling it is important to note that a landfill has different phases in its life cycle. These are:

1. **planning phase**: typically involves preliminary hydrogeological and geotechnical site investigations as a basis for actual design;
2. **construction phase**: involving earthworks, road and facility construction and preparation (liners and drains) of the fill area.
3. **operation phase (5-20 yrs)**: This phase has a high intensity of traffic, work at the front of the fill, operation of environmental installations and completion of finished sections.
4. **completed phase (20-100 yrs)**: from the termination of the actual filling to the time when the environmental installations need no longer be operated. The emissions have then decreased to a level where they do not need further treatment and may be discharged freely into the surroundings;
5. **final storage phase**: emissions are at acceptable levels, the landfill is integrated into the surroundings and no longer needs special attention.

The uncertainty about the length of the completed phase indicates that caution should be exercised in introducing energy and maintenance intensive environmental installations to abate the landfill emissions of the completed phase.

Potential Environmental Emissions

The potential environmental emissions from a sanitary landfill are summarized in Figure 4-2 for the operation phase and the completed phase. In addition, incidental events such as flooding, fires, landslides and earthquakes, which could result in severe environmental impacts, must be included in the environmental impact assessment procedure and may require preventive measures with respect to landfill site selection, design and operation.

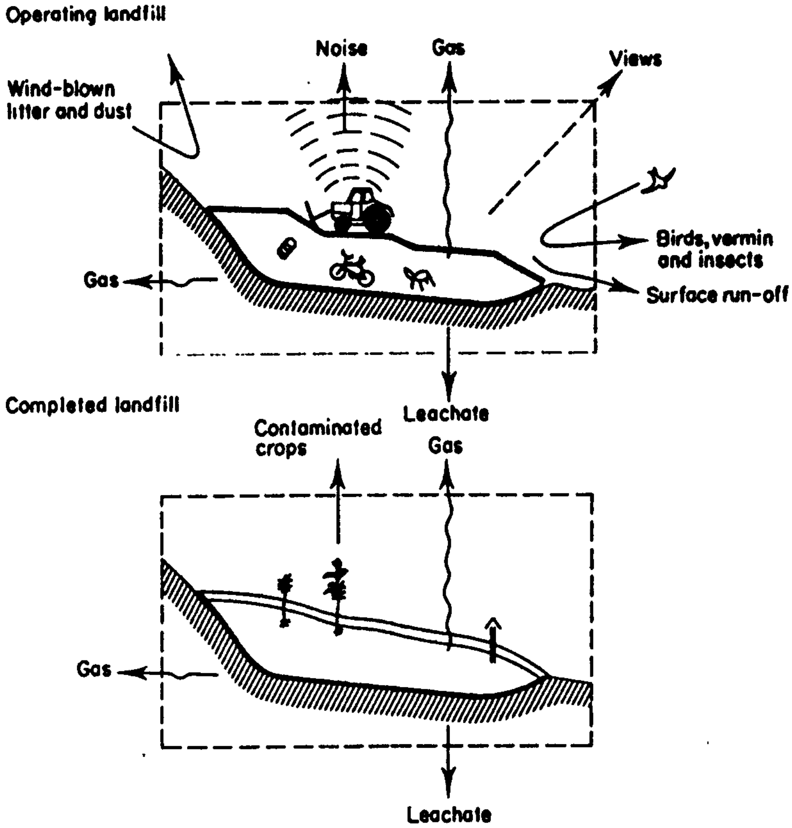


Figure 4-2: Illustration of the Major Environmental Aspects Related to Sanitary landfilling (source: Christensen et al, 1989)

The environmental aspects of an operating landfill are dominated by the nuisance imposed on the neighbourhood: wind-blown litter and dust, noise, odourous gases, birds, vermin and insects attracted by the waste, surface runoff and the psychological disturbance of the view to the landfilled waste. Gas and leachate problems also arise during the operation phase, demanding significant environmental controls:

- **wind-blown litter and dust** are continuous reminders of the ongoing landfill operation and a significant nuisance to the neighbourhood. By careful covering of the waste cells with soil, the problem may be reduced, but complete avoidance is impossible at the tipping front of the landfill. Spraying water on dirt roads and waste in dry periods, in combination with fencing and movable screens at the tipping front may minimize the problem;
- **noise** is caused by traffic of waste collection vehicles, emptying of the vehicles and by the compactors and earthmoving equipment. In some cases large gatherings of birds create a noise problem. The noise problem may be reduced by technical improvements of the equipment, by surrounding the fill area with soil embankments and by limiting the working hours. Plantings may reduce the noise level, if they provide a tall and tight vegetation;

- **birds, vermin, insects** and other animals are attracted to the landfill for feeding and breeding. Since many of these animals may act as disease transmitters, their presence may constitute a potential health problem. The aggressive and effective feeding patterns of seagulls right at the tip front, make it very difficult to effectively reduce their presence at landfills;
- **surface run-off** which has been in contact with the landfilled waste may be a problem in areas with intense rainfall or snow melt. If not controlled, heavily polluted run-off may enter directly into creeks and streams. Careful design and maintenance of surface drains and ditches, together with a final soil cover on completed landfill sections, may eliminate this problem;
- **views** are often important elements of the quality of residential and recreational areas. An operating landfill where equipment and waste are exposed, may psychologically affect the appreciation of an attractive area. This problem may be reduced by careful design of screening soil embankments, extensive plantings and rapid covering and revegetation of filled sections;
- **gas** released from the waste, resulting from degradation of the waste or from volatization of waste components, will migrate vertically out of the filled area or horizontally through porous soil layers into the soil of adjacent fields. The problems associated with the gas are odours, release of explosive/flammable methane, health aspects related to specific compounds and damage of the vegetation due to oxygen depletion of the root zone. Methane generation may start a few months after disposal of the waste and may continue for several decades. The gas control measures which may be introduced are liners, soil covers, passive venting or active extraction of gas for use or treatment before discharge to the atmosphere;
- **polluted leachate** from the waste appears shortly after disposal of the waste. The leachate is likely to be heavily polluted and may cause extensive groundwater pollution and, through subsurface migration, extensive pollution of streams. Liners, drainage collection, treatment of leachates and groundwater quality monitoring downstream of the landfill are necessary. Since the subsurface migration of groundwater and leachate may be slow, the consequences of improper leachate controls may not emerge until decades later.

At the completed landfill, the local nuisances are negligible. The environmental aspects related to gas and leachate still persist, however. If insufficiently covered, an additional environmental disadvantage may emerge at the site of the completed landfill. Vegetation and crops grown on the completed site may have been in contact through their roots with the waste material and may have become contaminated. However, at properly completed landfills the risk of contaminated vegetation and wildlife at the site is avoidable.

Minimizing Environmental Impacts

As can be discerned from the previous discussion, the environmental effects related to sanitary landfilling are varied, ranging from local nuisances which may be abated by a tidy operation of the site, to the potential contamination of regional groundwater resources by migrating leachate. While many of the environmental effects may be minimized by current technology, the long term aspects of gas and leachate still raise questions about the appropriateness of the current technology. Significant developments in the concepts and technology of landfilling, with a view to the long term effects, are expected in the decades to come. Meanwhile, meeting today's needs for landfill capacity, acceptable environmental impacts of a sanitary landfill can be obtained only if proper attention is paid to the environmental aspects at all stages and phases of a landfill: site selection, design, construction, operation and maintenance. The quality control measures required for ensuring a low level of impact on the environment from the landfill must be carefully documented.

Objectives

- to define what is meant by the term Sanitary Landfill, and to examine the factors which need to be considered in planning such a facility;
- to describe the physical, chemical and biological processes that take place in a sanitary landfill and to examine, in this context, the advantages and disadvantages of the co-disposal of MSW with other wastes;
- to describe how a sanitary landfill is designed and constructed and the precautions taken to protect water sources from leachate contamination and prevent dangerous emissions of landfill gas;
- to describe the various operations at a landfill site including the systems used for monitoring leachate, landfill gas and groundwater;
- to describe how the quantity of leachate and the rate of its production may be estimated;
- to present data on leachate quality and to describe how leachate is treated prior to its discharge to the environment;
- to describe how the quantity of landfill gas and the rate of its production may be estimated;
- to present data on the composition of landfill gas and to describe the techniques used for its treatment and utilization;
- to discuss the disposal of hazardous waste with special reference to practice in the Netherlands.
- to present a series of case studies to illustrate representative landfill designs.

4.2 PRELIMINARY ACTIVITIES

4.2.1 Site selection

The feasibility of land disposal of solid waste depends on factors such as the type, quantity and characteristics of the wastes, laws and regulations, public perception and acceptance, and the soil and site characteristics. This section focusses on those characteristics that are important when selecting a site for land disposal options. The design and management of landfills are site specific. The technical and economical feasibility will depend on the topography, soils, climate and hydrology of the site, on transport distances from the waste sources to the site and on current and projected land uses.

The process of site selection can be considered to have at least three major components:

1. **general evaluation:** problem definition and initial solution evaluation; this screens out site alternatives that clearly are not feasible;
2. **detailed analysis of feasible options:** closely evaluates the site, soil and groundwater characteristics, includes economic and political considerations, and narrows site options;
3. **final site selection and design:** involves detailed economic, technical and political evaluations of specific sites.

The **general site evaluation** is concerned with defining technical feasibility. The general area requirements are identified after consideration of waste and site characteristics. Because of the need to minimize pollutant migration and risks to public health and the environment, there may be only a few potential sites for evaluation. No site should be used for landfill disposal unless the geological and hydrogeological properties of the site have been carefully investigated and found to be satisfactory. Annex I provides general site selection criteria to be considered.

A **detailed analysis** is initiated after a number of sites have been determined to be potentially feasible. This analysis must:

1. evaluate the critical site characteristics of each option;
2. identify the land disposal method to be investigated for each candidate site;
3. define the detailed design requirements for each land disposal method and candidate site;
4. develop a cost-effectiveness ratio for each alternative;
5. encourage public participation throughout the planning stages;
6. determine whether land disposal continues to be feasible;
7. identify a site or sites for intensive field investigation.

Although this analysis primarily uses available published information, field evaluations, especially those concerning the soil properties, are desirable. General soil properties of interest include: permeability, pH, organic matter content, silt/sand/clay content and cation exchange capacity. In a field survey, samples for chemical analysis are taken and hydraulic tests and deep borings conducted to investigate the (hydro)geological properties. The sample and test points have to be carefully prepared, for these tests are relatively expensive.

On the basis of the results from the detailed analysis and field observations a **site can be selected**. Few sites are ideal for landfill, but many that are not can, to a certain extent, be engineered to be suitable. The site selection can be done by means of a multi-criteria analysis. The essence of a multi-criteria method is to make a systematic inventory of policy options on the basis of available, heterogeneous information and to classify them, analyse them and present them in the clearest possible way.

Characteristic of this method is that it is based on a number of different considerations-technical, economic, political. These criteria may be very different in nature and therefore not necessarily quantifiable in the same unit. Another important characteristic of a multi-criteria analysis is the fact that it explicitly takes account of different priority settings. This makes the approach eminently suitable for the evaluation of alternatives.

The site selection and investigation phase ends with the development of a working plan. This plan is the central document for planning and disposal licence applications and also the blueprint for eventual operation of the site. The plan should consist of two parts: a plan or series of plans, outlining the development and a description of the way operations are to be carried out.

The plans required are as follows:

1. **site location plan:** site survey plan and ground investigation summary: these plans show the aforementioned physical site data;
2. **site operational plan:** showing the site after its preparation;
3. **engineering plans:** showing details of any engineered features;
4. **restoration plan:** showing the forms and contours of the restored site.

4.2.2 Political and social considerations

Developments in environmental policy and legislation are strongly related to the assessment of potential environmental risks and the reaction of the community with respect to these risks. Industrialized countries have issued a series of environmental laws and regulations in the last 20 years. In developing countries, first steps have been taken to build an environmental law framework.

Waste management practices in developing countries are generally not well developed. In contrast with developed countries, uncontrolled recycling of waste has for many years played an important role. A very significant proportion of waste material is collected, treated and sold. Small scale dumpsites are crowded with people collecting waste (scavengers). In the vicinity of the dumpsite low-cost settlements are constructed. For a large part of the community this is the only source of income. Scavengers are equipped with an L-shaped metal rod with a pointed end. This is used to pick up and throw the recovered materials into the collection basket or sack. Since scavenging is not normally included in solid waste management planning, facilities at the dumpsite for washing, bathing or first aid are rarely available.

The growing awareness of environmental and health risks of waste dumping has led to policy developments with respect to landfilling. The concept of sanitary landfilling, which is a safe, but complex way of disposing-of waste was introduced. Within this concept, scavenging of the landfill site is no longer accepted because it poses a threat to the proper management of the landfill. However, the community loses an important source of labour and income.

Several other observations are valid for both developing and developed countries. A well-designed sanitary landfill is more expensive than a dumpsite. Its construction and maintenance costs are high. With respect to economy, large-scale landfill sites are less expensive. This kind of landfill has a considerable physical impact on the surrounding landscape. Community participation is in many cases not possible and the local community will not accept the selected landfill site in their surroundings. This is called the NIMBY syndrome (Not In My Back Yard).

To overcome these problems, the local community should be given the opportunity to participate in the decision-making process regarding landfill site selection and landfill design. At the landfill site, some space can be reserved for 'controlled scavenging' if the community insists in the continuation of scavenging activities. Communication of the activities planned as well as public education concerning landfills, are always important if success is to be assured.

The design and construction of landfills and the necessary environmental facilities are subject to environmental regulations. In some industrialized countries, maintenance is prescribed by law. A helpful tool for the assessment of potential environmental risks is an environmental management system. This system describes the technical status of the landfill and its environmental facilities; the tasks and responsibilities of staff, monitoring and maintenance programmes; staff education programmes (if necessary) and records of performance data and may therefore serve as an environmental protection handbook.

The design and construction of a landfill might also be subject to an Environmental Impact Assessment procedure in which an assessment is made regarding the environmental impacts of the proposed activity. Several alternative solutions to a problem are put forward for examination by an expert committee. The procedure is meant to facilitate the selection of the alternative with minimal environmental impacts. However, if this option has economic disadvantages, a less environmental friendly option may be chosen. Within the framework of an environmental impact assessment the community is allowed to participate.

4.2.3 Aesthetic and future use considerations

Aesthetic considerations

A large scale sanitary landfill, with an operational period of 20-30 years, greatly influences the surrounding area. Loss of aesthetic quality occurs in all phases since landfills are mostly located well away from urban centres, in the green areas of the countryside, which have both ecological and scenic value. Both qualities of the landscape are adversely affected.

During construction of the landfill, a formerly green area is transformed into a muddy brown, grey area. Vehicles and earth-moving equipment create a nuisance for people in the immediate vicinity. This problem can be overcome by screening the landfill site from the adjacent area with embankments covered with trees and shrubbery. The access road should be sited in such a way that minimal nuisance occurs. Collected waste should not be transported through densely populated streets and ecologically valuable areas.

During the long operational period, the access road will be heavily used by waste collection vehicles. At the landfill itself, the tipping process and wind-blown litter pose further threats to aesthetic values outside the landfill area. Raising of embankments may be necessary. As soon as possible the final cover should be placed over completed cells and planted with grass and shrubbery.

After completion of the landfill, the final contours should harmonise with the landscape. If this is not possible (e.g. if the orgininal landscape is flat) then the newly created mound should be so shaped as to be aesthetically appealing and thereby be an asset to the surrounding community.

Site restoration

After completion of landfill operations, the landfill site should be carefully restored. Poor restoration can all too easily alienate public confidence in the landfill. Restoration must be a prime consideration from the outset of landfill site development since the intended ultimate use of the land will influence site design, preparation and operation in various ways.

A plan for restoration of the landfill is part of the working plan. The content of the restoration plan will depend to some extent on its proposed future use, although all plans should include an assessment of the expected settlement and outline the means to be adopted for controlling leachate and landfill gas.

Landfill site restoration cannot be considered to be complete after the final soil cover has been placed and the land shaped to desired contours. If future use requires the planting of vegetation, a recuperation period is needed during which the land is carefully managed and cropped to help the soil recover from the effects of movement, storage and replacement.

One practical problem faced by a landfill operator is to achieve approved final levels. To do this succesfully, it is necessary to anticipate the amount of settlement that will occur and to ensure that it occurs as evenly as possible. It is better to overestimate settlement. It will mostly have taken place within 10 years, but may not be finally complete for up to 30 years. Section 3.2 deals with settlement in more detail.

The intended final (post-settlement) levels and contours of a landfill should be indicated when the restoration plan is drawn up. In determining final land form, restoration to its original contours may not necessarily be appropriate. Sometimes raising the final land level is aesthetically desirable. It may also be in the best interests of succesful restoration to modify contours to allow for adequate drainage or visual effect.

Another characteristic of a completed landfill is bearing capacity, a measure of the ability of the landfill to withstand foundation loads without shearing. Data on the bearing capacity are very limited. Greater density of solid waste in the landfill provides greater shearing resistance and hence larger bearing capacities.

There are many uses to which a completed sanitary landfill can be put. Some of these include green areas, recreation, agriculture and construction of buildings.

Use of the landfill site as a green area is most common. Expensive structures are avoided. Penetration of tree roots into the cap lining system must be avoided. Completed landfills are often used for recreational facilities. Specific applications include ski slopes, ball fields, golf courses, amphitheaters, and parks. Some small light buildings, such as sanitary facilities and equipment storage, are required for recreational areas. They should be so constructed as to keep settlement problems to a minimum. The intended future use of the landfill site should be worked out during the design phase. The construction of golf courses in particular, restricts the design of the landfill area. A golf course needs a landscape with hills, depressions and ponds; most landfills are designed to be a flat peak hill like the South African Tafelberg (table mountain). After completion of the landfill the shape can only undergo minor changes.

4.3 PHYSICAL, CHEMICAL AND BIOLOGICAL PROCESSES IN A LANDFILL

In this section the physical, chemical and biological processes in a landfill will be discussed. Important physical processes include the landfill hydrology, relevant to the calculation of the quantity of leachate produced and the settling processes which must be taken into account in a proper design of the protective liners and the gas and leachate collection systems. The microbial degradation process is the most important biological process occurring in a landfill. This process induces changes in the chemical and physical environment within the waste body, which determine the quality of leachate and quality and quantity of landfill gas.

In recent years, experiments have been carried out with the object of enhancing the microbial degradation processes. These processes are also described in this section. Finally, for many landfills co-disposal of hazardous wastes is considered. The consequences of co-disposal for the degradation processes are assessed.

4.3.1 Physical Processes

Landfill Hydrology and Leachate Production

Figure 4-3 gives an overall summary of the components which make up the hydrological balance of the controlled landfill. For obvious reasons, we are most interested in the amount of leachate generated from the landfill. The hydrological balance provides a tool for the calculation of the quantity of leachate generated. The principal factors governing the formation of leachate are as follows:

1. **water availability:** rainfall, the presence of surface water, water content of sludges, recirculation of leachate;

2. **characteristics of final cover:** type of soil and vegetation, presence of impermeable cover material, slopes;
3. **characteristics of tipped waste:** density, tipping methods, moisture content of waste when landfilled;
4. **method of rendering the site impermeable.**

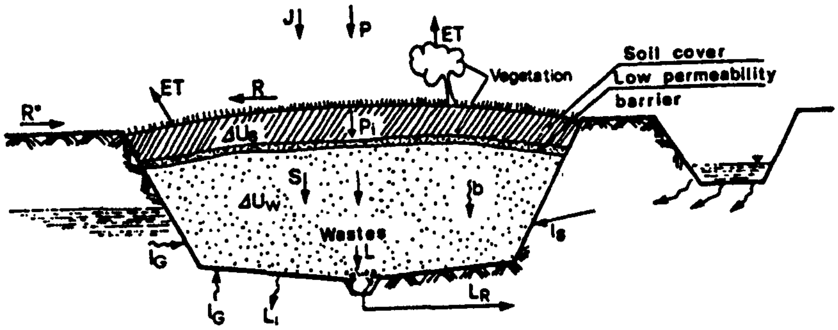


Figure 4-3: Schematic of the General Hydrological Balance in a completed Sanitary Landfill with Leachate Drainage System.

P: precipitation, J: irrigation or leachate recirculation, R: surface runoff, R^*: run-off from external areas, ET: actual evapotranspiration, $P_i = P + J + R^* - R - ET +/- \Delta U_s$, U_s: water content in soil, U_w: water content in waste, S: water added by sludge disposal, b: water production (if >0) or consumption (if <0) caused by biological degradation of organic matter, I_s, I_g: water from natural aquifers, $L = P_i + S + I_s + I_g + b +/- \Delta U_w$, L: total leachate production, L_i: infiltration into aquifers, L_r: leachate collected by drains (Source: Christensen et al, 1989).

The production of leachate (in this case the fraction of precipitation that ultimately forms leachate) in landfills with permeable cover material depends on the density of the waste body (compaction of the waste) and the slope and thickness of cover material. Loosely compacted waste produces more leachate than densely compacted waste. In western countries, the maximum seasonal peaks of leachate production are always observed at the end of winter and in spring, emphasizing the importance of evapotranspiration in reducing leachate during summer months. Special attention has to be paid to leachate production during operation of the landfill, since the final cover is absent and thus run-off and evapotranspiration hardly occur.

Calculation of the Hydrological Balance

In the following section each of the component parts of the hydrological balance is examined:

- **rainfall and surface run-off:** As with all cases of infiltration, the most critical situation occurs during periods of light rainfall over a long period of time; short bursts of heavy rainfall result in a quick saturation of the cover material with the result that the remainder is shed as run-off. The most important factors influencing the rainwater run-off are the topography (including slope), morphology of the soil, vegetation, permeability of the soil and the drainage systems installed. Calculation of run-off can be done by means of the so-called 'rational method'. R is directly proportional to P (R = c * P, c<1). The run-off coefficient c for grassed soil is lower than for bare soil; furthermore, c depends largely on the clay content of the soil and the slope: c increases with steeper slopes and higher clay contents. Table 4.1 gives typical values for the run-off coefficient c, valid for moderate climates:

Table 4.1: Typical values for the run-off coefficient c (Source: Christensen et al, 1989)

Soil Cover	Slope (%)	Soil Texture		
		Sandy Loam	Loamy Clay	Clay
grassed	0 - 5	0.1	0.2 - 0.4	0.3 - 0.5
soil	5 - 10	0.1 - 0.2	0.3 - 0.4	0.5 - 0.6
	10 - 30	0.2	0.3 - 0.5	0.5 - 0.7
bare	0 - 5	0.2 - 0.4	0.4 - 0.6	0.5 - 0.7
soil	5 - 10	0.3 - 0.5	0.5 - 0.7	0.6 - 0.8
	10 - 30	0.4 - 0.7	0.6 - 0.8	0.7 - 0.9

- **evaporation and evapotranspiration:** Vegetation growing on the final cover causes a greater water loss to the atmosphere (evapotranspiration) than the soil alone (evaporation). The evapotranspiration can be calculated using formulae developed by Thornthwaite or Penman. These approaches are fully described in hydrological literature.
- **infiltration and filtration through the filter material:** The net rainfall will fill the soil up to its maximum retentive capacity. If this capacity is exceeded, water will start to percolate into the strata underneath. If a low permeability layer is present, this will limit the flow of water, forming a saturated layer through which liquid will flow according to Darcy's law (Darcy's law: in a porous medium, the flow between A and B is proportional to the hydraulic gradient between A and B). A layer of freely draining soil placed above an (almost) impermeable layer and below the soil cover will allow water to drain out of the site, effectively eliminating most of the transport of water into the waste. Without this drainage the disposal of water from the water table will be through percolation to the waste and capillairy action into the soil above and from there by evapotranspiration.
- **movement of water through wastes:** Water percolating from the surface of a landfill tends to be absorbed by the waste until the field capacity is reached. Movement of water through the waste occurs when the water infiltration exceeds the field capacity, initially under unsaturated conditions and, if sufficient water is present, under saturated conditions. The permeability of waste is estimated to range from 10 m/day for non-compacted and non-shredded waste down to 0.1 m/day for fine compacted waste. The presence of an intermediate cover with lower permeability than waste may result in water accumulation above such a layer. Facilities for draining water should be installed for every separate waste and cover layer system to prevent the occurrence of water accumulation. In general, it can be assumed that leachate production will occur at a certain water content (generally less than the field capacity, due to short circuiting and channelling through the waste layers) and then it will gradually increase, reaching its maximum rate when field capacity is approached. The internal moisture content of waste is between 15-25% by volume, whereas field capacity is between 20-50%. The absorption capacity equals field capacity minus initial moisture content and thus ranges from 5-25%. The first appearance of

leachate occurs when a quarter of the absorption capacity is used. The calculation to determine the first appearance of leachate can be used as the basis to evaluate the quantity of waste that must be tipped in a waste cell before leachate appears.

other sources of leachate: Rainfall is not necessarily the only source of water in a landfill. The co-disposal of sewage sludges or the recycling of leachate contributes to the water content in the landfill. The water utilized in the anaerobic processes within the waste is only a very small portion of the amount of leachate produced.

Settling Processes in a Landfill

The deformation of the waste body of the landfill can be divided into three stages:

1. **short term deformation:** During the stage of primary consolidation, a substantial amount of settling occurs. This settlement is caused by the weight of the waste layers. This process may be enhanced by the movement of trucks, bulldozers or mechanical compactors. Especially bulky material (refrigerators, furniture) contains large holes, resulting in high compaction factors. This stage is complete before aerobic degradation processes occur.
2. **secondary compression:** In this stage the rate of settling is much lower than in stage 1. This is because settling occurs through compression. This secondary compression cannot be enhanced.
3. **decomposition stage:** During the degradation processes, organic material is converted into gas and leachate components. The settling rate increases compared to stage 2 and continues until all decomposable organic matter is degraded. The settling rate will slowly decrease with time.

Figure 4-4 is a schematic of the settling processes in a waste body.

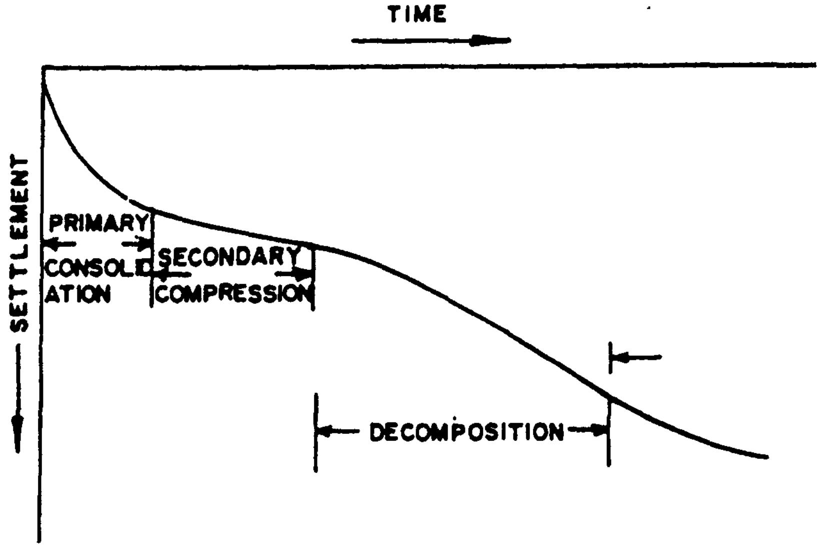


Figure 4-4: settling processes in a landfill (source: Bavelaar, 1989)

The ultimate amount of settling depends on the waste composition. In the industrialized world the initial waste density ranges from 50-150 kg/m^3. The final density, after completion of the settling is 500-600 kg/m^3. In developing countries however, these values are much higher. In

Calcutta, for example the initial waste density was about 550 kg/m^3; 6 months later, it had increased to more than 1100 kg/m^3.

4.3.2 Bio-chemical processes in a Landfill

Microbial degradation processes in a Landfill

Assuming that landfills mostly receive organic wastes, microbial processes will dominate the stabilization of the waste and hence govern the generation of landfill gas and the composition of the leachate. Soon after disposal, the predominant part of the waste body becomes anaerobic, and groups of bacteria start degrading the solid organic carbon, eventually to produce carbon dioxide and methane. The anaerobic degradation process can be divided into three stages:

1. solid and complex dissolved organic compounds are hydrolysed and fermented by the fermenters primarily to volatile fatty acids, alcohols, hydrogen and carbon dioxide;
2. an acetogenic group of bacteria converts the products from the first stage to acetic acid, hydrogen and carbon dioxide;
3. acetophilic bacteria convert acetic acid to methane and carbon dioxide; hydrogenophilic bacteria convert hydrogen and carbon dioxide to methane.

The overall process of converting organic compounds to methane, carbon dioxide, ammonia and hydrogen sulphide may be expressed by:

$$8\ C_vH_wO_xN_yS_z + (8v-2w-4x+6y+4z) * H_2O \rightarrow$$

$$(4v-w+2x+3y+2z) * CO_2 + (4v+w-2x-3y-2z) * CH_4 + 8y * NH_3 + 8z * H_2S$$

The hydrolysis process is very important, since the organic solid waste present must be solubilized before the micro-organisms can convert it. Hydrolysis is caused by extracellular enzymes produced by the fermenting bacteria.

The fermenters are a large, heterogeneous group of anaerobic bacteria, as well as the acetogenic bacteria. The acetogenic bacteria may also convert aromatic compounds containing oxygen (e.g. benzoic acid and phenols), but aromatic hydrocarbons (benzene, toluene) are not degraded. The methanogenic bacteria require very low redox potentials. They may also convert formic acid and methanol. The conversion of acetic acid to methane is the most important part of the methane-forming process (70%).

Another group of bacteria, the sulphate-reducing bacteria, reduce sulphate to sulphides. This group of bacteria which resembles the methanogenic group, also convert hydrogen, acetic acid and higher volatile fatty acids during sulphate reduction. Organic carbon is always oxidized to carbon dioxide as opposed to conversion by the methanogenic group of bacteria. A high activity of sulphate reducers may therefore decrease the organics available for methane production. Table 4.2 presents examples of occurring reactions. Figure 4-5 presents a flowsheet of the anaerobic decomposition of organic material.

Table 4.2: Examples of Important Reactions for Four Groups of Bacteria involved in Anaerobic Waste Degradation (source: Christensen et al, 1989).

Fermentative Processes

$C_6H_{12}O_6 + 2\,H_2O \rightarrow 2\,CH_3COOH + 4\,H_2 + 2\,CO_2$

$C_6H_{12}O_6 \rightarrow C_3H_7COOH + 2\,H_2 + 2\,CO_2$

$C_6H_{12}O_6 \rightarrow 2\,C_2H_5OH + 2\,CO_2$

Acetogenic Processes

$C_2H_5COOH + 2\,H_2O \rightarrow CH_3COOH + CO_2 + 3\,H_2$

$C_3H_7COOH + 2\,H_2O \rightarrow 2\,CH_3COOH + 2\,H_2$

$C_2H_5OH + H_2O \rightarrow CH_3COOH + 2\,H_2$

$C_6H_5COOH + 4\,H_2O \rightarrow 3\,CH_3COOH + H_2$

Methanogenic Processes

$4\,H_2 + CO_2 \rightarrow CH_4 + 2\,H_2O$

$CH_3COOH \rightarrow CH_4 + CO_2$

$HCOOH + 3\,H_2 \rightarrow CH_4 + 2\,H_2O$

$CH_3OH + H_2 \rightarrow CH_4 + H_2O$

Sulphate Reducing Processes

$4\,H_2 + SO_4^{2-} + H^+ \rightarrow HS^- + 4\,H_2O$

$CH_3COOH + SO_4^{2-} \rightarrow CO_2 + HS^- + HCO_3^- + H_2O$

$2\,C_3H_7COOH + SO_4^{2-} + H^+ \rightarrow 4\,CH_3COOH + HS^-$

$C_6H_{12}O_6$: glucose; CH_3COOH: acetic acid; H_2: hydrogen; CO_2: carbon dioxide; C_3H_7COOH: butyric acid; C_2H_5OH: ethanol; C_2H_5COOH: propionic acid; C_6H_5COOH: benzoic acid; CH_4: methane; $HCOOH$: formic acid; CH_3OH: methanol; SO_4^{2-}: sulphate; H^+: proton; HS^-: hydrogen sulphide; HCO_3^-: hydrogencarbonate;

The following abiotic factors affect methane formation in the landfill:

- **oxygen:** The absence of free oxygen is a necessary condition for the anaerobic bacteria to grow and perform the above mentioned processes. The methanogenic bacteria are the most sensitive to oxygen. However, in a landfill the aerobic zone is very small.
- **hydrogen:** Hydrogen is produced by both the fermentative and the acetogenic bacteria. At low hydrogen concentrations, acetic acid is formed while at high concentrations ethanol, butyric and propionic acid are generated. Further conversion by the acetogenic bacteria is only possible at low hydrogen concentrations. Hydrogen is consumed by the methanogenic and sulphate-reducing bacteria, even at very low hydrogen concentrations. If high hydrogen concentrations occur, the propionic and butyric acid concentrations will increase, resulting in a lowering of the pH.

- **pH and alkalinity:** The methanogenic bacteria operate only within a narrow pH range of 6 to 8. The pH range for fermentative and acetogenic bacteria is much wider. The methanogenic ecosystem in the landfill is rather delicate and balanced relations between the various bacteria groups are crucial for a good methane production rate. The presence of buffering material in landfill waste (soil, demolition waste) will improve the ability of the landfill environment to maintain a reasonable pH range. If sulphate is present in the waste, sulphate-reducing bacteria may, at low pH values, dominate the methanogenesis and convert the organics to carbon dioxide.
- **sulphate:** Both the sulphate-reducing bacteria and methanogenic bacteria convert acetic acid and hydrogen. When sulphate is present, the methane production is dramatically red uced. The suppression of methane formation by sulphate is not related to any toxic effects of sulphate on methanogenic bacteria but due to simple substrate competition. Sulphate and carbon dioxide are the principal electron acceptors in the degradation processes.
- **nutrients:** Apart from organic matter, the anaerobic ecosystem must have access to all required nutrients, in particular nitrogen and phosphorus. The anaerobic system assimilates only a very small part of the substrate into new cells and therefore requires much less N and P than the aerobic system. In most mixed waste landfills, the anaerobic ecosystem would not be limited by N and P, but insufficient homogenization of the waste may result in nutrient-limited environments. All the necessary micronutrients (Ca, Mg, K, Fe, Zn, Cu, Co, Mo, Se) are considered to be present in most landfills.
- **inhibitors:** In this paragraph the inhibitory effects of volatile fatty acids, carbon dioxide, cations and organic micropollutants will be discussed. In landfill environments, volatile acid concentrations rarely reach levels at which inhibitory effects on methane production are expected. Carbon dioxide significantly limits the removal rate of acetic acid. Cations stimulate the anaerobic ecosystem at low concentrations, while significant inhibition is observed at high concentrations. In landfill environments the cation concentrations are not high enough to inhibit the methane production. Specific organic compounds (organic micropollutants) may inhibit the anaerobic ecosystem, but fairly high concentrations are needed, occurring for example in landfills where significant loads of industrial chemicals or wastes are disposed of. The methanogenic group is the most susceptible to inhibition, but the acetogenic group may also be inhibited, for example, by chloroform.
- **temperature:** The anaerobic waste degradation rate is highly affected by temperature. The methanogenic bacteria contain a mesophilic group with a rate maximum at 40°C and a thermophilic group with a maximum around 70°C, but the latter are not relevant in landfills. In laboratory simulations the methane production rate has been proven to increase significantly (up to 100 times) when the temperature is raised from 20° to 40°C. Both the aerobic and anaerobic degradation of waste yields heat, although the anaerobic heat generation seldom results in a significant temperature rise. Anaerobic degradation of glucose only yields 7% of the heat generated by aerobic decomposition. Even in temperate climates, landfill temperatures of 30° - 45°C are possible if the waste layer is deep, the methane production is high and the water flux through the landfill is low.

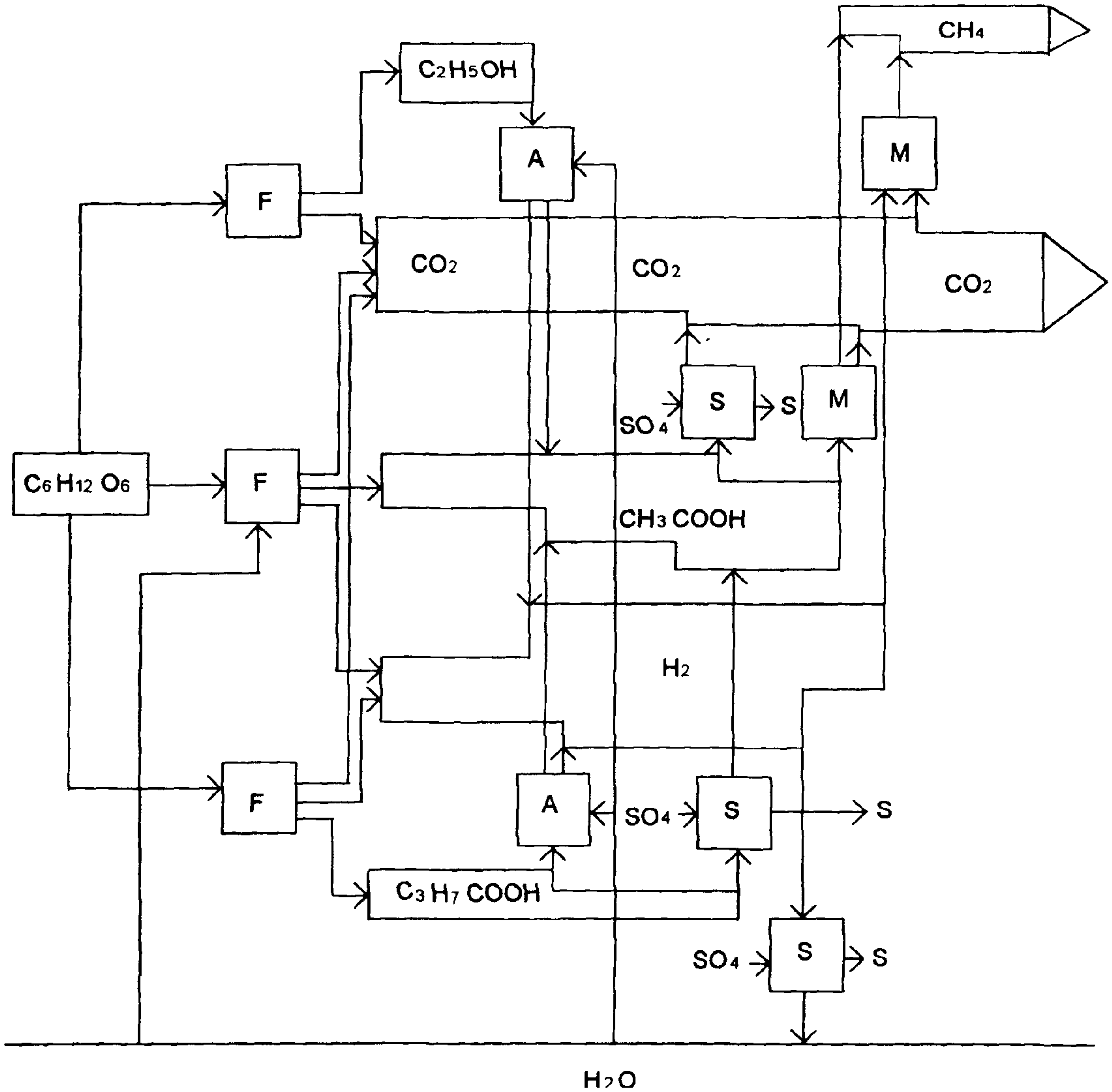


Figure 4-5: Flowsheet of Anaerobic Decomposition of Organic Matter: Fermentative (F), Acetogenic (A), Sulphate-reducing (S) and Methanogenic Bacteria (M)
(Source: Henry and Heinke, 1989)

- **moisture, water content:** The methane production rate increases by increasing moisture content of the waste. The main effect of the increased water content is probably the facilitated exchange of substrate, nutrients, buffer material, and dilution of inhibitors and spreading of microorganisms between the waste micro environments.

SAQ 4.1

The industrial waste of a particular factory has a very high sulphur content. What effects will this have on leachate and landfill gas?

SAQ 4.2

Give a generalized equation for the aerobic bacterial reactions by which organic matter in MSW is decomposed in a landfill.

The steps in the degradation process described above may occur in a certain sequence, governed by the redox conditions, with consequences for gas and leachate composition. Five phases can be distinguished:

Phase I: This is a short aerobic phase immediately after landfilling the waste, where easily degradable organic matter is aerobically decomposed (oxidized), resulting in carbon dioxide generation; the redox potential (Eh) starts to fall;

Phase II: In this first anaerobic phase, the activity of fermentative and subsequent acetogenic bacteria results in a rapid generation of volatile fatty acids, carbon dioxide and some hydrogen. The oxidation of the organic matter results in a further Eh drop. The leachate may contain high concentrations of fatty acids, calcium, iron, heavy metals and ammonia, the latter due to hydrolysis and in particular the fermentation of protein compounds.

Phase III: At the start of this phase, the Eh has decreased to a level where, in addition to oxidation of organic matter, reduction of organic matter and sulphur occurs. The existence of both oxidizing and reducing processes stabilizes the Eh, which remains at a constant level. Methanogenic bacteria convert the volatile acids to carbon dioxide and methane, while carbon dioxide is reduced to methane. The methane concentration in the gas increases, while hydrogen, carbon dioxide and fatty acid concentrations decrease. The conversion of fatty acids leads to a pH increase, resulting in a decreasing solubility of calcium, iron, mangenese and heavy metals. In this phase sulphate reduction processes also appear and heavy metals are precipitated as their sulphides. Ammonia is still being released and is not converted in the anaerobic environment.

Phase IV: The methane phase is characterized by a fairly stable methane production rate resulting in a methane concentration in the gas of 50-65% by volume. Low concentrations of fatty acids and hydrogen are maintained by the high rate of methane formation.

Phase V: Due to a growing lack of decomposable carbon in the landfill, the methane production rate will decrease, allowing oxygen and nitrogen to appear in the landfill due to diffusion from the atmosphere (if the protective layer is permeable). The Eh increases again.

Figure 4-6 presents the relationship between the mean oxidation state of carbon in the substrate and the amounts of carbon dioxide and methane generated during decomposition. Starting off with fats, proteins and carbohydrates, in phase II the movement along the line is to the right, as acetic acid and carbon dioxide are formed. In phase III and IV, the movements are to the opposite side as well: acetic acid is converted into both methane and carbon dioxide, carbon dioxide is partly converted into methane.

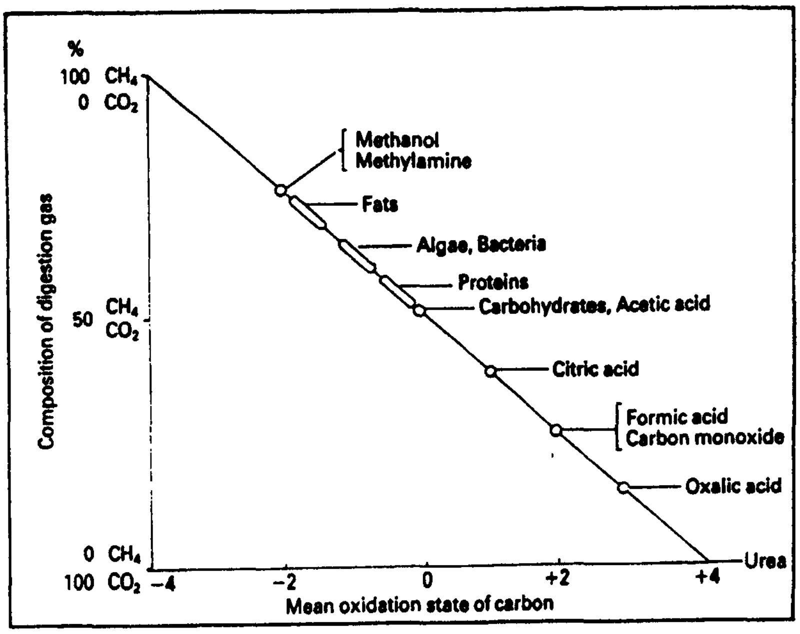


Figure 4-6: Relationship between different kinds of Organic Acids and the Methane Concentration (source: Christensen et al, 1989)

The idealized degradation sequence purposely presents no estimates of the duration of the phases involved, due to their dependence on the above-mentioned abiotic factors and local conditions. After the aerobic phase which lasts only for days, the time units applying to the other phases are months, years and decades. In the waste body (even in one waste cell), the acetogenic and methanogenic phases may occur simultaneously. Easily degradable waste is already producing methane, while more resistant waste (paper) is still being hydrolized and converted into acetic acid. Figure 4-7 illustrates the developments in gas and leachate composition in a landfill.

Recent Developments: Enhancement of Degradation

Enhancement of the degradation processes in landfills would result in a faster stabilization of the landfill and an enhanced gas production. The degradation may be enhanced in two ways:

1. the addition of partly composted waste;
2. recirculation of leachate.

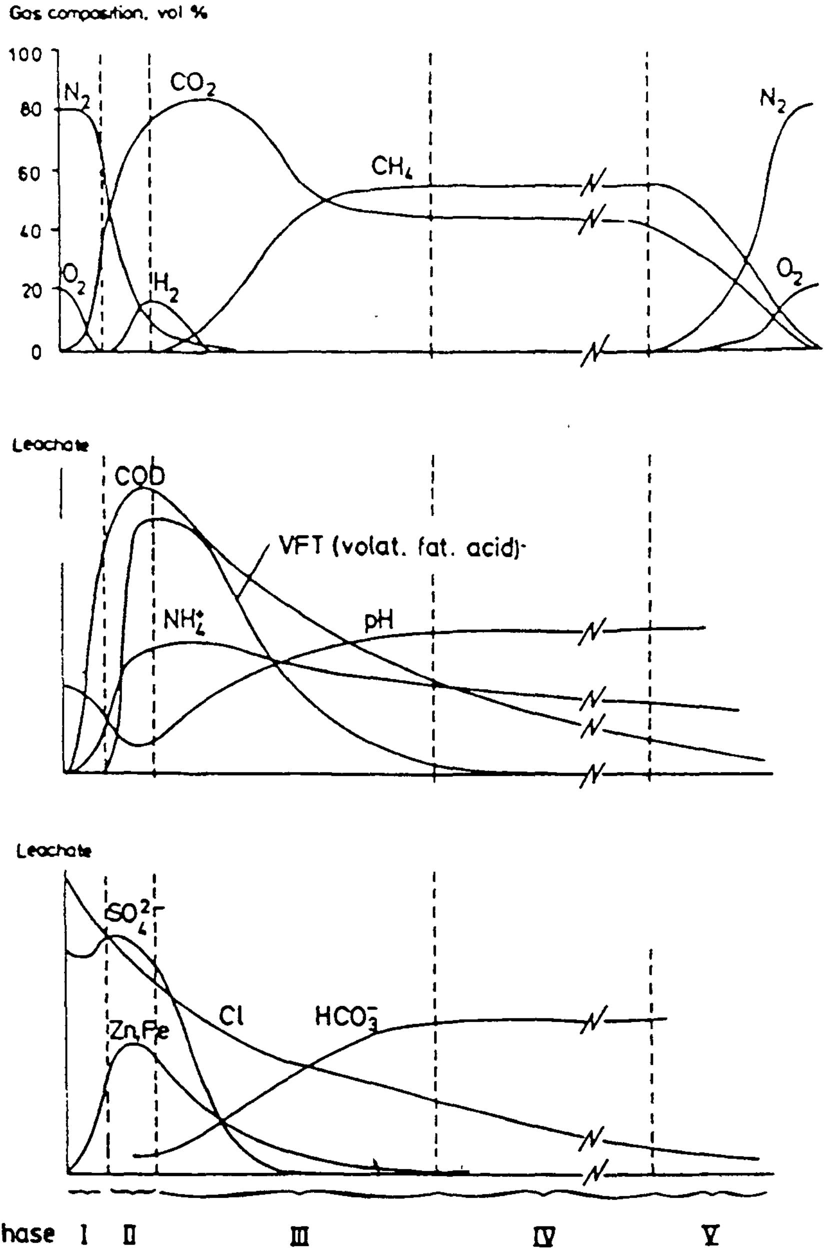


Figure 4-7: Illustration of Developments in Gas and Leachate Composition in a Landfill Cell (source: Christensen et al, 1989)

Partly Composted Waste Addition

The addition of partly composted waste may have different effects:

1. during composting, anaerobic processes also take place up to a certain degree, so that methanogenic bacteria may develop;
2. the readily degradable organics have already been decomposed aerobically, so the rapid acid production phase is overcome and the balance of acid and methane production bacteria can develop earlier;
3. a dilution effect lowers the organic acid concentrations.

Leachate Recirculation

In a moderate climate, leachate recirculation may have positive effects since:

1. the mean moisture content of waste is very low; therfore an increase is favourable;
2. a slow increase in moisture will cause a long period of gas production;
3. during warmer periods, recirculated leachate will evaporate, resulting in lower amounts of excess leachate.

Enhancement of aerobic processes can be achieved if landfills are operated with low compaction and the refuse is placed in thin layers without cover.

Under enhanced conditions, three distinct phases have been noted:

1. a lag phase before methane production starts;
2. a phase in which maximum production rates are established;
3. a phase where the methane production rate is controlled by solubilization of organic material.

Enhancement of methane production from waste is found to occur when leachate is recycled with additions of buffer (for proper pH control), nutrients (to shorten the lag phase) and microbial inoculum (to increase the rate of methane production). Excess sludge from wastewater treatment plants appears to be an excellent source of inoculum. Enhancement has a positive effect on the rate of methane production and the quality of the leachate produced.

Currently, these developments are being tested in pilot scale reactors. Within a few years, enhancement of degradation could be introduced and tested in newly made landfills.

Effects of Codisposal on Degradation Processes

Codisposal in a landfill is the controlled introduction of waste, even of a hazardous nature, into a municipal solid waste (MSW) landfill. This type of operation aims at reducing the danger of hazardous waste (HW) not by simply diluting it with municipal waste but also by taking advantage of attenuation mechanisms present in the landfill. These mechanisms induce immobilization or degradation of the toxic substances.

Co-disposal cannot be accepted indiscriminately for all types of toxic residues and the environmental situation of the area where the co-disposal landfill is to be located should always be carefully studied. The advantages and disadvantages of this practice are to be found inevitably in rules and regulations which must be respected in order to limit the danger of disposal.

The main problems linked to co-disposal may be summarized as follows:

1. The inhibiting effect on biological degradation of MSW due to the presence of toxic compounds in the codisposed HW;
2. The emission of toxic substances into leachate to a higher degree than that observed during disposal of MSW alone.

A number of attenuating phenomena influence the mobility of each substance:

- physical and chemico-physical phenomena: adsorption, filtration and dispersion;
- chemical phenomena: acid-base interaction, oxidization, precipitation, co-precipitation, ionic exchange, complex formation;
- biological phenomena: microbic, aerobic and anaerobic degradation.

A knowledge of the composition of the hazardous waste content which is to be codisposed with MSW helps to avoid some undesired reactions which may occur when incompatible wastes are mixed: generation of heat due to exothermic reactions (flame or explosion danger), generation of toxic gases such as arsine, cyanide, sulphuric acid, inflammable gas such as hydrogen, acetylene. Figure 4-8 schematizes undesired reactions caused when mixing the more common types of hazardous wastes.

1	Oxidising Mineral Acids	1											
2	Caustics	H	2										
3	Aromatic Hydrocarbons	H F		3									
4	Halogenated Organics	H F GT	H GF		4								
5	Metals	GF H F			H F	5							
6	Toxic Metals	S	S				6						
7	Sat Aliphatic Hydrocarbons	H F						7					
8	Phenols and Cresols	H F							8				
9	Strong Oxidising Agents		H	H F		H F		H		9			
10	Strong Reducing Agents	H F GT			H GT				GF H	H F E	10		
11	Water and Mixtures containing Water	H			H E		S				GF GT	11	
12	Water Reactive Substances	← Extremely reactive, do not mix with any chemical or waste material →											12

E	Explosive
F	Fire
GF	Flammable Gas
GT	Toxic Gas
H	Heat Generation
S	Solubilisation of Toxins

Figure 4-8: Schematic Summary of Undesired Reactions caused when mixing the more Common Types of Hazardous Waste (source: U.K. department of the environment, 1986)

A summary of the advantages and disadvantages of co-disposal of important waste streams follows:

arsenic waste: Under reducing conditions, a precipitation of As is obtained in the form of sulphide with a coprecipitation of ironsulphide, resulting in an attenuation factor of 10. It is necessary to control the amount of As loss in the form of arsine gas.

mercury bearing waste: Hg is reduced to sulphide in the layers of aged waste and will remain insoluble in this form in the solid matrix. A loss of mercury to the gas phase is possible. Organic mercury is more toxic, so that the permitted organic mercury waste load is much lower.

heavy metal waste: Under strict reducing conditions and a pH which is neutral and with a relatively low organic load, codisposal of heavy metal waste is allowed, since heavy metals are sufficiently immobilized. However, the amount of codisposable waste is limited by the influences of metal toxicity on the anaerobic ecosystem.

acid wastes: These wastes are unsuitable for codisposal with fresh municipal waste, due to the capacity to reduce pH values. This waste also increases heavy metal concentrations in leachate. Codisposal of small amounts of acid waste on aged waste however, can be allowed.

oil-based wastes: Waste matter possesses a considerable capacity for retaining oils. However, in the long term, the heavier and persistent fractions will create problems in management of sanitary landfills. The quantity of polar and slightly polar hydrocarbons in leachate can be lower than those observed in MSW landfills alone.

phenolic wastes: Attenuation in the phenol concentrations in leachate from a codisposal site may be explained by the absorption phenomena capable of delaying and therefore increasing the period of phenol presence inside the landfill. This permits anaerobic microorganisms to acclimatize resulting in their capability to degrade the phenolic compounds into methane and carbon dioxide. Codisposal of phenolic sludges even accelerate the anaerobic degradation rate.

wastes with particular organic compounds: Landfilling of wastes with a low degradability such as pesticides, PCB solvents and other hydrocarbon compounds, is not generally advised. Solvents such as benzene, toluene and xylene do accelerate the anaerobic decomposition. Insoluble or easily degradable solvents could be landfilled.

domestic sludges: The addition of sludges from wastewater treatment plants has already been advised as a method for improving sanitary landfill management. Methane production increases, and the solubilization of heavy metals decreases, due to the speedier onset of reducing conditions. If problems occur due to the high moisture content, mixing of sludge with ashes from power plants could be considered.

combustion residues: Residues from coal-fired power plants and incinerators contain a considerable amount of heavy metals. In addition to the indications previously mentioned (see heavy metal waste) two further factors contribute towards a positive decision regarding disposal:

1. the biostabilization processes in the waste are accelerated;
2. ashes have a high absorption capacity, inducing further attenuation of metal load in the leachate.

The lower permeability of combustion residues, however, may reduce the degree of leachate infiltration, thus causing an increase in time needed to reach total waste stability.

Co-disposal System

Hazardous wastes can be present in the form of liquids, sludges, solids and dusts and for each of these wastes a correct approach to co-disposal should be determined. With regard to liquid wastes, less compacted areas should be identified in order to facilitate the absorption of the waste. Liquid wastes are usually stored in a tank near the site and can be introduced into the landfill by means of trenches or lagoons, injection or irrigation. Sludges are also placed in trenches. During disposal of ligthweight wastes the disposal area must be kept wet to prevent dust emissions. Solid waste characterized by a high degree of impermeability must not be disposed over large areas. Figure 4-9 illustrates a co-disposal landfill site.

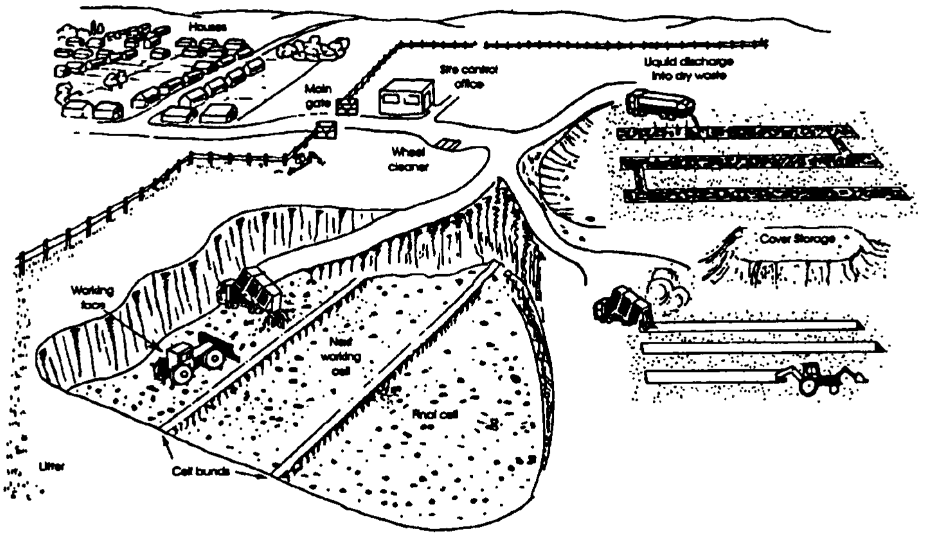


Figure 4-9: Typical Co-disposal Landfill Site (source: Batstone, 1989)

4.4 DESIGN, CONSTRUCTION AND MONITORING OF SANITARY LANDFILLS

This section deals with the engineering aspects of sanitary landfills, namely the design and construction of environmentally sound landfill sites. A description is first given of the environmental measures to be taken. Next, the landfill operation practices and necessary site infrastructure will be examined. Finally, since post-operational care (aftercare) will be needed for many years, monitoring systems will be described.

4.4.1 Environmental Considerations

As described in Section 4.1, the most serious environmental impacts result from the formation of landfill leachate and gas. The amount of leachate depends mainly on climatological conditions, its source being rainwater, while the source of landfill gas is the landfill itself.

In dry climates, only small amounts of leachate are produced. Most precipitation evaporates before it reaches the subsoil. In moderate and wet climates, precipitation exceeds evapotranspiration resulting in the production of larger amounts of leachate.

After completion, a landfill must be secured from the environment. However, in practice the protection level of the environment surrounding a landfill may vary according to the economic situation and climatological circumstances. Four levels may be distinguished:

Level 0

At this level, the environment is not protected at all. Waste is dumped into natural depressions or in excavations. Surface water or groundwater may have direct contact with leachate and waste, and will surely be polluted.

Level 1

The first improvement is made by choosing a site having a soil layer of low permeability well above the groundwater level. The wastes are covered with low permeablity soil. Scavenging is possible only for a limited time, before the waste is covered. In this case, the amount of leachate produced is lowered while attenuation mechanisms both in the waste body and in the bottom layer reduce the amount of pollutants emitted. In dry or moderate climates this kind of landfill is acceptable if the economic situation is poor. However, attention should be paid to migration of landfill gas.

Level 2

The level 1 landfill may be improved by constructing a leachate collection system and reducing the permeability of the bottom protective layer. This system collects and transports most of the produced leachate out of the landfill, where it may be treated in aerated lagoons. Further reduction of the amounts of leachate is possible by decreasing the permeability of the soil cover. However, a landfill gas collection system is necessary to facilitate gas migration out of the landfill. The waste disposed of is `covered with soil at the end of the day . Scavenging is not permitted. The level 2 landfill is far more expensive to build and requires construction and operating personnel with special skills. In order to secure proper functioning of the leachate and gas collection systems, a maintainance programme must be implemented.

Level 3

The permeability of bottom and top layers may be further reduced by utilization of synthetic liner materials in combination with low permeability soils. If the top layer of the completed landfill is impermeable, the production of leachate will eventually come to an end. Monitoring systems have to be installed to secure proper functioning of the protective measures as long as leachate is produced; sometimes the construction of a leak detection system may be advisable. Landfill gas should be utilized or flared and leachate treated in advanced facilities. The level 3 landfill is the most sophisticated one, but this kind of landfill may be too expensive and complex for some developing countries at this time.

In Section 4.2, a distinction was made between the environmental problems during the operational phase and completed phase. In the **level 0** approach, this distinction can hardly be justified, since nothing happens with the waste after tipping. In the **level 1** approach, the operational phase may take a few years. During this phase the waste is not sufficiently covered to substantially reduce the infiltration of rainwater into the waste. However, the bottom protective layer is already present and functioning. In **level 2 and 3** landfills, the operational phase lasts longer, sometimes up to 20 years. During this period the final cover may be locally absent, but the bottom protective layer and leachate collection system still function. After completion of the landfill, the amount of leachate decreases.

In industrialized countries, guidelines and regulations are formulated in order to guarantee the construction of environmentally sound sanitary landfills. For instance in the Netherlands, these provisions are laid down in the guideline 'Controlled tipping', issued in 1985. The basic elements of the policy involve:

1. the avoidance of contact between waste and soil, groundwater and surface water;
2. the prevention of polluted water dispersion into the soil;
3. the degree of control of the landfill operation;
4. the regular checking of the effectiveness of the provisions.

These elements are based on the so-called ICC-criteria (Isolate, Control and Check). The ICC-creteria are environmental protection criteria commonly applied to soil remediation problems. The provisions according to all items are to be installed during landfill construction.

4.4.2 Design of Liner and Drainage Systems

Liner Systems

The liner system in a landfill is the main line of defence against external migration of leachate and methane gas. A liner system may consist of synthetic as well as soil (clay) material or a combination of both. It must fulfil the following criteria:

1. **efficiency:** The efficiency refers to the ability to resist the seepage of leachate generated within the landfill. A commonly used performance requirement is to maintain less than 0.3m of leachate head on the liner.
2. **damage resistance:** Damage is most likely to occur during construction and operation of the landfill. Synthetic liners are easily damaged; clay barriers however have much better resistance to damage and possess self-healing properties.
3. **long-term performance:** Criteria for determining long-term performance are permeability, leakage resistance and chemical resistance. The permeability is often the most important factor in determining long-term performance.
4. **availability:** The availability of materials will impact liner design and planned performance. Soil bentonite mixtures, asphalt and soil cement are a few examples of fabricated materials that have been used for low permeability barriers.

Permeability of Liner Materials

Synthetic liner materials have very low permeability of 10^{-12} to 10^{-14} m/s. The permeability of soils will vary greatly. Typical conductivity of clays will range from 10^{-7} to 10^{-11} m/s. The permeability will determine the breakthrough and leachate rate of a clay liner. Breakthrough time can be estimated by the following equation (Darcy's law is assumed to be valid):

$$t = d^2.n / (k.d + k.h)$$

where:

t = breakthrough time in years
d = liner thickness in meters
h = hydraulic head in meters
k = permeability in m/year
n = effective porosity

Permeability of Clay Liners

In clay liners with a low permeabiliy (often less than 10^{-8} m/s) the pore water is bound by the clay particles. In swelling clay soils, for instance, negatively charged clay particles are surrounded by a diffuse double layer where positively charged cations are accumulated. Since water molecules act as dipoles, they are electrically bound in these diffuse double layers. In soils with a large amount of swelling clay materials the water molecules are bound so strongly that the hydraulic gradient needs to be quite high before all water molecules move freely and the flow obeys Darcy's law. At low gradients there may be no flow at all because the hydraulic gradient cannot overcome the binding forces. Darcy's formula now yields:

$$v = k \, . \, (i - i_0)$$

where:

v = filter velocity (m/s)
k = hydraulic conductivity in the linear range (m/s)
i = hydraulic gradient (-)
i_0 = start gradient for the linear (Darcyan) relation (-)

Most clay and silt materials are not appropriate for the construction of surface caps. The hydraulic conductivity of these materials is often too high. In situ clay layers may have a lower conductivity but for surface capping the clay has to be excavated and compacted again at the waste disposal site. With such disturbed soil it is almost impossible to re-establish the original degree of high compaction and low conductivity. In the Netherlands, regulations prescribe that the infiltration of rainwater through a surface cap should be less than 50 mm/year. The permeability of clay liners should be less than 5 x 10^{-10} m/s to fulfil this criterion.

Hydraulic conductivity values below 5 x 10^{-10} m/s can be realized quite well with bentonite, a pure clay consisting of the clay mineral montmorillonite. It is available in powder form and can be mixed with soil. Bentonite liners used for surface capping proved to be completely impermeable over a 3.5 year period in spite of large settlements. The bentonite content should be at least 5% (by weight), with a layer thickness of at least 15-20 cm. For bottom liners, higher bentonite contents are recommended as bentonite liners are more permeable for contaminated leachate than for clean (rain)water.

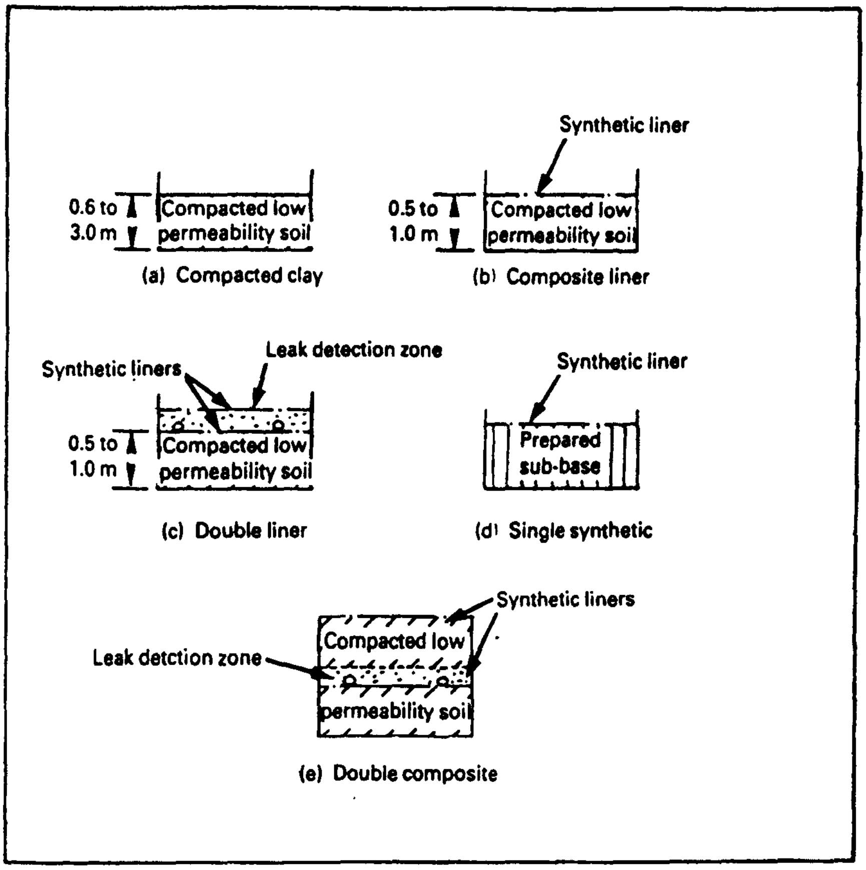
Apart from bentonite, other clay soils may also contain swelling clay minerals. A special Tertiary clay, found in The Netherlands, was used at a waste disposal site. Laboratory studies showed that the non-Darcy behaviour is of utmost importance here. The i_0 was about 40. In practice, it meant that no leakage of leachate would occur through this clay liner.

Long-term Resistance

The selection of the synthetic liner materials should be based on the waste stream expected for the facility. Common chemical constituents may have effects on synthetic liners. High density polyethylene (HDPE) material shows a high degree of resistance to most chemical constituents. The effect of leachate from solid waste landfills and hazardous waste landfills was tested by several investigators. The results show a steady or decreasing k-value with time for soil liners. Other physical properties of liner systems remain unchanged when exposed to leachate. Only when concentrated chemicals (e.g. acids) are concerned do k-values tend to increase.

Liner systems

Figure 4-10 shows several liner systems commonly used for landfills. Figure 4-10a presents a single clay liner. This liner design is used where a substantial thickness of natural low permeability soil is located beneath the landfill. The examples presented in fig. 4-10c;d rely principally on the synthetic liners as a hydraulic barrier. These designs are commonly used where low permeability soils are not available. A double liner with a leak detection/collection system is normally preferred because of the ability to collect leachate that may penetrate the primary liner. Composite and double composite designs (Fig. 4-10b;e) are suggested when vulnerable site conditions exist. The composite liner system provides long breakthrough time, low leakage rates and can withstand substantial damage without total failure of the liner system. However, these liners are costly and time consuming to build. In Figure 4-11, the latest double liner systems, as regulated in the U.S.A. are shown.



(a) Compacted clay

(b) Composite liner

(c) Double liner

(d) Single synthetic

(e) Double composite

Figure 4-10: Examples of different liner systems used in the U.S.A. (source: Christensen et al, 1989)

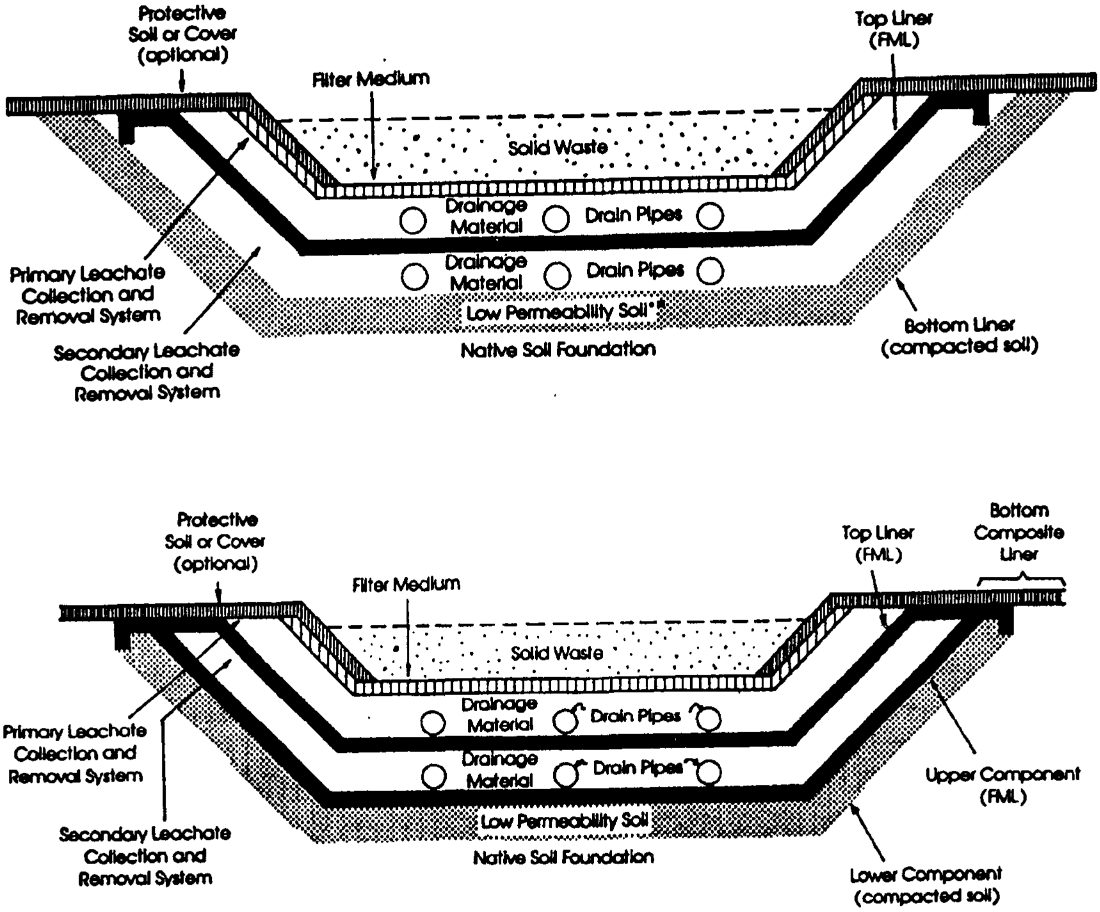


Figure 4-11: Schematic diagram of two double liner systems for a landfill (source: U.S. Environmental Protection Agency, 1990)

Liner Construction

The liner system must not only be designed properly, but must also be properly constructed. Synthetic liners must be free of holes, rips and punctures; seams must be securely welded to obtain strong, leak-resistant joints. A soil liner must be free of discontinuities such as poorly bonded lifts, voids and poorly compacted zones. The soil moisture/density relationship is critical to proper liner construction. As the soil moisture content decreases, more compaction effort will be required to eliminate discontinuities. Soil will become brittle and non-plastic when the moisture content is below the plastic limit and will be difficult to compact.

Contaminant Transport Through Clay Liners

In the preceding sections, only the water transport of pollutants is taken into consideration. In general, the contaminants are transported by water (advective transport), but even if water transport is non-existent, contaminant transport is possible through molecular diffusion. Diffusion is a process in which solutes in a solution seem to flow in response to a gradient of concentration due to the irregular movement of the solutes caused by the Brownian motion. Transport of contaminants by diffusion is only important if high concentration gradients occur and the advective transport is negligible. Contaminants may migrate more slowly than the transporting solution for a variety of reasons. Some of the causes of contaminant attenuation in soil include ion exchange, precipitation and biological reactions. A retardation coefficient may be calculated from the following relationship:

$$R = 1 + (\rho.Kp)/n$$

where:

R = retardation factor
ρ = dry bulk density (kg/m^3)
Kp = partition coefficient (m^3/kg)
n = effective porosity

The partition coefficient relates mass of solute sorbed per mass of soil to the concentration of the solute in solution in the expression:

$$Kp = \frac{\text{contaminant concentration attached to particulate matter (kg / kg)}}{\text{contaminant concentration in solubilized form (kg / m}^3\text{)}}$$

The partition coefficient is not a constant, but depends upon physical and chemical conditions. In general, Kp decreases with increasing concentration. For practical reasons and in cases when relatively low concentrations are concerned, the Kp is assumed to be independent of the solute concentration. In the literature, a wide range of values for specific substances is reported. Kp values << 1 indicate almost no attenuation. The breakthrough time of a contaminant can be calculated by dividing the water breakthrough time by the retardation coefficient R.

Comparison of Clays and Geomembranes

An interesting question is how the performance of geomembrane liners compare to clay liners. Table 4.3 presents data on a comparison test performed. Calculations of the breakthrough time showed that the breakthrough time for geomembranes is exceedingly fast when compared with that of the clay liner. This difference results even though the geomembrane has a hydraulic conductivity which is five orders of magnitude less than the clay and an effective diffusion coefficient which is about four orders of magnitude less. The reason for this difference is the relative thickness of the two liners, and not the relative transport properties.

Table 4.3: Comparison of a synthetic and natural liner system (source: Christensen et al, 1989)

Property	**Geomembrane**	**Clay**
porosiity	0.1	0.5
hydraulic conductivity, k(m/s)	1×10^{-14}	1×10^{-9}
diffusion coefficient, D(m^2./s)	3×10^{-14}	2×10^{-10}
thickness (m)	0.0015	0.9
hydraulic gradient	100	1.16

SAQ 4.3

Do contaminants in soil move as fast as groundwater? Explain your answer.

Leachate Collection Systems

A leachate collection system has to collect leachate and discharge it at defined sites outside the landfill (e.g. in a treatment facility) thus avoiding leachate build up at the landfill bottom. The build up of leachate could lead to the following problems:

1. high water tables in the landfill would result in a more intensive leaching and consequently higher concentrations of pollutants in the leachate;
2. an increase of the hydrostatic pressure head above the bottom liner, leading to higher leachate emissions through low permeable liner systems;
3. the stability of the landfill may be affected;
4. leachate may migrate out of the landfill on to the slopes.

A leachate collection system basically consists of a drainage layer of inert material with a high permeability and of drain pipes which have to collect the leachate and discharge it outside the landfill mound.

In flat areas the cross slope between the drain pipes and drain spacing have to be properly designed. The landfill bottom is convex with a minimum cross fall of 1%. The drain pipes are placed at the low points. This is necessary in order to transport the water to the drain pipes. The drains should be spaced at 50 m intervals. Split gravel trenches, suitable for a drainage layer of fine material should be placed at a distance of 15-20 m and should have a minimum width of 2 m. Figure 4-12 proposes a design of a leachate collection system.

Drainage Layer Material

Material with a high water conductivity, e.g. coarse gravel with a particle size ranging from 16-32 mm is recommended for the drainage layer. The gradation distribution has to be such as to restrain siltation of the drainage layer and of the drain slots of the drain pipes. A smaller grain size would increase the risk of clogging. The grains must not enter into the drain pipes. The drainage layer material must be resistant to landfill leachate and gas. Carbonate rocks as well as calcitic sandstones are totally unsuitable. Natural river gravel is generally appropriate.

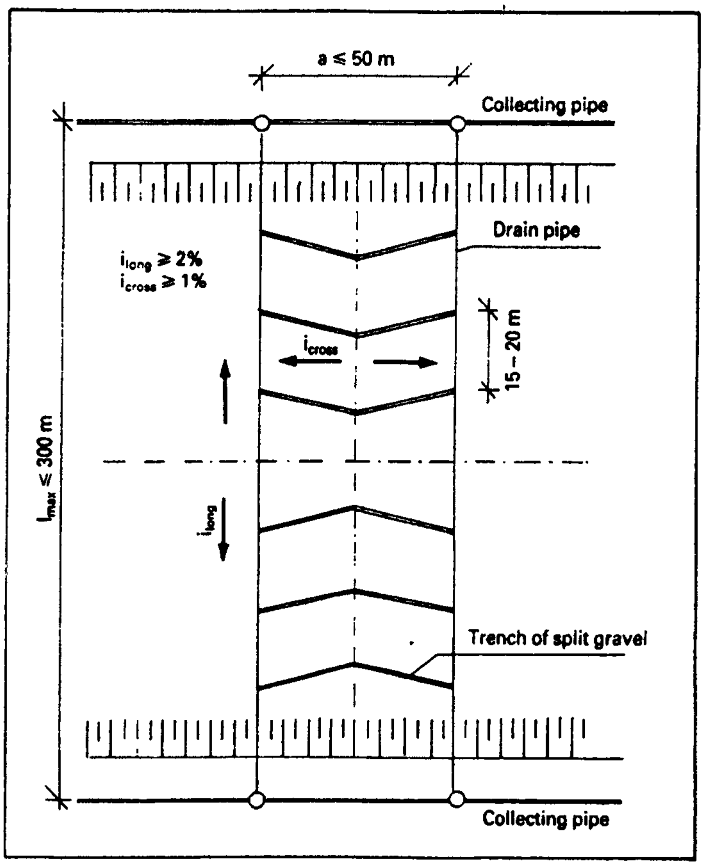


Figure 4-12: The Design of a Leachate Collection System (source: Christensen et al, 1989)

Drain Pipes

Pipes with holes or slots are used as drain pipes. When choosing the pipes and designing the leachate collection system it is important to bear in mind the necessity for inspection and maintenance of the drain pipes. Consequently, the pipes should be installed in a straight line in plan and longitudinal section. The minimum diameter of the pipes should be 200 mm in order to allow inspection by TV cameras and maintenance by high pressure flushing equipment. The distance between successive manholes should not exceed 300 m. The minimum slope of the drain pipes should be 2% in order to obtain a sufficiently rapid flow and, especially in the case of a low volume of leachate, to avoid sedimentation of particles washed into the pipe. The effect of settlement of the subsoil caused by the pressure of the landfill mound should also be considered, possibly needing even steeper slopes. The drain slots must be as wide as possible in order to avoid clogging due to precipitation of leachate constituents. The ultimate size of slots depends on the gradation of the drainage layer material. The smallest particle from the drainage layer must not pass the drain slots. The drain pipe materials have to be resistant to leachate contaminants and landfill gas. If a synthetic liner is applied, the liner should be protected from the gravel by a thin soil layer.

Manholes

Manholes must be installed both at the beginning and the end of a drain pipe. They should not be installed inside the landfill. Pipes entering the manhole should be provided with a water seal to avoid the access of air into the drainpipes.

Failures of the Leachate Collection Systems

Changes in physico-chemical and biological conditions within the leachate collection system may lead to clogging of drainage material and drain pipes, resulting in a dramatically decreased discharge capacity of the system. The precipitation of carbonate and iron, caused either biochemically or by air intrusion, is particularly critical. Acetogenic leachate may lead to more calcium carbonate and iron incrustation than methanogenic leachate. However, it is very difficult to ascertain the exact causes for siltation and incrustations in leachate collection systems. The clogging phenomenon is taken into account when determining the above mentioned design criteria.

Operation and Maintenance

The drain pipes have to be controlled by TV cameras immediately after emplacement of the first waste lift. Mechanical failure caused by compacting machines can be repaired without too many problems at this stage. It has been observed that deposits can easily be removed in the initial phase by means of flushing equipment. After concretion of clogging material, the incrustations cannot be dissolved from the pipe. It is important therefore to commence regular flushing of the leachate collection system as soon as possible.

SAQ 4.4

Why is it necessary to install a collection system for leachates?

4.4.3 Design and Construction of the Landfill

A working plan for the landfill will have been agreed between the operator and the licensing authority. The disposal licence will stipulate that, prior to any waste deposits, the designs, works and procedures in the working plan must be implemented. The preparations needed at a site before waste can be deposited may be considered under two headings:

- **site infrastructure**, that is the position of the buildings, roads and facilities that are necessary to the efficient running of the site;
- **site engineering**, the basic engineering works needed to shape the site for the reception of wastes and, generally, to meet the technical requirements of the working plan.

Site Infrastructure

Access to the landfill site should to be provided. The appearance of the **site entrance** is a major influence on how a landfill site is perceived by the public.

The size, type and number of **buildings** required at a landfill depends on factors such as the level of waste input, the expected life of the site and environmental factors. Depending on the size and complexity of the landfill, buildings will range from single portable cabins to purpose built complexes. However, certain features are common and should be borne in mind:

1. the need to comply with planning, building, fire and health and safety regulations and controls;
2. security and resistance to vandalism;
3. durability in service and the possible need to relocate accommodation during the lifetime of the site operations;
4. ease of cleaning and maintenance;
5. the availability of services such as electricity, water, drainage and telephone.

All landfill operators need to control and keep records of vehicles entering and leaving a landfill site. A **site control office** is needed to achieve this. At small sites a combined site control office and accomodation unit will usually suffice. At the site a **weighbridge** should be installed to record waste input data.

Vehicles leaving the landfill site could carry mud and debris onto the highway. **Wheel cleaning devices** may be installed to overcome this problem.

It is important that adequate information on the operation and regulation of a landfill is displayed at a site. At the site entrance a **notice board** should be provided, to give users and other interested parties necessary information (site name, site operator's data, opening hours etc.).

Except where a landfill site has a distinctive and effective natural barrier, adequate **security fencing** should be provided to prevent unauthorized access to landfill sites. Areas in which chemicals or valuable equipment are stored may also require fencing. **Litter fencing** is essential for controlling the dispersion of litter. High litter fences are usually erected around a large area of the site where several months of landfilling may take place in an exposed location. Low litter fences are erected adjacent to landfilling operations and are moved or extended on a day to day basis.

Site Engineering

Earthworks

The working plan may require extensive earthworks to be carried out before deposition of the waste can take place; this is particularly so, if artificial liners are to be installed. Such works may involve grading the base (including construction of 2%-slopes to drain leachate to the collection areas) or sides of the site and the formation of embankments. Material may also have to be placed in stock-piles for later use at the site. All such operations will require the use of earth moving machinery. Various features of landfill operations may require substantial earthworks: the cell method of operation requires the construction of cell walls. At some sites it may be necessary to construct earth banks around the site perimeter to screen the landfill operations from the public. Trees or shrubs may then be planted on the banks to enhance the screening effect. The construction of roads also involves earthworks.

Lining Landfill Sites

Where the use of a liner is envisaged, the suitability of a site for lining will have been evaluated at the site investigation stage. Liners should not be installed until the site has been properly prepared. The engineering required for the installation of liners at landfill sites is a technical and complex measure which should be entrusted only to competent specialists. The area to be lined should be free of objects likely to cause physical damage to the liner, such as vegetation and hard rocks. If synthetic liner materials are used, a blinding layer of suitable fine-grained material should be laid to support the liner. However, if the supporting layer consists of low permeable material (clay), the synthetic liner must be placed on top of this layer. A layer of similar fine grained material (thickness 25-30 cm) should also be laid above the liner to protect it from subsequent mechanical and environmental damage. Where synthetic liners are used, an 'anchor trench' around the periphery of the site to which the liner can be secured is usually required.

If a leak detection system is used, the leak drainage system must be placed on the first liner. Above the drainage layer, the second liner (the one that separates the leachate from the subsoil) is installed and covered with fine grained material.

Techniques for installing synthetic liners are well developed but remain highly specialized; improper installation remains the primary reason for failure of a synthetic liner.

During the early phase of operation, particular care should be taken to ensure that traffic does not damage the liner. Care should also be taken in placing the first lift of refuse; the build up of water and leachate should also be controlled. Where a drainage system has been installed above the liner, pipes should be cleaned out after the first lift of refuse. Subsequently, annual pipe cleaning is recommended.

The performance of a liner should be closely followed by monitoring the quality of groundwater close to the site. However, in the event of a leak occurring, pinpointing its origin and repairing the damage is almost impossible.

Preparation for Leachate and Landfill Gas Management

The basic elements of the leachate collection system (drain pipes, drainage layers, collection pipes, sumps etc.) must be installed immediately above the liner, before any waste is deposited. Particular care must be taken to prevent the drain and collection pipes from settling. During landfill operations, waste cells are covered with soil to avoid additional contact between waste and the environment. The soil layers have to be sufficiently permeable to allow downward leachate transport.

Landfill gas is not extracted before completion (including construction of final cover) of the waste body. Extraction wells (diameter 0.3 to 1.0 m) may be constructed during or after operation. If the wells are constructed during operation, they consist of elements which are placed on top of each other (progressive installation). The first element is installed before any waste is deposited. When a new waste cell is constructed, the extraction well is enlarged by one element, until the final height of the waste body is reached. If wells are to be constructed after completion, the wells have to be drilled almost to the base of the waste body. The well pipe (gas collection pipe) will be inserted into the extraction well after the final height is reached.

After completion of the site engineering works, waste can be tipped. Movement of soil will be necessary to enlarge the site embankments and to construct the soil layers between waste cells. After completion of the tipping activities, earthworks will be necessary to construct the final cover and prepare the site for future use.

Landfill Capping

A primary aim of restoration is to control and minimize leachate generation by minimizing water ingress into the landfill. This can be achieved by installing a low permeability cap over the whole site. Capping may also be used to facilitate landfill gas control or collection. A cap may consist of natural (clay) or synthetic (poly-ethylene) material. The thickness of a clay cap has to be at least 1 m. Uneven settlement of the waste may be a major cause of cap failure. Where large amounts of settlement are inevitable, it may be adviseable to delay placement of a permanent cap. In such circumstances temporary capping should be provided to minimize water ingress.

To assist in maintaining its integrity, a cap should be protected on both its upper and lower surfaces. Accordingly, before a cap is placed, the surface of the deposited waste should be graded and any irregular objects removed. In providing a firm base to allow compaction of the cap and to minimize damage from below, a buffer layer should be installed. Where a synthetic material is to be used for capping, a buffer layer at least 0.5 m thick is usually required. Inert material, which does not react with the waste or cap, may be used as a buffer provided that it is free from large stones and lumps. A mixture of coarse and fine gravel may be suitable. Designs for capping should include consideration of leachate and landfill gas collection wells or vents. The buffer layer may allow lateral gas movement below the cap.

For the cap to remain effective it must be protected from agricultural machinery, drying and cracking, plant root penetration, burrowing animals and erosion. An appropriate thickness of soil cover material is therefore necessary. The required cap cover depth depends on the intended post-operational use. In general, the cap cover layer must be at least 1 m thick. Percolation by rainfall through the soil cover will cause the water content of the soil above a low permeability cap to rise and eventually exceed its field capacity. If soil permeability or cap slope is not sufficient, the soil will be saturated and will form perched water tables, causing increased water infiltration into the landfill cap or damage to the cap construction. Therefore the cap should be constructed with a reasonable slope angle (> 4%) and the soil cover should be sufficiently drainable. Sometimes a sandy drainage layer between cap and soil cover has to be installed. A piped drainage system, when necessary, should be covered by at least 0.6 m of soil. Figure 4-13 shows a landfill cap design, based on the Austrian guidelines for sanitary landfills.

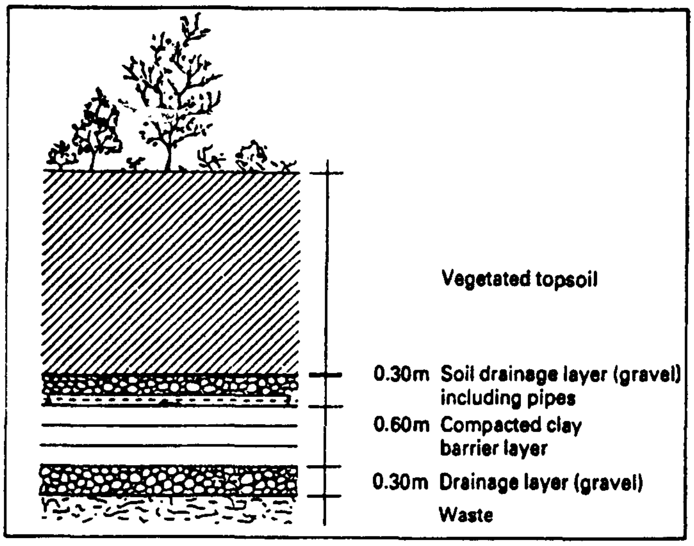


Figure 4-13: Landfill capping to keep out moisture (source: Christensen et al, 1989)

4.4.4 Operation of a Landfill

Daily Routines

All landfill operations require careful planning in advance of the first deposit of waste. The main features of the proposed operations will have been set out in the site operational plan which forms part of the working plan. How a landfill is operated determines to a large extent the environmental effects, and hence the public acceptability, of the operation.

One basic factor influencing the planning of site operations is the nature and quantity of incoming waste. The type of filling operations to be undertaken will be influenced by whether the waste is crude or pulverised or baled, household or commercial or industrial, alone or mixed. This in turn will affect the use of machinery required and also the use of cover material and litter control. The application of cover material during or at the end of a working day is an essential part of landfill practice. The type of cover material used and its availability are important aspects when considering how the site will be operated.

Following its collection, household waste will usually be taken directly to a landfill.

Method of Filling

Three variations in landfilling techniques can be distinguished:

1. **trench method:** This involves the excavation of a trench into which waste is deposited. The excavated material is then used as cover;
2. **area method:** Waste may be deposited in layers and so form terraces over the available area. However, with this type of operation, excessive leachate generation may occur. Operational control is difficult;

3. **cell method:** This method involves the deposition of waste within pre-constructed bunded areas. It is now the preferred method in the industrialized world since it encourages the concept of progressive filling and restoration.

The Cell Method

Daily cells are often constructed within a larger cell. At a shallow site it is preferable to place one daily cell on top of another so that the larger cell is brought up to final level before moving to the next larger cell, thereby assuring progressive restoration. Operating a cellular method of filling enables waste to be deposited in a tidy manner since the bunds serve to both conceal the tipping operation and at the same time trap much of the litter which may be generated. When a cell is brought up to its final level, it can be capped. Some void space may be lost due to building the cell walls. This drawback may be overcome in two ways: by utilizing suitable incoming wastes for wall construction or by removing the wall at the end of the day and using the material as cover. Cell walls should be at least 2-3 m higher than the heigth of the daily lift.

By careful design and operational management it is possible to ensure that the water retention capacity of the deposited waste is not exceeded in order to minimize the generation of leachate.

Refuse Placement

The working face should be sufficiently extensive to permit vehicles to manoeuvre and unload quickly and safely without impeding refuse spreading and compaction and allow site equipment to be operated easily.

Pushing waste over a vertical face is not acceptable. It should be deposited at the top or base of a shallow sloping working face. Machines may then be used to push the waste up or down the slope. The method predominant in the UK, for example, is to deposit waste from the top of a working face; a high degree of compaction can then be achieved, provided that the operator spreads the waste thinly. Conversely, waste may be deposited at the base of a working face and be pushed up the slope in thin layers. When the waste is being discharged from vehicles at a lower level than the remainder of the site, windblown litter is less likely to occur. The slope of a working face should be easy; a suggested optimum slope is about 1 in 12 (8%).

Depositing waste in thin layers and using a compactor enable a high waste density to be achieved. Each progressive layer should not be more than 30 cm thick. The number of passes by a machine over the waste determines the level of compaction.

Covering of Waste

At the end of each working day, all exposed surfaces, including the flanks and working face, should be covered with a suitable inert material to a depth of at least 15 cm. This daily cover is considered essential as it minimizes windblown litter and helps to reduce odours. It will also inhibit colonisation of the site by rodents and flies and facilitate movement of vehicles over the waste.

Daily cover only fulfils a transient function and should therefore not be confused with intermediate or final cover. Intermediate cover refers to material used for the end of a phase of landfilling whilst final cover refers to the material for covering of the final lift of deposited waste. Cover material may be obtained from on-site excavations or inert waste materials coming to the site. In addition, pulverised fuel ash or sewage sludge may be used to cover the waste.

Site Equipment and Manning

The plant most commonly used on landfill sites. includes steel wheeled compactors, tracked dozers and loaders, rubber tyred wheel loaders and hydraulic excavators. At small sites recieving low volumes of waste, a compactor alone may be adequate to spread and compact the waste as well as handle and place cover material. Rubber-tyred wheel loaders are versatile machines and therefore may be useful for small sites or as back-up machines on large sites. Scrapers are used for excavating and moving cover materials.

Employees should be competent, well trained and adequately supervised; training should include site safety and first aid. Since a landfill site may pose dangers to both site operators and users, emergency plans should be laid down and tested from time to time. High visibility clothing should be worn at all times and all employees should be encouraged to be alert and safety conscious. Where visitors are allowed on the site they should be closely supervised to ensure their safety. The number of employees required to operate a landfill site will obviously depend on many factors.

Monitoring Systems

A theme running through this chapter is that the landfill is a complex reactor where physical, chemical and biological processes transform polluting wastes into environmentally acceptable deposits. Because of the complexity of these processes and their potential environmental effects, monitoring is needed to confirm that the landfill is behaving in a predicted way. Processes within or close to the landfill may continue for many years after completion. Therefore, monitoring should also continue beyond cessation of operations. Proper planning of the total landfill operation, including aftercare, should overcome this problem.

A monitoring scheme is required for providing detailed information on the development of leachate and landfill gas within, and beyond a landfill. The scheme should be site specific; it should be drawn up at the site investigation stage and implemented, as far as practicable, as the first stage in the site preparation.

Monitoring of a landfill and its environment is not solely the responsibility of the landfill operator though he must bear the major share. Authorities like the waste disposal authority of water pollution boards will also wish to undertake some monitoring to ensure that the conditions specified in the disposal licence are being adhered to and remain appropriate. All parties should therefore get together early in the site preparation stage to agree to the monitoring scheme. Analyses undertaken by the three parties should be on a consistent basis to facilitate the comparison of results.

Leachate and Gas monitoring

Leachate and gas monitoring play a central role in the management of landfills. Data on leachate/gas volume and composition are essential to the proper control of leachate/gas generation and leachate/gas treatment facilities so as to ensure the protection of environmental quality. Knowledge of the chemical composition of leachate and gas is also required to confirm that attenuation processes within the landfill are proceeding as expected. Changes in chemical composition can act as a warning system and help identify problems caused. Leachate and gas monitoring should not be confined to the landfill itself, but should also take place outside the landfill boundary.

There is a temptation to combine landfill gas and leachate monitoring in the same borehole. Care must be taken to ensure that any equipment used to monitor leachate is compatible with a landfill gas environment. The practice of lowering pumps into monitoring boreholes is not to be encouraged at sites where gas is evolving.

Various systems for monitoring the leachate level have been used, mostly based on pipes installed prior to landfilling. Small bore perforated plastic pipe is cheap and easy to install, but has the disadvantage that the pipes are easily damaged during infilling. Placing pipes within a column of tyres offers some protection.

Groundwater Monitoring

A continued groundwater monitoring programme for confirming the integrity of the liner system is essential. Such a programme should begin before installation of the liner to provide baseline data for comparison with later results. At an early stage of site preparation therefore, a number of monitoring boreholes need to be provided around the site. The location, design and number of boreholes should be agreed with the appropriate authorities and will depend on the size of the landfill, proximity to an aquifer, geology of the site and types of waste deposited.

During operation and after completion of the landfill, the performance of the environmental protection facilities should be regularly checked. This is usually done by examining groundwater samples. However, it may take a long time before pollution reaches a monitoring borehole. Especially under these circumstances, the construction of a monitoring system directly under the tip body by means of a horizontal drainage system should be considered. This drainage system also offers the possibility, in case of liner disfunctioning, removing polluted groundwater and thus prevent further dispersion of pollution. However, the groundwater withdrawal facilities have to perform their duties until the production of leachate ceases.

If a double liner system is installed, monitoring will be much more accurate and easier to perform. Water should be regularly flushed through the secondary leachate collection system. If this water is polluted, the primary leachate barrier will be damaged. If repair is not considered possible, the leachate collected with this system must also be transported to the leachate treatment facility.

4.5 LEACHATE

Every landfill produces leachate. The leachate contains significant amounts of pollutants that should be removed before discharge. This section starts with a description of the leachate quantity and quality with respect to time. Thereafter, treatment options are considered. The design of drainage layers in the waste body and leachate collection systems was described in section 4.4 because these systems constitute an integral part of the landfill design.

4.5.1 Leachate Quantity and Quality

Leachate Quantity

In Section 4.3.1 the landfill hydrology was examined. The amount of leachate produced under steady-state conditions equals the precipitation less the amount by direct run-off of precipitation and evapotranspiration:

$$L = P * (1-c) - E$$

where:

L = amount of leachate produced
P = precipitation
c = run-off coefficient
E = evapotranspiration

In practice, steady state conditions never occur and the water/moisture storage capacity of the cover material and the waste body will be two important factors. During rainy periods, the moisture content of the soil and waste will increase, while in dry periods the moisture content decreases. These phenomena cause a flattening of leachate generation. The equation for the non-steady state condition is:

$$L_t = P_t (1-c_t) - E_t +/- Ss_t +/- Sw_t$$

where:

Ss = storage change in the cover material, a negative sign represents greater storage during precipitation, causing a decreased infiltration in the waste. A positive sign means that the water storage in the soil decreases, contributing to infiltration. (Capillary movement is negotiated in the evapotranspiration)
Sw = storage change in the waste body.

The quantity of leachate generated varies with time. During the operational phase of the uncovered landfill, the infiltration of rainwater into the waste is substantial, but the water storage capacity of the waste body at first prevents the generation of leachate. When time elapses, leachate production occurs. If the waste body becomes saturated, the quantity of leachate generated equals the infiltration. When the landfill is covered, the infiltration of rainwater into the waste decreases sharply. If the waste body is saturated, the quantity of leachate produced will drop sharply and the waste body becomes unsaturated again. However, if the waste body is not saturated the quantity of leachate produced does not vary much. Eventually, the leachate quantity will equal the rainwater infiltration from the waste cover.

The average quantity of leachate produced in landfills in Germany and the United Kingdom ranges from 10-60% of the precipitation. With an average yearly precipitation of 750 mm this means that 75 to 300 litres/year of leachate is generated per square metre of the landfill. The compaction of the waste (water retention capacity), thickness and slope of soil cover (run-off, evapotranspiration) are important factors for the production of leachate. A clayey soil cover, constructed with a slope reduces leachate production substantially.

SAQ 4.5

A landfill site extends over an area of 2 x 10^6 m^2. The annual precipiation is 2000mm and average annual evaporation is 500mm.

a) Estimate the maximum rate of production of leachate in m^3/d.

b) State what measures can be taken to reduce this amount.

Leachate Composition

During the degradation sequence the leachate quality changes dramatically. The aerobic phase is too short to produce leachate. The acetic phase is characterized by high concentrations of organics with BOD/COD-ratio > 0.4 and low pH. Values greater than 0.4 indicate a good biodegradability. After the transition to the methanogenic phase the pH becomes neutral, the BOD and COD concentrations are decreased and the BOD/COD-ratio is low, approximately. 0.1, indicating that the organic content has a low biodegradability. The ammonium concentrations are also very high; they show a low increase during the initial stage of operation and later-on relatively constant values. During the acetic phase, the high organic acid content results in increasing solubility of some inorganic substances e.g. metals. During the methanogenic phase in the landfill, much more carbon is transferred from the solid phase to the gas phase. When the gas production dies down, the organics concentration in the leachate follows the same pattern. Table 4.4 presents average values for leachate composition during the acetic and methanogenic phases.

4.5.2 Leachate Treatment

In general, the concentrations of various substances occurring in leachate are too high to allow leachate discharge to surface water or into a sewer system. These concentrations have to be reduced by treatment. In this section leachate treatment processes will be described. (Nota bene: (bio)chemical and physical backgrounds as well as design considerations will not be dealt with in this chapter. For an elaboration on those aspects we refer to UNESCO's text on Wastewater Treatment). The first alternative is to treat the leachate in the waste body itself, by means of recirculation.

Table 4.4: Average Values for Leachate Composition (source: Glas and Jans, 1991)

Parameter	**Acetic phase**	**Methanogenic phase**	**Inorganic Leachate**
pH [-]	4.5 - 7.5	6.5 - 9	7 - 11
BOD	1000 - 30000	1500 - 5000	< 100
COD	15000 - 40000	1500 - 5000	< 1000
BOD/COD [-]	0.6	0.06	
SO_4	50 - 2000	10 - 500	100 - 2000
Cl	1000 - 3000	1000 - 3000	1000 - 5000
Ca	500 - 2000	50 - 200	50 - 3000
Mg	50 - 1000	40 - 250	
Fe	500 - 3000	50 - 300	50 - 3000
Mn	0.5 - 50	0.05 - 40	
Zn	0.1 - 100	0.05 - 5	
Sr	0.5 - 15	0.5 - 5	
$NH_4/NO_3/NO_2$	500 - 1500	500 - 200	<50
AOX	[µg/]10-100	10 - 100	
As	[µg/]10-100	10 - 100	
Cd	[µg/]10-100	5 - 20	
Ni	[µg/]100-500	50 - 500	
Pb	[µg/]100-500	50 - 500	
Cr	[µg/]50-00	50 - 500	
Cu	[µg/] < 5	< 5	

all units expressed in mg/l, unless stated otherwise

Effects of Leachate Recirculation on Leachate Composition

Recirculation of leachate through a landfill combines anaerobic pretreatment within the landfill, regarded as a fixed-bed reactor (FBR),with evaporation occurring during each cycle. Due to these features recirculation can contribute towards the minimization of problems arising from the high variations in the quantity and quality of leachate. As mentioned earlier, the highest BOD, COD and heavy metals concentrations occur shortly after dumping of the waste (acetic phase). If external treatment of this highly polluted leachate can be avoided by internal pretreatment then the working capacity of the treatment plant can be reduced. A suitable measure to take is that of enhancement of methane production through improvement of conditions such as water content and transport. This can be achieved by recycling of leachate. The amount of leachate transported is enhanced however, posing a greater threat to the environment if the bottom sealing is damaged or non-existent. Moreover, multiple leachate elutriation could result in higher concentrations of salts in the leachate.

The following procedures for the handling and treatment of leachate are recommended for reducing the BOD and COD concentrations.

1. preparation of an anaerobic fixed bed landfill reactor by aerobic pre-stabilization of a bottom layer consisting of aerated waste or compost;
2. recycling of all leachate with a BOD level higher than 500 mg/l to the landfill reactor;

3. recycling of pre-treated leachate from the landfill reactor by means of spray irrigation (creates odour problems in the acetic phase) to minimize the quantity;
4. external treatment of excess amounts of leachate.

A moisture content of more than 30% is essential for satisfactory methane production. A higher water content will not mean further enhancement.

Biological and Physico-Chemical Leachate Treatment

In general, leachate can be treated biologically and chemically. Characteristics which could influence biological treatment are a high concentration of organic and inorganic substances, variations in the biodegradable fraction of organic substance depending on age of the landfill and a low amount of phosphorus. A BOD/COD value of 0.4 indicates that organic components will be easily broken down by bacteria whilst lower values signify that the organic fraction will be less biodegradable and therefore that biological treatment systems are not advised. Furthermore, leachate from landfills may contain substances which may diminish biological treatment efficiency. The compounds which may affect treatibility are:

1. **metals:** If metal inhibition is considered to be a problem, simple pretreatment using lime to precipitate and remove the metals as hydroxides should be instituted.
2. **carbon compounds:** These include chlorinated solvents, cyanide compounds and phenols. High concentrations of both phenols and cyanide compounds can be biogically oxidized by acclimatized biological systems. Chlorinated solvents will almost certainly be rapidly volatilized with the biological system.
3. **ammonia:** The ammonia concentrations in leachate usually will not affect the biological system; far higher concentrations are needed for this to occur.
4. **chloride:** Chloride is tolerated at relatively high concentrations by aerobic processes after acclimatization.
5. **sulphide:** Within the landfill, complexation and precipitation of sulphides reduce the sulphide concentration in the leachate. Aerobic processes can satisfactorily treat 1000 mg S/l without impairing performance.

Anaerobic biological treatment is generally more susceptible to poisoning by toxic substances. Aerobic processes have the capacity to acclimatize to the presence of certain toxic organic substances.

Aerobic Biological Treatment

Leachates from recently landfilled waste can be readily degraded by biological means, due to the high content of volatile fatty acids. The following methods of aerobic treatment are possible:

- **aerated lagooning:** Aerated lagooning is accomplished by use of special devices which enhance the aerobic processes of degradation of organic substances over the entire depth of the tank. The leachate is continuously agitated by means of surface aerators or air pumps in such a way that the mixture obtained hinders the formation of layers in anaerobic conditions and facilitates the introduction of oxygen from the athosphere. The organic substances are aerobically degraded; the degradation process is faster than under anaerobic conditions. Treatment efficiencies for COD and heavy metals of more than 90% are possible (BOD/COD>0.4). Treatment efficiencies for COD rapidly decrease with decreasing BOD/COD ratio. The effluent resembles the leachate from stabilized landfills in the methanogenic phase. The sludge produced is intermittently disposed of onto the landfill. Inhibition of the degradation by high metal concentrations has not been observed. Short detention times or low temperatures however, may affect the efficiency in a negative way. Ammonia will be removed (transferred into organic nitrogen in biomass) if the BOD/COD ratio > 0.4. A disadvantage is that acidified leachate will cause foaming and odour problems.

- **activated sludge plants:** These differ from aerated lagoons in that discharged sludge is recirculated. The retention period can be shorter than in an aerated lagoon as the sludge content can be carefully controlled by means of a recirculation system. A sedimentation unit is necessary for the separation of sludge which is returned to the tank. The treatment efficiencies and boundary conditions are comparable with those for aerated lagoons. If stabilized leachate is treated, the high ammonia content relative to a low organic content may cause inhibiting effects.
- **rotating biological contactors:** The biomass is brought into contact with circular blades fixed to a common axle which is rotated. The disks are half-immersed in the leachate tank. The rotational movement means that alternately part of the disk is immersed in the leachate and subsequently comes into contact with atmospheric oxygen which is used by the biomass present on the disk to aerobically degrade the organic substances. Leachate with low BOD and high ammonia concentrations has been treated succesfully in this way. However, if the ammonia loading is too high, the oxidation is not complete and nitrite is formed.
- **trickling filters:** The trickling filter is made up of tanks several meters in depth filled with gravel or synthetic material. The wastewater is sprayed over the surface of the filling material after being pumped over the top of the filter. The passage of the leachate through the filter is downwards as it moves over the filter elements. The free spaces allow the passage of air. The treatment of high strength leachates could lead to clogging and scaling mainly due to the precipitation of calcium carbonate and oxidized iron and manganese. The removal rate for ammonia and BOD can be high.

Anaerobic Biological Treatment

Anaerobic biological processes have several potential advantages over aerobic processes. These include the generation of methane gas and much lower production of biological solids in the form of sludges. In addition, the systems have no need of power-driven aeration equipment. In an anaerobic treatment system, complex organic molecules are fermented in the same way as in the landfill. A disadvantage is that the microorganisms are inhibited easily by acidic pH-values, leading to a net washing-out of microbial cells. This problem may be overcome by using an anaerobic filter, to which microorganisms are attached. For a self-supporting anaerobic process a minimum concentration of app. 7000 mg COD/l is required. Anaerobic processes are most useful for treatment of relatively strong leachates (acidified leachate); they may be uneconomic for more dilute flows. Anaerobic treatment is best used as a pre-treatment method because this technique does not remove ammonia and produces a turbid effluent. Two anaerobic processes are described in more detail below:

- **anaerobic lagooning and digesters:** The degradation process is carried out by means of both physical and physico-chemical processes (sedimentation, flocculation, precipitation) which prevent aeration of the liquid mass. The anaerobic processes which occur produce simple compounds. The emission of odours is prevented by the formation of a skin at the liquid surface, aqueous phase caused by the progressive floatation of sludge by gas bubbles. Nitrogen is removed only to a minimal degree by means of assimilation (cellular synthesis of new bacteria). Organic nitrogen is hydrolized to ammonia. Heavy metals are precipitated and enmeshed in the bacterial mass. An aerobic digester consists of a closed container, whereas an anaerobic lagoon is an open tank. The contents of the digester are continuously agitated by re-introducing the biogas produced during the degradation processes, accelerating the process of degradation. Removal rates for COD of over 90% are possible if the temperature is not too low.

- **anaerobic filters:** Recent advances in anaerobic techniques have revived interest in the filter process as a means of treating leachate. New reactors (upflow anaerobic sludge blanket, UASB) have been used to treat leachates of high strength. Advantages include a high loading capacity and a short retention period of treatment thus implying small plant size. Chemical conditioning of acidified leachate is necessary to prevent operational problems. Sludge production is minimal, nutrient requirements are low, and because of high energy biogas production, an energy surplus may be obtained. The initial capital costs are high. Results show, that high COD removal rates are possible, especially with loading rates < 10 kg COD/m^3 per day.

Final considerations on the technical feasibility of aerobic and anaerobic leachate treatment processes are as follows:

Aerated lagoons are the favoured method of treatment, because of their simplicity and the absence of an expensive sludge recycle facility. High BOD/COD removal efficiencies are possible, but low temperatures decrease degradation. Floating aerators may be used. Construction of the lagoon is a simple operation involving excavation at the landfill site and application of a liner to prevent seepage.

Activated sludge plants: This treatment may be less appropriate because it demands greater operator skill and control equipment not compatible with landfill sites.

Trickling filters are not appropriate for the treatment of strong leachates mainly because of filter clogging.

Rotating biological contactors are recently being considered for reducing the ammoniacal nitrogen content of leachate from aged wastes. They require very little maintenance, are simple to install and use very little power.

Anaerobic lagoons can be successfully employed in countries with a prevailing temperate climate. It is not a complete method of treatment, but could be used for storage, balancing and as a rough pretreatment stage.

Anaerobic digesters have proved to be an effective means of removing both the organic load and heavy metals. If high removal efficiencies are required, the plant costs are high, due to reactor size and heating.

Anaerobic filters: The development of UASB reactors has shown promise, because of high efficiencies and very low detention times and not least the generation of additional biogas.

Physico-chemical Treatment

After biological degradation, effluents still contain significant concentrations of different substances. The COD values range from 400-1500 mg/l, ammonia from 20-50 mg/l, while organic halogens (AOX) are still present, being hardly removed during biological treatment. Physico-chemical treatment processes could be installed to improve the leachate effluent quality. Some processes are described below:

- **flocculation-precipitation:** By adding chemicals to the water, a floc is formed. Metals attach to the floc. Separation of the floc from water often takes place by sedimentation or flocculation. Most organics in high strength leachates are volatile fatty acids with low molecular weight and cannot therefore be precipitated. Only with leachates from the methanogenic phase is COD and AOX removal in the range of 40-60%. Ammonia is not removed.
- **adsorption:** Activated carbon adsorption is not an effective process for volatile fatty acids or very large molecules (humic acid) which could block the pores. The best effect of adsorption occurs after biological treatment (elimination of volatile fatty acids) and flocculation (reduction of large molecules).
- **reverse osmosis:** In contrast to the other techniques this is a separation process involving two liquid streams: a low polluted permeate stream and a high-polluted concentrate stream. With new developments of membrane material it is possible to obtain permeates with very low concentrations of pollutants. However, very small organic molecules are not held back. Reverse osmosis is not suitable for acidified leachate. A very troublesome disadvantage is the production of a highly polluted aqueous concentrate. Often the separation of ammonia is poor, although this could be improved by adjustment of pH.
- **vaporization:** Vaporizing means separating leachate in a clean water stream and in a solid phase containing all pollutants. In reality, the separation is not so definite and accurate. Volatile components (chlorinated organics, ammonia) may be present in the effluent, requiring additional treatment steps. At this time, vaporization is not a well-proven technology.

Combination of Treatment Technologies

Every treatment technology (biological, physico-chemical) shows some deficiencies in meeting existing and anticipated future effluent standards. Table 4.5 assesses the leachate treatment processes described above:

Table 4.5: Assessment of Some Leachate Treatment Processes (source: Glas and Jans, 1991)

Process	COD	N	Metals	Salts
aerobic treatment	+	+	0	-
anaerobic treatment	+	-	+	-
floc-precipitation	0	-	++	-
reverse osmosis	++	+	++	++
vapourization	++	0	++	++

The solution could be an optimum combination of two or more methods. The combination of biological treatment, followed by adsorption and flocculation is a very effective process for treatment of landfill leachate and possibly for hazardous waste leachate. Figure 4-14 presents experimental results of this combined process. The AOX removal rate was 75%. Vaporization combined with reverse osmosis is far too expensive a process, so that it should be applied only to extremely hazardous waste leachate.

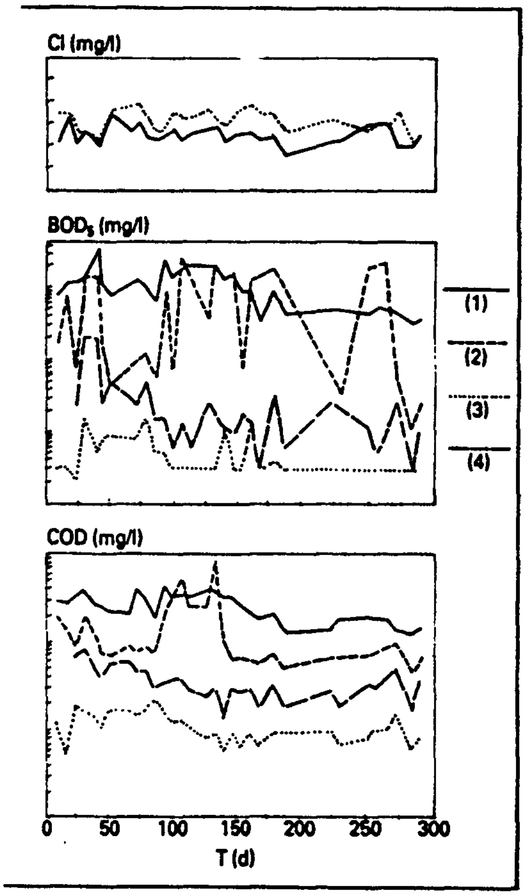


Figure 4-14: Influent and Effluent Quality Values vs. Time Observed during Full Scale Treatment Tests, using Biological Treatment + Absorption + Flocculation

(1): influent; (2): biological treatment effluent; (3): flocculation unit effluent; (4): adsorption unit effluent (source: Christensen et al, 1989)

SAQ 4.6

How can a leachate that contains too high a concentration of heavy metals be treated?

4.6 LANDFILL GAS

Landfill gas can be utilized as a source of energy, because it contains a high percentage of methane. It is produced during the anaerobic decomposition of tipped organic matter. In this section the quality and quantity of landfill gas is first described; this is followed by a description of the design of a landfill gas extraction system. Finally, landfill gas pretreatment, necessary for utilization and associated safety aspects, is discussed.

4.6.1 Landfill Gas Quality and Quantity

There is little data on the total amount of gas generated from solid wastes in a landfill. Available data is largely from lysimeter studies in which refuse is placed in enclosed spaces, and the gas involved is measured. Little data is available from full-scale landfills, partly because of the long period of monitoring required and also because of the difficulties of measurement. Theoretical model results, data from lysimeter and full scale landfills, and a mass balance approach can be used to get some idea of total gas generation.

The amount and composition of the generated gas can be predicted for different substrates using the general anaerobic decomposition equation (substrate plus water yield methane, carbon dioxide and ammonia, as mentioned in Section 4.4.2). The equation shows that the gas composition is a direct function of the material decomposed at a specific time. Climatic and environmental conditions will also influence the gas composition. Due to the heterogeneous nature of the landfill environment, some acid-phase anaerobic decomposition occurs along with the methanogenic decomposition. Since aerobic and acid-phase degradation gives rise to carbon dioxide and not methane, there may be a higher carbon dioxide content in the gas generated than would be predicted from the above-mentioned equation. Furthermore, depending on the moisture distribution, some carbon dioxide goes into solution. This can appear to increase artificially the methane content of the gas measured in the landfill.

In general the gas contains 55% methane (and 45% carbon dioxide), but quantities between 35 and 75% are reported in the literature. Lower methane concentrations are often a result of landfills that are either early or late in the decomposition process. Unusual refuse composition or very dry conditions may also show reduced methane figures. In some landfills, up to 20% of hydrogen is measured. Hydrogen is usually converted to methane and is present at very low concentrations (well under 1%). Dry conditions or unusual refuse composition may be the original cause for high hydrogen content, but other factors inhibiting the methane formation could also be important. However, elevated hydrogen levels over a short period are common and simply indicate the transition from acid-phase to methanogenic decomposition.

Measuring the gas composition is readily accomplished with gas chromatographs, explosimeters, portable gas analysers etc.

The above-mentioned equation can be used to estimate the total amount of gas to be produced in a landfill. Table 4.6 provides values of the amount of gas generated per kg dry refuse.

Table 4.6 : Amount of Gas Generated per kg dry refuse (source: Christensen et al, 1989)

Cellulose	829 l/kg
protein	988 l/kg
fat	1430 l/kg
typical US municipal waste	520 l/kg
weight organic components	100-300 l/kg
waste + sewage sludge	210-260 l/kg
lysimeter, closed container	0.5-40 l/kg
full-size landfills	50-400 l/kg

The first three entries are substances consisting of 100% organic matter. The fourth entry is the theoretical amount of gas to be generated based on the use of the above mentioned equation for municipal solid waste collected in the United States. It assumes a perfect biological system and perfectly degradable materials which are converted to carbon dioxide and methane. The fifth entry indicates typical values that would be obtained if all of the waste is not decomposed e.g. only the food waste and 1/3 of the paper waste may decompose. These assumptions allow for the fact that the refuse will not be completely decomposed, that some of the refuse will be decomposed to end products other than carbon dioxide and methane, such as cell mass, and that there will be some materials which will not even be decomposed under methanogenic conditions. Such resistant materials will include plastics and lignin (under anaerobic conditions). The sixth entry gives data from an ideal anaerobic system: anaerobic digesters. The digesters are stabilized by sewage sludge as a seed and substrate source. A well mixed, properly controlled digester would provide virtually optimal conditions for methane formation and, these values may be considered the best that could be achieved in a landfill. The seventh entry shows data from lysimeter and closed container tests with waste. These sources were supposed to give the best approximation for landfill gas production, but actual values are usually lower because it is difficult to establish good conditions for methane production. The eigth entry gives data from measurements at full-scale landfills. However, it is difficult to convert the amount of gas measured to the maximum landfill gas production value, because during a measurement, gas is withdrawn from a small part of the landfill only, the so-called 'zone of influence'. It is very difficult to determine this zone and relate it to the whole landfill area.

A major problem in determining the total amount of gas produced is that the gas has to be monitored over a long period of time, which is the total time required for decomposition in the the landfill. Another approach to determine the amount of gas generated from a landfill is a mass balance approach. The weight of materials in the leachate is subtracted from the weight loss of refuse to obtain the weight of the gas generated. The mass balance technique is probably the most accurate method for measurement of the total amount of gas generated, assuming that anaerobic decomposition to form methane and carbon dioxide is the predominant mechanism by which refuse is converted to gaseous end products.

Rate and Duration of gas generation

Theoretical approaches to the rate of gas generation in a landfill generally involve developing models based on first-order kinetics, expressed as:

$$- \delta c/\delta t = k * c$$

This equation states that the rate of loss of decomposable matter is proportional to the amount of decomposable matter remaining. If the decomposable matter can be translated directly into gas generation, such as the equation (section 4.2.2) indicates, the above mentioned equation can be rewritten in terms of the rate of methane formation and the total amount of methane to be formed. This first-order expression is the most widely used model of gas generation rates at a landfill.

A zero-order kinetic expression indicates that the rate of methane generation is independent of the amount of substrate remaining. Many landfills appear to produce gas according to zero-order kinetics, at least during periods of the most active gas generation. Factors such as the availability of moisture, nutrients, organisms and substrate limit the amount of methane to be formed to a relatively constant value independent of time. Another important factor is that the landfill system may consist of waste layers with different ages, thus resulting in different rates of gas production. The overall production rate averages the contributions from all waste cells and layers. In full scale landfills, the typical yearly gas production rate ranges from 10 to 20 l/kg. if the total amount of gas to be produced is 150 l/kg (most likely value in the U.S.A.). Methane generation lasts for app. 10 years (zero order kinetics). The amount of methane produced in the lag phase and die-off phase is neglected. In Germany, total gas production is 120-150 l/kg; the methane content is somewhere between 55 and 65%. The period in which landfill gas can be used is calculated as up to ten years after the landfill is closed.

Composition of Landfill Gas

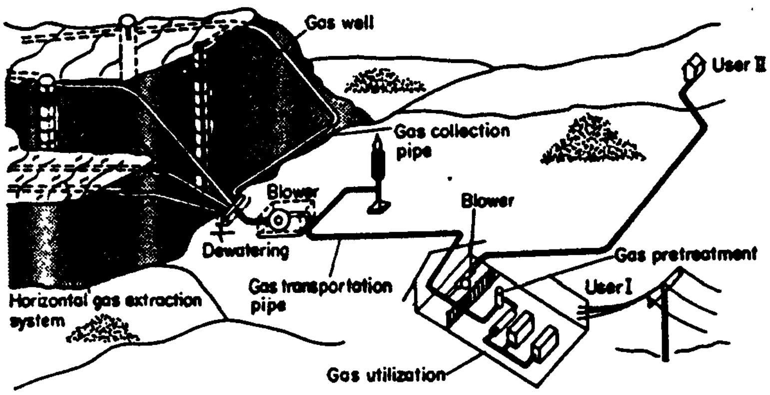
The necessity of landfill gas extraction is obvious from the point of view of emission minimization. Besides methane and carbon dioxide, some hydrogen sulphide and organic trace elements that are toxic, and in some cases carcinogenic, are emitted with the gas from the landfill. Furthermore, metals at low concentrations have been detected. In addition, explosive mixtures can build up. The proportion of air in landfill gas is dependent upon the type of gas extraction operation and is caused by air being sucked into the landfill and leaks in gas extraction pipes, valves and tubings. Trace organics may cause corrosion problems during landfill gas utilization. Table 4.7 provides typical values of concentration ranges of halogenated hydrocarbons in landfill gas. These values are expressed in mg/Nm^3.

Table 4.7: Concentration Range of Halogenated Hydrocarbons in Landfill Gas (source: Christensen et al, 1989; U.K. department of environment, 1986)

Gas	Formula	Concentration range [mg/Nm3]
trichlorofluoromethane	CCl_3F	1-84
dichlorodifluoromethane	CCl_2F_2	4-119
chlorotrifluoromethane	$CClF_3$	0-10
dichloromethane	CH_2Cl_2	0-6
trichloromethane	$CHCl_3$	0-2
tetrachloromethane	CCl_4	0-0.6
1,1,1-trichloroethane	$C_2H_3Cl_3$	0.5-4
Chloroethene	C_2H_3Cl	0-264
Dichloroetheane	$C_2H_2Cl_2$	0-294
Trichloroethene	C_2HCl_3	0-182
tetrachloroethene	C_2Cl_4	0.1-142
chlorobenzene	C_6H_5Cl	0-0.2

4.6.2 Design of Landfill Gas Extraction Systems

Landfill gas is extracted out of the landfill by means of gas wells (Fig. 4-15). These wells are normally drilled by an auger or driven into the landfill at a spacing of between 40-70 m.



. General scheme for a gas extraction and utilization plant (Müller and Rettenberger, 1987).

Figure 4-15: General Scheme for a Gas Extraction and Utilization Plant (source: Christensen et al, 1989)

In addition, or as an alternative, horizontal systems can be installed during the operation of the landfill (Fig 4-16). The gas wells consist mainly of perforated plastic pipes (HDPE) surrounded by coarse gravel and are connected with the gas transportation pipes by means of flexible tubings (Fig 4-17). A vacuum is necessary for gas extraction and transportation and is created by means of a blower that is, in most cases, installed in a building at the border of the landfill.

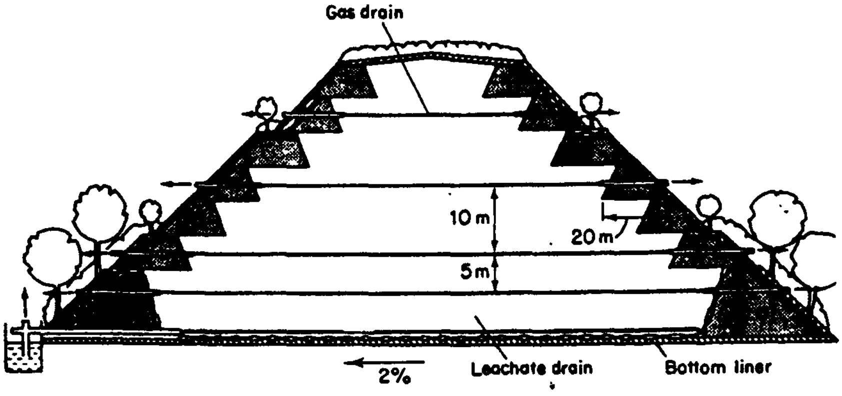


Figure 4-16 Possible design of a horizontal gas extraction Scheme (source: Christensen et al, 1989)

The most important influencing factors concerning planning and construction of landfill gas extraction systems are:

- settling
- water tables in landfills
- condensate
- gas quality

The amount of settling to be expected is mainly dependent upon the degree of compaction during the implacement of the waste. For example, the initial average density of a 20 m high waste body can be increased by 25% if the waste load increases by 10 m of waste. A total settling of about 2-3 m can be expected. Severe differential settlements often take place in landfills, caused mainly by different local emplacement densities and different superimposed waste loads on top.

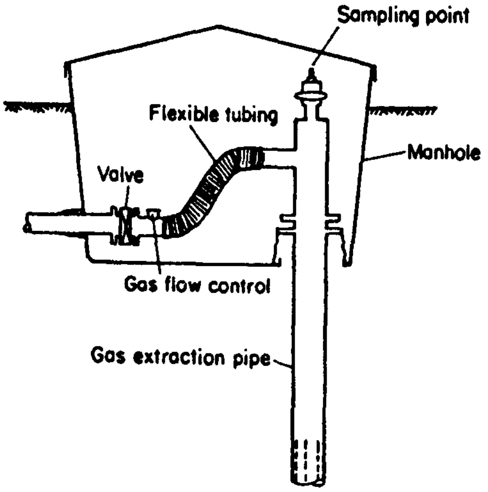


Figure 4.17: Gaswell head (source: Christensen et al, 1989)

For reasons of differential settling, the horizontal gas transportation pipes and the connecting tubings to the vertical gas wells are especially endangered. In order to avoid pipe breakage, flexible tubings made of non-corrosive plastic material should be used (Fig. 4-17). Local settling of horizontal gas transportation pipes can cause accumulation of condensate, resulting in pressure loss and sometimes the clogging of the whole pipe. The following design criteria are recommended for the emplacement of landfill gas pipes:

1. Emplacement of the pipes with relatively steep slopes in the same direction of the gas flow, thus condensate and gas will flow in the same direction.
2. Gas transportation pipes should be installed mainly in virgin soil; the number of pipes placed in a landfill should be minimized.
4. Gas transportation pipes with low slopes may be supported by steel or wood constructions underneath the pipes in order to avoid local settling.
4. Settling of pipes can be observed by connecting steel rods at certain distances directly to the pipe, so that they reach the landfill surface. The pipe length above the landfill is an indication of settling.
5. Dewatering installations for removing condensate from the pipes have to be installed in the landfill area.
6. The slope of the gas transportation pipes should be at least 2%; steeper slopes should be chosen if possible.

From many landfills, **high water tables** within the landfills have been reported. This may result in filling gas wells with leachate, so that gas extraction becomes impossible. This means that deep vertical gas wells down to the bottom of the landfill are not necessary since they fill up with water..Gas wells also have the effect of dewatering the landfill. Installations to encourage water percolation out of the gas wells should be constructed. Furthermore, gas wells should be built so that pumping-off of water by means of submersible pumps is possible. Horizontal gas extraction pipes can become filled with water. For this reason, horizontal ditches, filled with coarse gravel, should be put in place with relatively steep slopes. In landfills, the **condensate** should be able to drain out of the pipes back into the landfill by means of syphons. In many cases the condensate is led back into the vertical gas wells. After removal, the condensate also has to be removed from the transportation pipes outside the landfill. The condensate is treated separately. If landfill gas has to be transported over long distances, the possibility of dewatering the gas by cooling should be considered. Gas dewatering has a positive effect on the useful life of the machines with which the gas is in contact. The **gas quality** is another important factor. Landfill gases are very corrosive, and this property must be considered when materials for pipes and engines are selected. HDPE-material and carbon steel have proven adequate, but other materials are often used. Rubber and silicone should not be used.

4.6.3 Landfill Gas (LFG) Utilization

If landfill gas is not utilized, it should be burnt by means of flaring. LFG utilization however can save on the use of fossil fuels since the heating value of landfill gas is approximately 6 kWh/m^{3}· LFG can also be utilized in internal combustion engines to produce electricity and heat, in conjunction with heat recovery and for heating alone. The overall efficiency of the conversion of LFG into electricity is about 33%, but this can be increased to about 80-85% if the heat from the cooling water is also used. The efficiency of using LFG for heat production (buildings or industry) would increase to 80-90% if it were possible to use the LFG throughout the year.

It is important that LFG should be extracted during the operation phase of the landfill.

Pretreatment of Landfill Gas

In combustion engines, trace components in LFG may be converted into strong acids, causing corrosion. In the landfill of Braunschweig, Germany, trace organics concentrations ranging from 700-1000 mg/Nm^3 have been detected, after an engine broke down completely due to corrosion. This problem can be solved when specific oils developed for LFG-engines are used. Also during the time of active gas extraction, the trace organics concentrations will significantly decrease.

Removal of trace organics (e.g. chlorinated hydrocarbons) from gas, before it is fed to internal combustion engines, is possible by using activated carbon columns or organic solvents. Since the activated carbon is loaded after 12-24 hrs, the desorption of the adsorbed hydrocarbons has to occur at this frequency. The desorbed hydrocarbons are concentrated by means of cooling. Due to the loss in effectiveness with each desorption cycle and the high price of activated carbon, costs are high. In addition, pretreatment becomes more ineffective if low concentrations have to be treated. Activated carbon and iron compounds are effective in reducing hydrogen sulphide concentrations.

In the USA, LFG is treated to 'pipeline quality' using carbon dioxide absorption processes. These processes are expensive and only economical if LFG from landfills with capacities exceeding 10 million tons is used. In the USA gas turbines are used to generate electricity. They have fewer problems with chlorinated hydrocarbons, but their efficiency is lower when compared with internal combustion engines. A new development is the upgrading of landfill gas to pipeline quality (95% methane) by using a molecular sieve.

4.6.4 Safety Aspects

Landfill gas consists of a mixture of flammable, asphyxiating and noxious gases and may be a hazard to health. If methane concentrations in the atmosphere rise to between 5-12%, explosive mixtures are present. If the oxygen content in LFG exceeds 11%, this is also true. Precautions must therefore be taken so that explosions are avoided. The best way to do is to avoid the build-up of explosive mixtures. Measuring the gas quality in different sections of the plant on a regular basis gives an insight to the occurrence of explosive mixtures.

Within a landfill, hydrogen sulphide is not normally present in concentrations exceeding 10 parts per million. In some landfills however, hydrogen sulphide concentrations may be much higher, due to the presence of large quantities of material containing sulphide. In this case the gas represents a considerable hazard.

The presence of carbon dioxide increases the density of landfill gas above that of methane and as a result it may be heavier then air. Gas liberated in a closed area, or even in the open under calm conditions, may not be uniformly mixed with air. As a result, stratification may enable flammable volumes of gas to collect and remain in buildings, structures, pipework or areas which were previously thought to be free from flammable gas concentrations.

Risks of fire, explosion or asphyxiation may be avoided during operation, restoration and the post closure management period by:

1. siting plant handling flammable gas in the open air;
2. controlling sources of ignition in the vicinity of the plant. Electrical equipment should be sited in a safe place when used in a hazardous area;
3. monitoring, to ensure operations on a landfill are carried out only where the LFG concentration is within safe limits;
4. controlling gas extraction rates and monitoring abstraction pipes to ensure that any air drawn in does not create potentially hazardous mixtures;
5. restricting entry into any shaft where gas may accumulate. If access is considered to be essential various safety procedures should be considered and agreed before permission is granted;
6. ensuring that all personnel are aware of the potential risks on the surface of the site and avoiding any practice which could lead to ignition. 'No Smoking' notices are obligatory and fires should not be lit.

SAQ 4.7

The local authority for a town is concerned about the safety aspects of their landfill gas system. What possible risks and hazards should be examined?

4.7 HAZARDOUS WASTE DISPOSAL

Introduction

Residues and process-induced wastes from various types of hazardous waste treatment processes have still to be disposed of. For disposal there are three options:

- codisposal with municipal waste
- disposal into a monodisposal landfill
- disposal into a hazardous waste landfill.

Co-disposal of hazardous waste is dealt with in section 4.2. A monodisposal landfill is one in which only one kind of waste may be deposited. For this purpose it is specially designed. In most cases the (bio)chemical properties of the waste are an important design factor. A hazardous waste landfill is a multipurpose landfill in which all kinds of hazardous waste may be deposited. Care has to be taken, however, that combinations of wastes do not lead to extensive heat-production or explosive reactions. It is necessary therefore to have a complete description of the nature of every separate waste that is to be disposed. In a hazardous waste landfill, biological processes do not play an important role. Attenuation has to be provided by the chemical properties of the waste itself. Therefore, more care should to be taken in the undersealing of the waste body. Leachate that may occur is usually very toxic and is therefore not easily treated. The formation of excessive leachate has to be avoided by immediate capping of the waste.

Hazardous waste Disposal in the Netherlands

In the Netherlands, co-disposal of hazardous (chemical) wastes and municipal wastes is prohibited. The hazardous wastes are divided into 5 classes:

- **C-3:** moderately polluted wastes, such as sludges from drinking water production and sulphur residues may be deposited into a specially designed landfill. The landfill design resembles the design for a municipal landfill: the landfill basin consists of a HDPE liner. Collected leachate is treated physico-chemically. After completion, the landfill is covered by a HDPE liner.
- **C-2:** this chemical waste contains higher concentrations of toxic substances than C-2 waste. Examples of this waste class are metal sludges, sludges from tanneries, residues from incineration gas treatment facilities. In the Rotterdam area, a specially designed landfill for this kind of waste has been built. This design will be elaborated upon in the next paragraph.
- **C-1:** This heavily contaminated waste must be deposited under specific conditions, such as former salt mines. Mercury batteries, chlorinated activated carbon are among the substances that be disposed of in this way.
- **B:** This kind of hazardous waste cannot be treated at this time; in the near future however, treatment may be feasible.
- **A:** Bulk-wastes, produced in quantities of more than 5,000 tons/year. These types of waste are produced by only a few enterprises. Examples are: shredderwastes, lime-containing residues, industrial treatment sludges. In most cases, the producers have taken sufficient measures to treat or dispose their waste themselves.

C-2 Disposal Site

In the Rotterdam area, a specially designed disposal site has been built to store C-2 waste, with a capacity of 230,000 m^3. At the disposal site, a huge theoretically impermeable concrete basin has been built. Its dimensions are 320 x 50 x 11-17 m. The basin is situated 1 m above the highest groundwater level. Around the landfill perimeter, a drainage system has been installed as a safety precaution, to lower groundwater levels if necessary. To avoid dispersion of potential contaminants via groundwater, a vertical liner construction has been drilled into the subsoil. Under the concrete floor, a drainage system has been installed, to monitor the landfill behaviour. This system may be used to drain off polluted leachate if necessary in the future.

The concrete walls are protected from chemical attack by a synthetic liner. The concrete floor is covered by a bituminous layer of 100 mm and two rubber-containing bituminous layers of a few mm's thickness.

The working front and the deposited waste are temporarily covered by a moveable sloping roof. The disposal facility will be operated as follows: waste will be unloaded into containers. A specially designed crane will place the waste into the storage body. After the waste layer has reached its final height (11 - 17 m), the temporary roof will be moved to an adjacent cell and the waste covered with a temporary HDPE-liner. The construction of the final cover starts 2 years after cessation of the landfill operations. The final cover consists of a double composite liner system, comprising two 2 mm thick HDPE liners separated by a sand-bentonite layer and a drainage layer. If the principal protective layer is disfunctional, the rain water will be drained off to a gutter at the top of each concrete wall.

Leachate will be generated not only by precipitation but also by consolidation of the waste. Measures have been taken to collect polluted leachate. The leachate is transported to an external treatment facility.

After completion of all operations, the site will be restored into an artificial dune. This is due to the fact that the disposal facility is located close to the seashore. In the surroundings of the landfill, three other disposal facilities have been built. One of them is specially designed for C-3 waste while two landfills are designed to store contaminated harbour sludge. All landfills will be restored into artificial dunes after cessation of operations. In the immediate vicinity, no human settlements are found. The landfill area is formerly reclaimed land, destined for industry. Nowadays the area has high recreational value.

4.8 CASE STUDIES

4.8.1 Indonesia - the Bandung Sanitary Landfill Pilot Project

Introduction

In Indonesia solid waste management has not yet been fully optimised because of several occasional problems concerning technical, institutional, management, financial, legal, public participation and environmental aspects. Recent progress has been focused on solid waste collection but disposal sites are still causing serious sanitation and environmental problems including groundwater and river pollution. Within the 'National solid waste management strategy preparation', sanitary landfill has been selected as the most appropriate method for urban solid waste disposal in Indonesia.

The sanitary landfill pilot project was developed with the cooperation of the Bandung Municipal Cleansing Enterprise and coordination of the Directorate of Environmental Sanitation of the Ministry of Public Works. The project aims at serving as a demonstration project for the art of sanitary landfilling in Indonesia. Preliminary studies, including siting and design, commenced in 1986, construction started in 1988 and operations in 1989. French advisers participated in all stages of the project. The French Agency for Waste Recovery and Disposal has participated in the preparation of guidelines for sanitary landfills in Indonesia.

Characteristics of Domestic Solid Waste in Indonesia

In the pilot project, the following data are generally considered as a basis for design:

- waste volume: 2.5 l/inhabitant/day;
- waste density: 250 kg/m^3;
- yearly production: 180 kg/inhabitant;

waste composition:

- organic matter: 75%
- paper/cardboard: 10%
- plastics 10%
- metals 2%
- textiles 2%
- miscellaneous: 1%

The capacity of the Sukamiskin (Bandung) Sanitary Landfill:

- filling area: 17,500 m^3
- height of filling: 8 m.

The estimated site capacity is between 72,450 and 116,550 ton, depending on the degree of compaction (density) that can be achieved.

Bandung Sanitary Landfill design, construction and operation

Site Location

The site is located approximately 6 km from downtown Bandung, at the boundary of an irrigated rice field and a dry field in a hilly zone. Its elevation above sea level is about 750 m.

Hydrogeological data

A geotechnical evaluation of the site had been made before the beginning of the design phase. The subsoil consists of bedrock of volcanic origin, covered by a 3 m thick clay and 4 m thick silty clay layer. The average soil permeability (Darcy coefficient) is

10^{-6} m/s. An aquifer is located between 6 and 40 m below natural soil level. Its flow direction is not constant over the year.

Rainfall mostly occurs as heavy thunderstorms. Annual precipitation was measured at 2,000 mm. After heavy rainfalls, traffic difficulties occurred.

Lining and Drainage

As the average permeability of the subsoil is too high, a compacted earth layer has been placed at the bottom of the landfill with an average 5% slope. Above this layer, a leachate collection system has been installed. It has been designed with a comb configuration: two main drains and five lateral drains with an average 25 m spacing. Slotted PVC-pipes 100 mm in diameter were used. About 9 l/s of leachate was produced and transported from the waste body to the leachate treatment facility.

Leachate Treatment

Two stabilization ponds in series (capacities 2250 and 1200 m^3) have been designed, as large as possible within the limited area available on the site. The biological treatment process is an aerobic facultative one. The pond bottom layer was made of compacted clay, but will be replaced with a synthetic liner. Also, the efficiency of the treatment process will be improved by surface aeration or recirculation. Plastics and other litter sometimes covered the ponds leading to disfunctioning of the treatment plant.

Landfill Gas Management

Landfill gas utilization will be practised in the future. Four wells have been planned with a 40 m radius of influence for each well. The gas wells are progressively installed during operation. If necessary, additional wells can be added by drilling after completion of operation.

Equipment and Infrastructure

At the landfill site, a weighbridge, vehicle wash area and some buildings were installed. At first, the site was fenced, but the fence was recovered by scavengers. A track dozer and a track loader were available for operations.

Operations at the Landfill

A waste placement plan has been developed. This plan describes the different phases of operation from the beginning to the completion of the landfill operation. The trench method has been used for landfilling.

Each morning, before commencement of work, the site supervisor inspects the status of the landfill site. In particular the following items are examined: waste tip, run-off drainage system, stabilization ponds, landfill gas system, operation road, earth scraping area. Based on the results of this inspection and on the waste placement plan, the site supervisor indicates to the landfill staff the location of the disposal area and the daily working programme for the maintenance of the landfill.

Waste collection trucks unload as near as possible to the working face. Blowing litter is controlled by portable fences. A bulldozer is used for spreading the waste. The waste is covered daily by a soil layer with a thickness after compaction of 20 cm. When the waste body reaches a thickness of 1.5 meters, the cell is covered with a final cover layer of at least 60 cm.

To monitor the overall landfill performance, daily forms are completed by landfill staff. Recorded data concern:

- origin, nature and quantities of deposited waste;
- daily operations;
- leachate and landfill gas production;
- status of the treatment plant;
- environmental data (rainfall, wind etc).

Scavenging

In Indonesia, as in other Asian countries, sanitary landfill operations should not be considered without taking into account the presence of scavengers. The activity of scavengers is important as a material recovery process and a source of income. Such activity may have several impacts on landfill operations, among which is the safety of the scavengers themselves.

The quantities of solid waste recovered by scavengers have been recorded each day. The average quantity of recovered material was less than 0.15% of the weight of deposited wastes. However, a large amount of material is recovered before arriving at the landfill site, especially during all stages of the collection process. During landfill operations the average time required by the scavengers to recover material from one truck was less than 30 minutes.

Closure of the Site

At the time of writing, the landfill operations had almost been completed. As there is almost no experience in sanitary landfilling in Indonesia the assessment of required post-closure operations is one of the objectives of the landfill demonstration project. A specific post-closure operational plan has to be developed. This plan must include the following elements:

- maintenance of surface drainage structures, leachate and gas management facilities;
- maintenance of final cover including revegetation, reforestation of eroded areas, and regrading of areas experiencing settlements;
- regulations concerning land use and zoning restrictions.

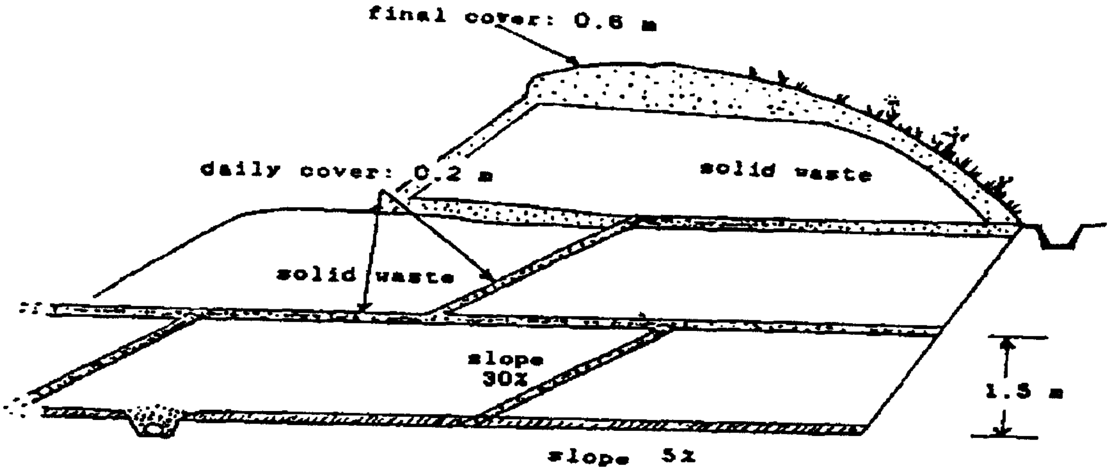


Figure 4-18: Cross Section of the Bandung Sanitary Landfill (source: Government of Indonesia, 1991)

4.8.2 Sanitary Landfilling in Malaysia

Municipal solid waste management in Malaysia is the responsibility of local authorities, such as municipal and district councils. The origin of these local authorities can be traced back to the setting up of government bodies for the provision of cleaning services in urbanised areas. Today, cleansing service is still considered the most important service provided by municipal and district countries. With the government's ongoing national policy towards privatisation of public works and services, a rapid movement towards privatisation of public cleansing works is underway. Under such circumstances, the local authorities are facing solid waste management problems.

A questionnaire survey of final solid waste disposal and a study on the actual situation of landfill sites was conducted to collect basic data and to grasp the existing situation in the local authorities. The data is now being analyzed, and this will be followed by the preparation of technical guidelines for sanitary landfills.

The questionnaire showed that covering of waste after disposal is only recently being practised. A particular problem is the availability of cover material. This is going to be an important criterion when selecting the landfill site. The survey also found that almost nothing was done to control leachate movement. Odour, fly-problems and littering are other problems. Smoke and other dangers from open burning, either spontaneous or purposely started by scavengers, are also major problems at existing sites.

Important measures required for upgrading existing landfill sites into Sanitary Landfills are listed below:

1. installation of an all-weather access road;
2. installation of gates, fences, ditches and notice boards to clearly demarcate the landfill site;
3. conducting landfill operations at a central working face;
4. securing cover material;
5. using a semi-aerobic landfill system (with leachate recirculation);
6. installation of gas vents;
7. installation of ditches to collect surface run-off;
8. using a combination of the area-trench and area-depression methods for landfilling operations;
9. implementation of waste classification before tipping;
10. recording data on vehicle disposal loads and operations of vehicles and manpower.

The first step is the securing of cover material for daily cover requirements.

A masterplan for solid waste management for the Penang State has been formulated. The optimum plan, obtained as a result of looking into the state's financial resource availability and technical level, is to implement landfilling of wastes and at the same time to work on improving efficiency of the present waste collection system. The masterplan establishes several levels of sanitary landfill operations which the municipalities can implement in steps. Therefore, each local authority must first examine its financial capability, technical level etc. and then select a sanitary landfill operation level which is suitable to the conditions of its area for implementation. Four levels are distinguished which may be compared with the environmental protection levels mentioned in Section 4.5.

In Malaysia, there is growing concern over the environmental problems associated with solid waste landfilling. The appropriate technology approach may help to succesfully implement waste disposal technology at a level appropriate for the society in Malaysia as well as in other developing countries.

4.9 WORKED EXAMPLES

In Wasteland, a sanitary landfill has to be designed. The landfill is sited 8 km from the city limits of Urbanville, the capital of Wasteland. The landfill will be constructed on the higher part of the banks of a small river. The landfill site will not be threatened by river flooding; its lower section is at an elevation 10 m above the highest river water level while its upper part 50 m above water level. The site dimensions are 800 x 800 m. The landfill itself will be 400 x 500 m, the remainder of the site being used for storage of soil, equipment, leachate treatment facility etc.

The original slope of the site surface is 5%. At the lower section, the highest groundwater level is 1 m below surface level. The subsoil consists of a four meter thick clay layer, average permeability 10^{-10} m/s. At the upper section, the highest groundwater level is 5 m below surface level. Here the subsoil consists of sandy clay or sand, with average permeability of 10^{-5} m/s. Near to the river, the subsoil also consists of clay, permeability 10^{-10} m/s.

The bottom of the landfill has to be located at least 1 m above the highest groundwater level. At the upper section, the original soil will be excavated and replaced by a 1 m thick clay layer. The original soil will be used for embankments and daily and intermediate covers.

The working face will start at the upper section of the disposal area. Each year, a cell with dimensions 37.5 x 200 x height will be completed and covered with soil (thickness 0.5 m). Cell dimensions include necessary earth bunds. When filling a new cell, most of the existing earth bund is removed. After removing the bunds, the dimensions are 34.5 m x 200 m x height.

After 10 years most of the settling will have occurred and the cell restored. The restoration starts with the emplacement of a layer, considered to be impermeable, on top of the soil cover. The rate of leachate generation rate will immediately fall. Two years after restoration, leachate will no longer be generated. During this post-closure period, a total volume of leachate of 1.5 m^3 per m^2 will be generated. The height of the landfill will be increased by 1.5 metres.

During the first 10 years, landfill gas will be collected. Landfill gas generation starts after 1 year and lasts 12 years. After 6 years, the highest generation rate is recorded. 60% of the disposed-of waste consists of decomposable matter. However, only 15% of decomposable matter will decompose.

The adsorptive capacity of the waste is 20% by volume. After a quarter of the adsorptive capacity is used, leachate generation will begin, at which time 20% of infiltrating water will be converted to leachate. After 45% of the adsorptive capacity is used, 40% of infiltrating water will become leachate. After 5-8 years, the waste adsorptive capacity is entirely used. A leachate collection system will be constructed. The system consists of a 1% collection pipe with a length of 500 m to which 21 slotted drains, each 400 m, are connected. The collection pipe will have a diameter of 1.5 m. Inspection and maintenance is possible. Leachate will be transferred to the leachate treatment facility by pumps. The collection system and drainage layer have a thickness of 0.5 m.

Before landfill operations commence, the collection pipe will be installed. During operations, the site will be progressively engineered. For each cell, original soil will be excavated; a protective clay layer will be installed (if necessary), followed by the drainage layer and the slotted drains. Finally, the drains are connected to the collection pipe. Run-off of rainwater from the original surface and adjacent area will be collected in a ditch around the perimeter of the site. A temporary ditch at the lower side of the landfill, helps to keep run-off away from the collection pipe.

Figure 4-19 shows a schematic plan view of the landfill site and its surroundings while Figure 4-20 shows a cross-section of the landfill site.

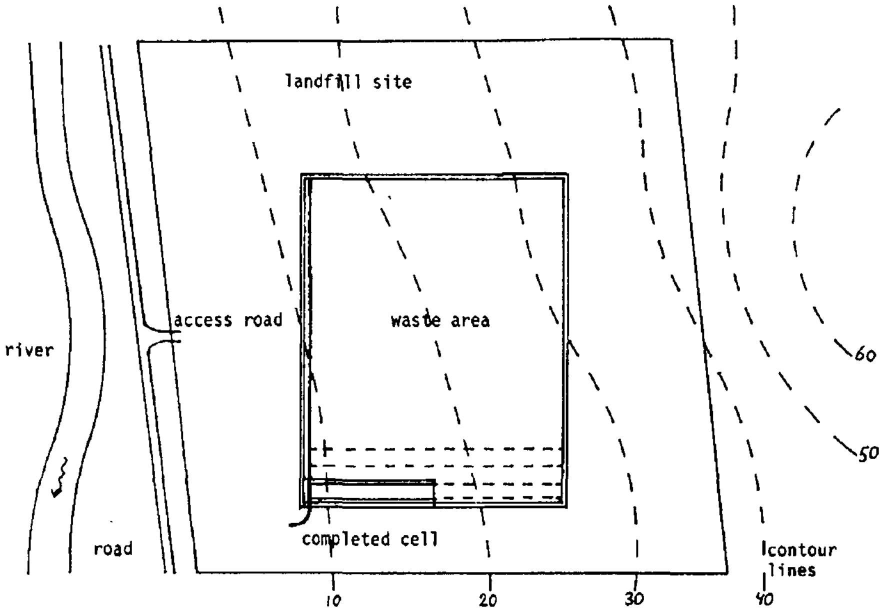


Figure 4-19: Schematic Top View of the Landfill Site

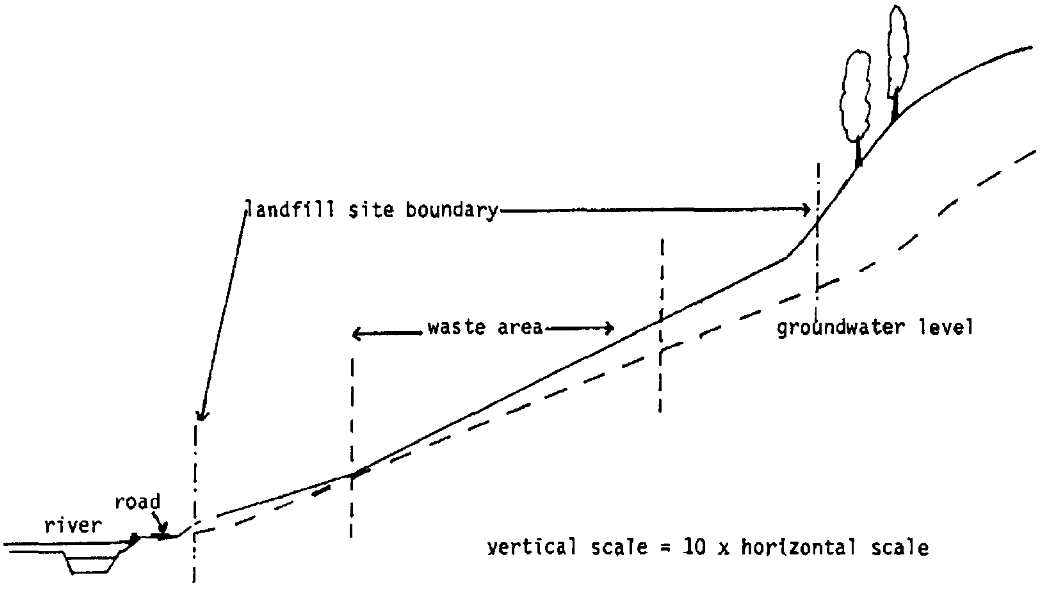


Figure 4-20: cross-section of the Landfill Site

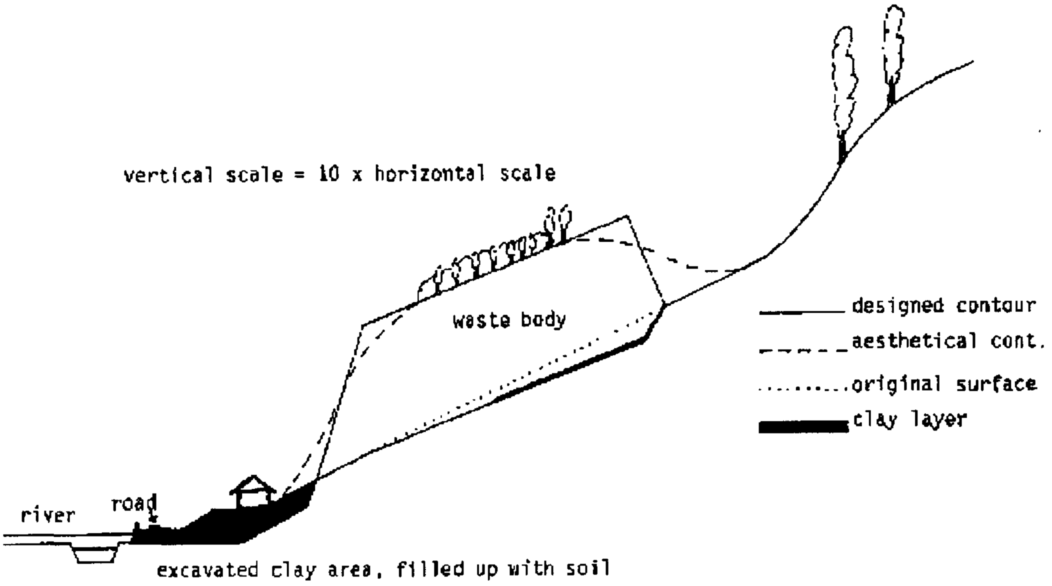


Figure 4-21 Cross section of completed landfill site

Important additional data are:

Precipitation:	1,500 mm/yr
Evapotranspiration (potential):	500 mm/yr
Evapotranspiration (actual):	300 mm/yr
Run-off coefficient:	0.2
Waste generation:	100,000 tons/yr
Waste collection density:	400 kg/m^3
Waste emplacement density:	800 kg/m^3
Final density:	1000 kg/m^3
Operational period of the landfill:	30 years

Questions:

1. Obtain the final height of the landfill at both the upper and lower sections of the landfill, after restoration. Neglect space needed for embankments and daily and intermediate covers.

2. The decomposable matter may be expressed as $C_{101}H_{179}O_{18}N_{12}S_{8}$. If 100 % will decompose, what is the total volume of gas generated and how many m^3 of water are needed for the conversion? Which gases will be present in the landfill gas generated and what percentage will each contribute to LFG? What is the quantity of LFG generated per kg of waste?
(Use microbial conversion equation, and calculate number of moles. One mole of gas represents 22.4 litres. Assume all sulphur will be converted to hydrogen sulphide. (In practice, sulphide will precipitate with metals, so lower hydrogen sulphide levels are normally found.)

3. In practice, only 15% of decomposable matter will be actually converted. How much LFG will be produced? How much water is needed? How much LFG will be generated per kg waste?

4. What will be the total volume of LFG generated per waste cell?

5. What will be the maximum LFG generation rate per cell?

6. What will be the maximum amount of LFG generated over the entire landfill? During what period will this amount be reached?

7. How much leachate (m^3 per m^2) will be produced during the first ten years in one cell (use waste with bunds cell dimensions)?

8. At what time will the generation of leachate occur (Assume that the height of the waste body immediately after operations commence, reaches its maximum)? How much leachate will be produced in the first and second year (m^3 per m^2 as well as m^3 per cell)?

9. What will be the maximum volume of leachate generated in the landfill (m^3/yr) Over what period will this volume be generated (Use waste cell dimensions only)?

10. The necessary retention time in the treatment unit is 1/50 years. The retention time is the only important parameter relating to treatment efficiency. What dimensions should be given to the treatment unit (Basin height must be less than 1/30 of basin length, basin width is 0.5 x basin length)?

11. What is the direction of the groundwater flow? If information on the groundwater quality is required in order to check whether the clay liner is still properly functioning, what can be done?

12. What measures can be taken if the groundwater under the landfill site appears to be polluted?

13. Draw a cross section of the completed landfill. Pay attention to a proper fit into the landfill surroundings.

Solution

1. Thickness waste body after settling:

$$\frac{100{,}000 \text{ tons/yr} * 1 \text{ ton/m3} * 30}{400 \text{ m} * 500 \text{ m}} = 15 \text{ metres.}$$

Thickness of drainage and cover layer = 0.5 + 0.5 + 1.5 = 2.5 m.

Landfill base lower section: 1 m above groundwater level, in this case surface level: landfill height 15 + 2.5 = <u>17.5 m</u>

Landfill upper section: 1 m above groundwater level, thus 4 m below surface level: landfill height 15 + 2.5 - 4 = <u>13.5 m</u>

2. The landfill capacity is 3,000,000 tons, therefore 60% decomposable matter is 1,800,000 tons. 1 mole of $C_{101}H_{179}O_{18}N_{12}S_8$ is 2.103 kg. Thus number of moles is 1,800,000,000/2.103 = 856 * 10^6 moles.

8 moles of $C_{101}H_{179}O_{18}N_{12}S_8$ + 482 moles of H_2O will be converted into 313 moles of $\underline{CO_2}$, 495 moles of $\underline{CH_4}$, 96 moles of NH_3 and 64 moles of $\underline{H_2S}$. Thus, the water used is given by:

H_2O: 482/8 *856 * 10^6 = 51.6 * 10^9 moles, 1 mole = 18 grammes, therefore 1 m^3 = 1000 kg = 55,555 moles. Water used is 51,600,000,000/55,555 = 0.93 * 10^6 m^3.

The gases generated are:
CO_2: 34.5 * 10^9 moles,..............= 34.5/94.3 = 36 %
CH_4: 54.0 * 10^9 moles,..............= 53/94.3 = 57 %
H_2S: 6,8 * 10^9 moles,...............= 6.8/94.3= 7 %
gas: 34.5 + 54.0 + 6.8 = 94.3 * 10^9 moles
NH_3: 10.4 * 10^9 moles
Total volume generated is 94.3 * 10^9 moles * 0.0224 m^3/mole = 2.090 * 10^9 m^3.

LFG generation LFG generated per kg of waste = 2,090 litres/ 1.8 kg = 1111 l/kg.

3. LFG produced = 0.15 * 2.090 * 10^9 = 0.314 * 10^9 m^3.

   LFG produced per kg of waste = 0.15 * 1111 = 167 l/kg.

   Water used = 0.15 * 0.93 * 10^6 = 0.14 * 10^6 m^3.

4. The landfill consists of 30 cells. Per waste cell, 0.314 * 10^9 * 1/30 = 10.5 * 10^6 m^3.

5. In a waste cell, the gas generation rate increases from 0 after 1 year to its maximum level after the 7th year. Thereafter the rate decreases to 0 after the 13th year. Assume a linear increase of the generation rate, then the maximum rate equals twice the average rate. The average rate is 1/12 * answer to last question; maximum rate is 1/6 * answer to last question = 1.75 * 10^6 m^3/yr.

6. Between 14 and 31 years the gas generation rate reaches its maximum level. This level is 10.5 * 10^6 m^3/yr.

7. Precipitation = 1,500 mm = 1.5 m^3/m^2.
   Actual evapotranspiration = 0.3 m^3/m^2.
   Run-off = 0.2 * 1,500 = 0.3 m^3/m^2.
   Waste adsorptive capacity = 0.20 * 15 = 3 m^3/m^2.
   Water used during decomposition is negelected. It can be calculated that this is app. 0.02 m^3/m^2 per year.

   Leachate produced = 10 * (1.5 - 0.3 - 0.3) - 3 = 6 m^3/m^2.

   Leachate total = 37.5 * 200 * 6 = 45,000 m^3.

8. Leachate first appears after 0.25 * 3 = 0.75 m^3/m^2 of water has infiltrated. During the first year, the cell is not very well covered (this happens after one year) so

evapotranspiration and surface runoff do not occur. After six months, 0.75 m^3/m^2 of rain has been precipitated and has infiltrated.

First half year: no leachate
Second half: L = P - storage in waste body;
L = 0.75 - 0.8 * 0.75 = 0.15 m^3/m^2 = 0.15 * 37.5 * 200 = 1,125 m^3.

Second year: Now a cover is installed, so E and run-off are important.
Infiltration = 1.5 - 0.3 - 0.3 = 0.9 m^3/m^2.
Additional storage in waste body is 60%, thus:
L = 0.9 - 0.6 * 0.9 = 0.36 m^3/m^2 = 2,700 m^3.

9. A waste cell produces leachate for a period of 12 years. After 0.5 years, leachate production begins. The leachate production rate increases up to 5-7 years after cell completion and then remains constant. After 10 years the leachate production rate decreases sharply. For 30 years, a new cell will be completed every year. Between 12 and 32 years, the leachate generation rate (averaged over the landfill), will be constant. This rate equals the total leachate production in one cell. This is the answer to question 7 plus 1.5 m^3/m^2 (after restoration):
L = (6 + 1.5) * 34.5 * 200 = 50,250 m^3/yr.

10. The volume of the treatment facility must be at least 50,250 * 1/50 = 1,005 m^3. A pond of 40 x 20 x 1.25 m satisfies this volume.

11. The groundwater flows from the upper part of the landfill site to the lower part. The groundwater at the lower boundary of the waste body may be regularly analyzed.

12. The polluted groundwater may be extracted from the subsoil. The depth of the borehole depends upon the vertical dispersion through the groundwater aquifer. The strength of the extraction unit has to be chosen in such a way that, below the well, the flow changes direction and thus also is directed towards the well. The groundwater may be treated in the leachate treatment facility.

13. Figure 4.1 shows a cross-section of a properly designed completed landfill.

SAQ 4.8

Given that MSW densities in high-density baling are 1000kg/m^3 and that a poorly run landfill site has MSW densities of 650kg/m^3 of compacted waste, by how much longer, and by how many tonnes, will the adoption of baling extend the life of the site which has a capacity of 2 x $10^5 m^3$ and receives, on average, 10,000 tonnes of MSW per year?

SAQ 4.9

How could scavenging at a sanitary landfill be kept under control?

ANNEX I
Site Selection Criteria

Engineering

- **physical site:** Should be large enough to accommodate all solid wastes produced in the period that is was designed for.
- **proximity:** Locate as close as possible to waste sources to minimize handling and reduce transport costs. Locate away from water supply and property line.
- **access** Should be all-weather, have adequate width, with minimum traffic congestion.
- **topography**: Should minimize earth-moving, take advantage of natural conditions. Avoid natural depressions and valleys where water contamination is likely.
- **geology**: Avoid areas with earthquakes, slides, faults, underlying mines, sinkholes and solution cavities.
- **soils:** Should have natural clay liner or clay available for liner, and final cover material available.

Environmental

- **surface water:** Locate outside 100-year floodplain. No direct contact with navigable water. Avoid wetlands. Avoid areas where normal runoff will inundate the site.
- **groundwater**: No contact with groundwater. Base of fill must be above highest groundwater table. Avoid sole-source aquifers. Avoid areas of groundwater recharge.
- **air:** Locate to minimize fugitive emissions and odour impacts.
- **terrestrial and aquatic ecology:** Avoid unique habitat area and wetlands.
- **noise :** Minimize truck traffic and equipment operation noise.
- **land use** : Avoid populated areas and areas of conflicting land use such as parks and scenic areas.
- **cultural resources:** Avoid areas of unique archaeological, historical and paleontological interest.
- **legal/regulatory:** Consider national, regional and local requirements for permits.
- **public/political:** Gain local acceptance from elected officials and local interest groups.

Economic

- **property acquisition:** Actual land costs plus related costs.
- **site development**: Excavation, grading, liner, new roads, and other development costs.
- **annual costs:** Fuel costs, operating labour, maintenance, land preparation, utilities and overhead.

GLOSSARY

abiotic factor

Factor not originating from biological activity.

advective transport

Movement of solutes by groundwater flow.

aerobic bacteria

Aerobic bacteria need oxygen for growth.

anaerobic bacteria

Anaerobic bacteria grow in an oxygen deficient environment.

aquifer

A subsurface zone of rock or soil where relatively high groundwater flows are possible

BOD

Biological Oxygen Demand, a measure of the amount of material present in water which can be readily oxidized by micro-organisms and is thus a measure of the power of that material to take up the oxygen in water supplies.

borehole

A hole drilled in the ground or landfill in order to obtain samples of the geological strata, wastes or liquids. Also used as a means of venting or withdrawing gas from landfills.

buffering capacity

A measure of the ability of waste to neutralize acidic or alkaline wastes added to it.

COD

Chemical Oxygen Demand, a measure of the total amount of chemically oxidizable material present in liquid.

consolidation

In this context: settlement of the waste body; the amount by which a landfill surface sinks below its original level due to compaction by its own weight or that of landfill machinery.

elutriation

In this context: spraying of recirculated leachate.

diffusion

The process by which molecules and particles migrate and intermingle, the sole energy source being that due to random motion of the molecules.

diffusive transport

Transport of solutes caused by diffusion.

evapotranspiration

The total water transferred to the atmosphere by evaporation from the soil surface and transpiration by plants.

first-order kinetics

Physico-mathematical expression to describe a reaction ($A \rightarrow B$) in which the reaction velocity is proportional to the amount or concentration of the reactant (A).

halogenated organic compounds

Organic chemicals containing one ore more of the halogens, fluorine, chlorine, bromine or iodine.

heavy metals

A term for those ferrous and non-ferrous metals having a density greater than about 4000 kg/m^3 which possess properties hazardous to the environment. The term usually includes the metals copper, nickel, zinc, chromium, cadmium, mercury, lead and arsenic.

hydraulic gradient

Slope of the water table.

inoculum

Bacterial substratum, added to a waste body in order to enhance microbial decomposition

landfill gas

A by-product from the digestion by anaerobic bacteria of putrescible matter present in waste deposited on landfill sites. The gas is predominantly methane together with carbon dioxide and trace concentrations of a range of vapours and gases.

leachate

Liquid which seeps through a landfill and by doing so, extracts substances from the deposited waste.

litter

The haphazard distribution of waste on land. At landfill sites, this is usually the light, windblown fraction in household waste such as paper and plastic which escapes before the waste is compacted and covered.

lysimeter

An experimental construction used to simulate conditions in a landfill to allow disposal processes to be studied.

mesophilic group c

A group of bacteria, whose optimum temperature range is 40°C.

morphology of the soil

Shape and size of soil particles.

oxidation

The loss of electrons by an atom or ion in a chemical reaction.

percolate

The flow of liquid through material by gravitational effects.

permeability

A measure of the rate at which a fluid will pass through a medium. Synonymous with hydraulic conductivity when the fluid is water.

porosity

The ratio of the space occupied by voids or pores to the total volume of the material containing them.

precipitation

1. The process of producing a solid from solution by the formation of a precipitate;
2. rainfall, hail, snow or sleet.

putrescible

Readily decomposed by bacterial action. Offensive odours usually occur as by-products of the decomposition.

redox

A chemical reaction involving oxidation of one chemical and reduction of another.

reduction

A chemical reduction is one in which electrons are added to an atom or ion.

run-off

Rain or melted snow which drains from the land surface.

saturated zone

A geological stratum in which all the void space is filled with water.

sorption

The process by which fluid is taken up by a solid or liquid.

vent

Usually refers to a facility provided in a landfill to permit the escape to the atmosphere of gases and vapours generated by deposited waste during biodegradation.

zero-order kinetics

Physico-methematical expression to describe a reaction (A → B) in which the reaction velocity is constant, not depending on the concentration of the reactant (A).

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ANSWERS TO SELF ASSESSMENT QUESTIONS

SAQ 4.1

The effects of a high sulphur content in the waste are:

- a high concentration of hydrogen sulphide in both leachate and landfill gas;
- suppression of methane content in landfill gas (if mixed with MSW).

SAQ 4.2

$$\text{Organic matter} + \text{oxygen} \xrightarrow{\text{microorganisms}} CO_2 + H_2 + NH_3 + \text{energy}$$

SAQ 4.3

This depends on the kind of contaminant. Contaminants with low partition coefficients are hardly retarded relative to groundwater movement, for example, the chloride ion Cl^-.

Contaminants with higher K_p values are significantly retarded.

Among the causes of contaminant retardation are:

- ion exchange;
- precipitation;
- biological reactions.

SAQ 4.4

A collection system for leachates is necessary.

- to avoid a high water table in the landfill, which would result in high concentrations of pollutants in the leachate;
- to avoid a high hydrostatic pressure head above the liner, which would lead to higher emissions of leachate through the liner;
- for stability of the landfill;
- to avoid leachate migration from the landfill on to the slopes.

SAQ 4.5

a) P- E = 1500mm/yr
= 1.5m/yr

Total production of leachate = $1.5 \times 2 \times 10^6$
= $3 \times 10^6 m^3/yr$
or $8{,}220m^3/d$ on average

b) Provide a surface capping with low permeability. The bulk of excess water would then be forced to run off in specially constructed collector drains.

SAQ 4.6

Heavy metals can be removed from the leachate by adding lime to precipitate them as hydroxides.

SAQ 4.7

The risks and hazards associated with landfill gas arise from its potential for causing fires, explosions and asphyxiation. These hazards may be reduced by avoiding:

- migration and build-up of landfill gas in the landfill;
- a composition of gas which has levels of oxygen, hydrogen sulphide and pH that constitute explosive, flammable or asphyxiating mixtures;
- a build-up of landfill gas in the shafts and structures;
- any practice or operation that could lead to ignition.

SAQ 4.8

The adoption of high-density baling will extend the landfill site life by:

$$\frac{1000 - 650}{650} \times 100 = 54\%$$

As the landfill (non baling) has a total capacity for

$$200{,}000 \times \frac{650}{1000} = 130{,}000 \text{ tonnes}$$

or 13 years of 10,000 t/yr, then baling will give an extra $\frac{54}{100} \times 13 = 7$ years of life on the basis of this calculation.

SAQ 4.9

Scavenging at a landfill may be controlled by:

- registering the scavengers and supplying them with a distinct reflective jack;
- providing sanitary facilities such as showers and toilets;
- providing a hardstand or conveyor belt on which the trucks can unload their refuse.

5 RESOURCE RECOVERY AND WASTE TREATMENT

5.1 INTRODUCTION

As indicated in Chapter 1 - Introduction, the management and disposal of municipal solid waste can be achieved by a mixture of:

1. waste reduction
2. recycling
3. waste-to-energy production
4. land disposal

Chapter 5 deals primarily with item 2: Recycling and item 3: Waste-to-energy production. Ultimately, of course any aspect of waste management includes item 4: Land disposal.

Resource recovery includes *materials* recovery through recycling certain waste components towards production of "new" components, and *energy* recovery through the incineration of pretreated wastes to produce energy for heating, or through 'slow burning' of organic wastes in composting and biogas production.

Waste treatment, as opposed to waste disposal, refers to those processes that are used specifically to prepare wastes through screening, pulverizing or sorting for further processing, or *treating*, in incineration, composting, biogas production and waste heat recovery. prior to landfilling the residuals from these treatment processes.

The purpose of this chapter then is to provide information, understanding and know-how of two areas: (1) the opportunity for and methods of recovering materials and energy from municipal solid wastes, and (2) the kinds of waste treatment methods which can be used prior to land disposal. These two areas are sometimes combined and are therefore treated in one chapter. Some examples include:

- The removal of certain materials from the waste stream, such as glass, paper, plastics, metals and others for direct reuse by consumers or recycling of the materials recovered in the production of new materials by industry (the materials recovery aspect), and the consequent reduction in the quantity of solid wastes to be treated and disposed (the treatment and disposal aspect).

- The use of incineration of solid wastes for the production of energy for central heating systems (the energy recovery aspect), and the consequent reduction in the quantity of solid wastes to be disposed of (the treatment and disposal aspect). Note that for reasons of air pollution control the treatment of incinerator stack discharges becomes necessary and sometimes also the treatment of residual ashes prior to landfilling.

- The use of composting of organic wastes for the production of agricultural fertilizers (the resource recovery and treatment aspect combined).

The essential reason for **resource recovery** is economic. In its simplest form, scavenging of dumps by individuals provides them with goods at the cost of their manual labour. Municipal authorities in many parts of the world now encourage separation of certain reusable products by the householder, and separate collection and resale to relevant industries. Central sorting of municipal wastes is also common. It increases the complexity and the cost of treatment and disposal, unless the sale of recovered products outweighs the cost. If there is insufficient demand for the recovered materials, the system fails. There are many examples, particularly in the developed world, where recycling systems, which were well intentioned and engineered, failed because of lack of markets. This is the greatest constraint on large scale increases in resource recovery at present.

Chapter 4 deals with the topic of waste disposal on land through *sanitary landfill.* Land disposal always was, is and will be the most commonly used method of solid waste disposal worldwide. With increasing urbanization and industrialization, and the consequent increase in land costs in and near urban areas, other forms of waste treatment and disposal came into use. *Incineration* of solid wastes is the most common of these. Incinerators were built in urban areas, reducing the distance of transport, and thus the cost, for collection systems. As air pollution concerns grew, treatment of flue gases became more stringent, increasing the cost of incineration for waste disposal. Combining incineration for waste disposal with the production of energy for central heating systems in urban areas became common practice in many cities. In recent years the concerns of the public over environment and health have made it much more difficult to site landfills and incinerators in or near cities. The use of incineration and heat recovery from waste is most predominant in cities of the developed world, particularly in Europe, Japan and more lately in the United States.

A much older form of waste treatment and reuse is *composting.* The use of waste organic matter, - human faeces and urine, animal faeces and urine, food and plant matter (garbage) and domestic solid waste, and farm waste plant matter - has been practised by farmers for thousands of years to aid in the maintenance of agricultural production. The biological decomposition of some or all of these organic wastes under controlled conditions is called composting. It results in a dark, nutrient-rich soil conditioner. While composting, in one form or another, is used world-wide, its greatest use at present occurs in the developing countries, particularly in China. Most farmers in developed countries prefer the use of chemical fertilizers.

A related process is *biogas production.* The input materials are essentially the same as for composting. However, the desired product is not a natural soil fertilizer, but the biogas produced in the anaerobic decomposition of organic matter. It can be used as a source of energy for cooking, heating and lighting on a farm operation, and for heating or power generation in larger installations. As with composting, its major use occurs in developing countries.

Finally, with the ever increasing use of natural materials and the creation of new materials, special attention to the reuse of certain materials and products contained in solid waste has occurred in recent years. The most important of a long list of possible items are presented: paper and paper products, metals, glass, plastics and automobiles.

Objectives

The objectives of this chapter are:

- to examine the potential of the recovery of material and energy resources from municipal solid waste
- to emphasise the differences between developed and developing countries and the influences of these differences on the techniques and constraints of resource recovery
- to introduce the techniques and equipment used for resource recovery
- to describe the process of incineration with energy recovery and present flow diagrams for a typical incinerator operation
- to describe the techniques used for the composting of organic wastes and the conditions required for optimal efficiency
- to describe the techniques used for bio-gas production and to examine the advantages and disadvantages of this technology
- to discuss the merits of the recovery of the most important materials found in municipal solid waste and the constraints which apply to their recovery
- to present a number of Case Studies to illustrate the diversity of resource recovery techniques and operations in different countries

Chapter 5 is organized as follows:

Section 5.2 Resource Potential of Solid Wastes

- the opportunities and constraints of recycling materials and energy from municipal solid waste, and its effect on reducing the remaining wastes to be treated and disposed of.

Section 5.3 Processing Techniques and Equipment

- coverage of those techniques which are required for effective materials and energy recovery, such as hand sorting, screening, mechanical separation, air separation, optical separation, drying and dewatering.

Section 5.4 Incineration and Energy Recovery

- coverage of these topics is quite brief as they do not apply as much to developing countries.

Section 5.5 Composting and Biogas Production

- coverage of this topic is more extensive as they are used extensively in developing countries.

Section 5.6 Selected Materials Recovery

- coverage of recovery of paper and paper products, plastics, metals, glass, and automobiles.

Section 5.7 Case Studies

Section 5.8 Problems/Questions

A series of problems/questions for users of the manual to work on.

References and Bibliography

Summary listing of all materials used in Chapter 5.

As in other chapters the need for brevity necessitates choices to be made for inclusion and exclusion of material. Technical materials and examples which are primarily applicable to developed countries have been given less emphasis than those applicable to developing countries.

References and bibliographic material are included to provide additional material for the reader. It is realized that much of the information comes from sources that may not necessarily be available in libraries. Therefore included in some references are addresses where the particular references can be obtained.

An important omission throughout this chapter is a discussion on costs. Reasons for this omission include:

- inadequate or possibly misleading information reported on individual projects and cases
- the changing technology and experience in resource recovery
- difficulty of making international comparison of projects carried out over the past two decades when inflation and currency fluctuations have occurred throughout.

The best remedy is to obtain costs from similar projects carried out recently and locally.

5.2 RESOURCE POTENTIAL OF SOLID WASTES

5.2.1 Overview

The attention paid to solid wastes as a source of recoverable materials is very recent in the developed countries, but very old in the developing countries. As the difficulties to locate sites for landfilling and incineration plants grew in urban cities of the developed world, much more attention has been given to reducing the amount of solid waste generated, and to reducing the amount to be landfilled or incinerated through separating at source or centrally those products for which a steady market for recycling could be found. Many experiments and trials for recycling systems have been and are currently carried out. While successes have been reported by many, the key issue is to provide for a stable market for the recycled components. Successful participation by householders and industry in separating potentially valuable products and proper collection and temporary storage by municipalities have nevertheless been abandoned in some cases, because anticipated markets and prices for the recycled products have not materialized on a steady basis.

This situation is very different in developing countries, and to a lesser extent in some rural parts of developed countries. The age-old practice of scavenging wastes put out in front of houses on the streets and in open dumps or landfill sites, practised at one time all over the world, remains today a very common practice in most of the developing countries of the world. Furedy (1992) reports on a number of case studies in Asia. For street pickers and dump-pickers this activity is their only job and livelihood. They are often unaware of the real health dangers of their work. The first objective of the several projects initiated by private and municipal agencies is to provide a safer and more organized environment for the many people and their families who exist on picking of wastes. Reduction of quantities of waste to be disposed of by municipal authorities is of much lower importance. It is ironic that where recycling from wastes is most prevalent, the wastes themselves have much less valuable material to be recovered, since the householders themselves are more careful in what they waste.

In the following subsections different aspects concerning the resource potential of solid wastes are discussed. It is important to remember that the emphasis in the developed world is very recent and experience is gained rapidly. It is also important to remember what works in the urban areas of developed countries, may be inappropriate to transfer to urban areas of poor countries, because of the very different social and economic situations.

5.2.2 Why Recycle?

Municipal solid wastes contain materials which have been thrown out by the initial user, but which may be of value to someone else if properly separated and cleaned. Solid wastes also contain materials which can be burnt to produce energy. The street and dump pickers of Calcutta can answer this question very directly: by selling the recovered goods to itinerant buyers and small shops they earn a living, albeit a very meagre one (Furedy, 1992). For the manager of the office of solid waste disposal of an American city the answer may be: it may extend the life of the local land disposal site by a few more years through reduction in the quantities of solid wastes which need to be disposed there, and, if he is fortunate to have steady markets and good prices for the recovered materials, he may be able to reduce the overall operating costs for solid waste disposal of the city.

Environmental groups will stress the savings in resources and energy, and the benefits to the natural environment through less land required for landfills and reduced air pollution because of less material to be burnt. The industrialist who buys the recovered material, usually mixed with new virgin material, may appreciate the lower material cost, but the quality control manager will likely complain about the variability in the recovered portion and the problems caused for the final product, about which some of the customers will complain to the sales department. As a recession hits, the demands for manufactured goods decreases, often resulting in lower prices for raw materials, and consequently in reductions in the quantities and the prices paid for recovered materials. The manager of the solid waste office of the American city may be forced temporarily to dispose the separated materials in the landfill site, because no one wants it! He did his job well, but the "system" let him down.

The above stories will indicate that there are legitimate but differing viewpoints on 'why recycle'. However, there can be little doubt today, that resource recovery from waste material is an important part of waste management. It reduces the demand on natural resources, it can produce energy and it also reduces the quantities which must be disposed of.

5.2.3 What and how much is and can be Recycled?

Composition of Urban Solid Wastes

Cointreau (1986) provides the following information on quantities and composition of urban solid wastes, with special emphasis on developing countries (see Table 5.1).

Table 5.1 Patterns of Municipal Refuse Quantities and Characteristics for Low, Middle and Upper Income Countries

	Low-Income Countries /a	Middle-Income Countries /b	Industrialized Countries
Waste Generation (kg/cap/day)	0.4 to 0.6	0.5 to 0.9	0.7 to 1.8
Waste densities (wet weight basis- kg/m^3	250 to 500	170 to 330	100 to 170
Moisture Content (% wet weight at point of generation)	40 to 80	40 to 60	20 to 30
Composition (% by wet weight)			
Paper	1 to 10	15 to 40	15 to 40
Glass, Ceramic	1 to 10	1 to 10	4 to 10
Metals	1 to 5	1 to 5	3 to 13
Plastics	1 to 5	2 to 6	2 to 10
Leather, Rubber	1 to 5	--	--
Wood, Bones, Straw	1 to 5	--	--
Textiles	1 to 5	2 to 10	2 to 10
Vegetable/Putrescible	40 to 85	20 to 65	20 to 50
Miscellaneous inerts	1 to 40	1 to 30	1 to 20
Particle Size, % greater than 50mm.	5 to 35	--	10 to 85

/a Includes countries having a per capita income of less than US\$360 in 1978.
/b Includes countries having a per capita income of more than US\$360 and less than US\$3,500 in 1978.
Source: Cointreau (1986)

Several conclusions can be drawn from Table 5.1, which will influence selection of appropriate waste management technology. Municipal solid waste in cities of developing countries differs from that of industrialized countries in that:

- waste densities are high, generally 2 to 3 times higher than those in industrialized countries;

- moisture contents are high, generally averaging about 3 times higher;
- composition is largely organic with the portion of vegetable/putrescible materials typically 3 times higher;
- there may be a substantial amount of dust and dirt in cities where sweeping and open ground storage is part of the collection system; and
- particle size is much smaller, often exhibiting less than half of the materials in the over 50 mm range than would be seen in refuse from industrialized countries.

As a result of the above conclusions regarding the nature of urban refuse in developing countries, the following considerations are commonly true relative to appropriate technology:

- compaction trucks which achieve a final density of about 400 kg/m^3 and a compaction ratio of 4:1 in industrialized countries, commonly achieve a compaction ratio of 1 1/2:1 in developing countries;
- landfill dozer/compactors designed to achieve a final density of about 600 kg/m^3 and a compaction ratio of 6:1 in industrialized countries, would achieve a compaction ratio of only about 2:1 in developing countries;
- incineration would generally not be self-sustaining in developing countries, much less produce recovery energy, because of the high moisture content characteristic of the wastes;
- biodegradation techniques, such as methane generation and composting are often technically viable because of the high organic content of the refuse;
- because of the smaller particle sizes characteristic of refuse in developing countries, size reduction facilities such as shredders would provide only marginal benefits to a resource recovery option; and
- materials which could be recovered by processes such as air flotation and magnetic separation are present in such small amounts that mechanical sorting for purposes of recycling glass, metals and plastics is generally not economical. (Cointreau, 1986).

SAQ 5.1

You need to establish the quantity and composition of the wastes generated in a community of 5,000 people. Currently all wastes are brought to an open dump by either the municipal trucks or by private citizens/businesses. How would you go about doing this?

Describe the plan, steps of implementation, needed equipment and manpower in sufficient detail, so that you could organize this undertaking effectively.

SAQ 5.2

The solid wastes from a summer camp with 100 children and a staff of 25 are to be collected once per week. If bottles and cans (representing 20% of the weight) are removed, paper wastes (40%) are burned in the camp incinerator, and only the wastes from the kitchen (30%) and miscellaneous wastes from cabins (10%) are collected, what volume will need to be picked up weekly? (from Henry and Heinke (1989)).

SAQ 5.3

The composition of solid waste from a residential community is as follows:

Combustibles	% by weight	Noncombustibles	% by weight
Paper and cardboard	35	Metal	10
Food wastes	15	Glass	10
Garden trimmings	10	Ash	10
Others (textiles, rubber, leather, wood, plastics)	10		

Estimate a) the moisture content, b) the density, and c) the energy content of this waste based on typical values for the components. (from Henry and Heinke (1989)).

Types and Extent of Recycled Materials

Having reviewed quantities and composition of solid wastes we can now turn to the question of what and how much is currently recovered for recycling.

Theoretically, most consumer discards are available for recycle. However, there are several practical limitations to what can be recycled.

1. *Market demand*: Recycling really means 'recovery and reuse'. Not until a commercial enterprise reuses the recovered material in the production of a new material or product has recycling been achieved. Whatever the reasons for rejection of recycled material may be, if there is no sale, then no recycle.
2. *Technical difficulties in recovery*: Municipal solid waste is a very heterogeneous mixture of many components. Unless separation of desired recyclable materials occurs at the household, it may be technically, and economically, difficult to obtain the desired quality of material. Examples include paper and paper products, glass, plastics etc.

3. Storage facilities and costs may limit certain materials from recycling, ie. flammable wastes.

Tables 5.2, 5.3 and 5.4 provide information on the amount of various components recycled.

Table 5.2 Recovery Rates for Aluminium, Paper and Glass in Selected Countries,1985

Country	%		
	Aluminium[1]	Paper[2]	Glass[3]
Netherlands	40	46	53
Italy	36	30	25
West Germany	34	40	39
Japan	32	51	17
United States	28	27	10
France	25	34	26
United Kingdom	23	29	12
Austria	22	44	38
Switzerland	21	43	46
Sweden	18	42	20
Average	28	39	29

1. includes industrial recycling
2. 1984 data
3. In Europe most of the glass is refillable, recovery rates apply only to non-refillables.
4. 1983 data

Source: Pollock (1987) from several sources

Table 5.3 Major Commodities recycled in the United States, 1984

Component (%)	Generated (10^6 tons)	Recycled (10^6 tons)	Percentage Recycled
Paper and paperboard	62.3	12.9	21
Glass	13.9	1.0	7
Metals	13.9	0.9	7
Plastics	9.7	0.1	1
Rubber and leather	3.4	0.1	3
Others	45.1	0	0

Source: Franklin Assoc. (1984 and 1988)

Table 5.4 Solid Waste Management in the United States, Japan and West Germany, 1988

	U.S.	Japan	West Germany
Recycled/Reused, %	10	50	15
Waste-to-Energy, %	5	23	30
Land filled/Other, %	85	27	55
Total %	100	100	100

Source: in Taylor (1989) from Franklin Assoc. (1988) and others

The following observations can be made from these data:

- Japan, and to a lesser extent West Germany, recycle a much greater percentage of their waste stream. (Table 5.4) They also generate less solid waste per capita than the U.S. (see Chapter 2)

- Paper and paper products almost universally are recycled the most, about 20 to 50%. Glass and metal follow at some distance. (Tables 5.2 and 5.3)

- In the U.S. landfilling predominates (85%), whereas it is lowest in Japan (27%) and in between in West Germany (55%). The higher the population density, the lower is the use of landfill. The reverse is true for waste-to-energy usage. West Germany may be generally indicative of European practice.

The specifics of the most important recycled materials are provided in greater detail in Section 5.5.

How much more is likely to be recycled? As already indicated this will likely vary with countries (even among the industrialized world) and certainly with different components. The U.S. Environmental Protection Agency has set a national goal of 25% for overall recycling, indicating that recycling is still in its infancy in the United States. In Japan and in Europe it appears that a much higher goal, perhaps as high as 50% may be realizable, which eventually might also be achieved in the urban areas of North America.

What about recycling statistics in the developing countries? The simple answer is probably: lots of recycling/reuse but little data. As indicated earlier (Table 5.1) much less waste is generated, because of lower consumption of goods, more direct recycle by the householder, extensive recovery and resale through the private system of street and dump pickers and second-hand shops, and in a few cities official recycling/recovery by the municipal authorities. Even if the latter were to provide data on the extent of recycling for the wastes under their control, those percentages would be a substantial underestimate, because they would not include the unofficial, but extensive private recycling.

So far the discussion has dealt with materials recovery. The second important component is energy recovery. Table 5.4 provided information on the substantial use of waste-to-energy plants in Europe and Japan, and more recently also in the United States. Abert (1985) provides extensive information on 12 waste-to-energy recovery systems in eight European countries. As indicated in the discussion following Table 5.1 neither incinerator nor waste-to-energy recovery are much used in developing countries, because of the much higher moisture content of the wastes, and the generally much less usage of capital and technologically intensive solutions.

On the other hand biogas production and composting are often technically and sometimes economically feasible because of the organic content of municipal solid wastes in developing countries (Cointreau, 1986).

Energy recovery and biogas production are dealt with in Section 5.5

5.2.4 Management Structure for Recycling

At the present time, in most cases, solid waste management in urban areas is a municipal service similar to water supply, wastewater treatment, street cleaning and fire protection. In some cases all or part of these services required by a city are turned over to the private sector. With respect to the recycle/reuse portion of solid waste management, direct involvement of commercial companies makes good sense. As has already been pointed out, existence of markets at a reasonably steady volume and price, is the most important issue for successful recycling. But the Office of Solid Waste Management of a city has control only over the separation, recovery and collection, not over reuse. As the business of waste disposal is rapidly growing, private enterprises have virtually taken over the industrial need for waste disposal, and might well be in a better position to take over all, or at least the recycle portion of waste management of cities. For waste-to-energy facilities, the recent trend has been the private or commercial approach, especially for the larger facilities. Some local officials feel the private sector can deal with the complexities and variables of waste disposal markets more effectively and expeditiously outside of the political arena. Others recognize that no contract with a private company can relieve the local government from the responsibility of solid waste disposal and associated environmental impacts, and so it does not make sense to give up control. Perhaps a combination of public and private collaboration is the answer. (Taylor. 1989)

In developing countries the age-old system of street and dump pickers and resale shops is in fact a reasonably well-working private system of recovery and reuse. The local government still retains overall responsibility for collecting the remaining solid wastes and depositing/managing them in landfills. Furedy (1992) reports on, and recommends improvements through community action in Asian cities:

> *"Worldwide, solid waste management is being transformed by national planning for waste reduction, the promotion of recycling, and stakeholder cooperation. But there is no large city in Third World Asia that has yet applied these principles to solid waste management. What this review of some community based projects suggests is that the ways in which new approaches will emerge in Asian cities may differ from the patterns seen in the past decade in the West and Japan. Although the physical and political problems of overflowing dumps and lack of sites for new ones are real and often very urgent, these have not so far created a general interest in waste issues in Asian cities. Until the call for national solid waste planning (Sakurai, 1990) is acted upon, creative thinking in municipal solid waste management seems likely to be shaped by the experiment of community groups and nongovernmental organizations with social as well as environmental goals.*
>
> *Because the most immediate social problems of municipal solid waste management in poorer Asian cities relate to the recovery of resources by poor people, the social orientation leads community based organizations to seek improvements in methods of resource recovery. Because of their orientation to employment and social advancement for underprivileged persons, the main projects described here have had to find ways in which street people can become legitimate waste collectors, and informal waste traders can contribute to community projects. Because their financial resources are slim, their social purposes are adjusted to market realities. Their educational aims are to change attitudes towards waste workers and waste work as well as to change waste management habits.*
>
> *Although poor neighbourhoods have urgent need for waste services, project participants are finding that, in working towards comprehensive solutions to solid waste problems, it is more effective to begin in affluent and middle-class areas. Source-separation and decentralized composting are more worthwhile and feasible in these areas because the wastes have more recyclables, the householders understand the purpose of waste reduction, they can pay for collection services, and there is space for composting. If these experiments in waste-sorting, trading and composting prove sustainable, then it should be possible to regularly cross-subsidize services to more needy areas.*
>
> *Starting from community activities, the project participants are developing an understanding of the complex resource and waste issues in modernizing societies. They are demonstrating how social, economic and ecological goals are relevant to the daily problems of waste collection and disposal, and so are helping to develop diverse motivations for environmental improvement. Among the projects mentioned here, there is a range of ideas that, if translated into practice on a larger scale, could form the basis for community action to ameliorate solid waste problems throughout the large cities of Asia, Africa and Latin America."*

Some of the case studies reported by Furedy (1992) are included in Section 5.6.

5.2.5 Summary

It is hoped that the material presented leaves six important thoughts with the reader:

1. The disposal of solid wastes is not just a technical and economic matter, but also a social and organizational issue.

2. Collaboration between the public and private sector will likely lead to more satisfactory solutions.

3. The existing situations in *developed* and *developing* cities and countries differ greatly and each must develop appropriate legal, social, technical and economical solutions to their solid waste management problems which will often differ greatly from each other.

4. Recovery and reuse, often called recycling for short, makes eminent sense, as one step in a four-part process of (1) waste reduction, (2) recycling, (3) waste-to-energy recovery, and (4) land disposal. The relative use of the four parts will depend on local circumstances.

5. Recycling and waste-to-energy recovery is generally still in its infancy. Much more is likely to happen in the next decades.

6. The most important items for successful recycling programs are market, market and market.

5.3 PROCESSING TECHNIQUES AND EQUIPMENT

5.3.1 Overview

Processing techniques are used to improve the efficiency of operations in recovering resources, conversion products and energy from solid wastes. The major techniques employed are:

1. volume reduction through compaction, (see Chapters 3 and 4)
2. size reduction through mechanical means, (covered in this section)
3. separation of components (manual and mechanical) (covered in this section)
4. moisture content reduction through drying and dewatering. (covered in this section)
5. volume reduction through incineration, (see section 5.3)

The first, compaction, is primarily used to improve the efficiency of collection and land disposal of wastes and is covered in Chapters 3 and 4. Item 5 is primarily associated with incineration and energy recovery and is therefore covered there. The other three techniques are introduced here.

Before employing any of these techniques it is important to familiarize oneself with the industrial trade literature on the specific technique for current engineering data on design and performance of equipment. These techniques will be employed, often in combination, prior to the main processes of recovery of materials for recycling, incineration, with or without energy recovery, and of biogas production and composting.

As shown in Table 5.1 there are significant differences between developing (low income) countries and developed (industrialized) countries with respect to volume (or density) of solid wastes, with respect to moisture content, and with respect to particle size (Cointreau, 1986). To recapitulate:

- waste densities in developing countries are high, generally 2 to 3 times higher than those in industrialized countries. Therefore, volume reduction through compaction or incineration is less required or possible in developing countries.

- moisture contents of solid wastes in developing countries are about three times as high as in developed countries. This makes drying/dewatering of wastes expensive to the extent of not using these operations, nor is incineration feasible because burning of wastes is not self-sustainable.

- particle size of solid wastes is generally much smaller in developing countries. Therefore the use of techniques to reduce particle size is often not effective.

In general therefore, it can be said that the processing techniques and equipment covered in Section 5.2 are likely to be of less use in waste disposal and treatment of solid wastes in developing countries as compared with industrialized countries. Furthermore, such equipment may more likely be produced in industrialized countries, and therefore their purchase for use in developing countries would be a drain on the often limited foreign exchange resources of the developing country, further limiting the use of such equipment. Because of the greater emphasis of this manual on the needs of developing countries, coverage of techniques and equipment in this section will only be cursory. If more information is required the reader should refer to other textbooks and the industrial literature of equipment manufacturers for the applicable process.

5.3.2 Size Reduction Through Mechanical Means

There are several reasons why size reduction by a number of techniques may be used in the overall process of waste treatment and disposal. These include:

- Wastes may be *shredded* ahead of **landfilling** to provide a more homogeneous product, which may require less cover material and less frequent covering, than without shredding. This can be of economic importance where cover material is scarce or needs to be brought to the landfill site from some distance.

- Wastes may be *shredded, milled* or *screened* ahead of recovering materials from the waste stream for **recycling**.

- Wastes may be *shredded* to achieve a greater density before **baling** them, a process that is sometimes used ahead of long distance transport of solid wastes.

- Wastes may be *shredded* or *milled* in order to make a better fuel for **incineration** and **waste energy recovery facilities**. These size reducing techniques, coupled with separation techniques such as screening, result in a more homogeneous mixture with relatively uniform size, moisture content and heating value, thus improving the subsequent steps of incineration and energy recovery.

- Wastes may need to be *shredded* and/or *screened* ahead of moisture reduction through drying and dewatering.

Equipment used for Size Reduction

The type of equipment, their mode of action and their general application are listed in Table 5.5.

TABLE 5.5 Types, Mode of Action, and Applications of Equipment Used for Mechanical Size Reduction

Type	Mode of Action	Application
Small grinders	Grinding, mashing	Organic residential solid wastes.
Chippers	Cutting, slicing	paper, cardboard, tree trimmings, yard wastes, wood, plastics.
Large grinders	Grinding, mashing	Brittle and friable materials. Used mostly in industrial operations.
Jaw crushers	Crushing, breaking	Large solids.
Rasp mills	Shredding, tearing	Moistened solid wastes. Most commonly used in Europe.
Shredders	Shearing, tearing	All types of municipal wastes.
Cutters, Clippers	Shearing, tearing	All types of municipal wastes.
Hammer mills	Breaking, tearing,	All types of municipal wastes. Most cutting, crushing commonly used equipment for reducing size and homogenizing composition of wastes.
Hydropulper	Shearing, tearing	Ideally suited for use with pulpable wastes, including paper, wood chips. Used primarily in the papermaking industry. Also used to destroy paper records.

Source: Tchobanoglous et al (1977)

The most frequently used equipment for reducing the size of particles in solid wastes is a **hammermill**. It is a large piece of equipment. Hammers, fastened flexibly to a shaft, usually rotating horizontally at high speed, crush the solid waste particles between the hammer and breaker plates or cutting bars fixed around the periphery of the round chamber. Abert (1985) reports on the use of hammer mills as a first step of size reduction in five waste energy recovery plants in Europe and provides perspectives on their use for developing countries. In two plants (Spain, Sweden) a **flail mill** is used instead of the hammermill. Rather than solid masses of steel, which make up the hammers in the hammermill, the flail mill has wire or chain breakers attached to a rotating shaft. The flails cut up organic material, open plastic bags, but fold up or go around objects that they cannot cut.

5.3.3 Separation of Components

Separation of components contained in solid wastes are required for:

- recovery of valuable materials for recycling
- preparing solid wastes by removal of certain components prior to incineration, energy recovery, composting and biogas production

The most effective way of separation is manual sorting by the householder prior to collection. In many countries such systems are now routinely used. The municipality generally provides separate, easily identifiable containers into which the householder deposits segregated recyclable materials such as paper, glass, metals etc. Usually a separate collection is carried out for the recyclable material. At transfer stations and landfill sites separate areas are set aside for each of the recyclable materials for householders to deliver materials when there is no municipal collection system.

Techniques and Equipment of Solid Wastes Separation

Table 5.6 provides summary information on the separation of solid waste components. Some of the more important centralized separation techniques are briefly discussed below:

- Previewing of waste stream and manual removal
- Screening
- Air Separation
- Magnetic Separation
- Optical Separation

Previewing

Previewing of the waste stream and manual removal of large or hazardous materials is necessary prior to most types of separation or size reduction techniques. This is done to prevent damage or stoppage of equipment such as shredders or screens. Items such as rugs, pillows, mattresses, large metallic or plastic objects, wood or other construction material, paint cans, etc. are to be removed.

Screening

Screening is the most common form of separating solid wastes into size-classified components by the use of one or more screens. Screens can be used before or after shredding or milling. Screens are also used after air separation of wastes.

The most commonly used screens are rotary drum screens, - also called trommel (the german word for drum) screens -, and various forms of vibrating screens. Figures 5.1 and 5.2 illustrate types of screens. Rotating wire screens with relatively large openings are used for separation of cardboard and paper products.

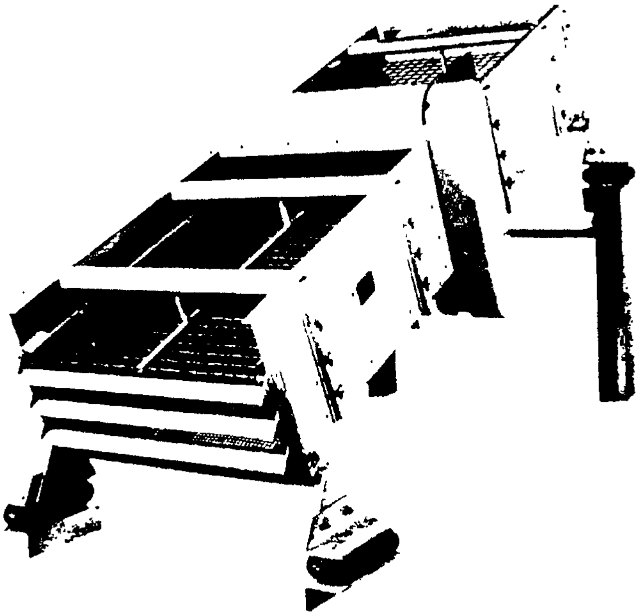


Figure 5.1 Vibrating screen (Universal Vibrating Screen Company) (from Tchobanoglous et al (1977))

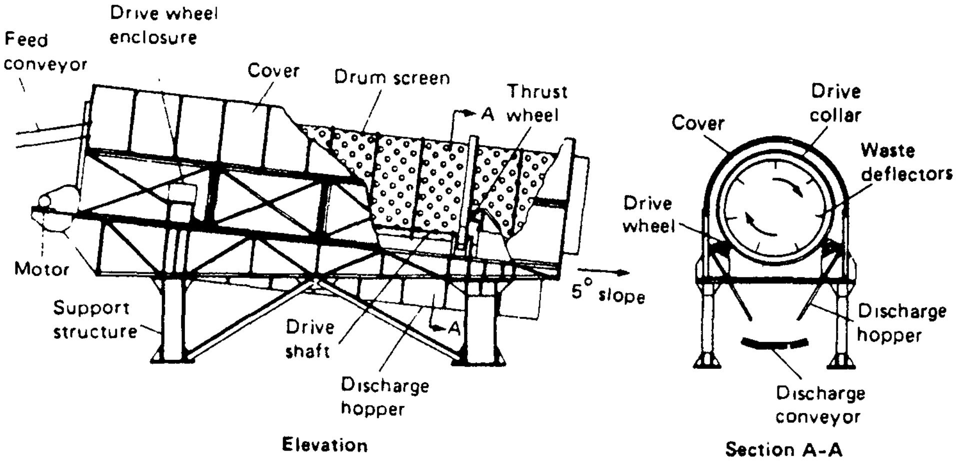
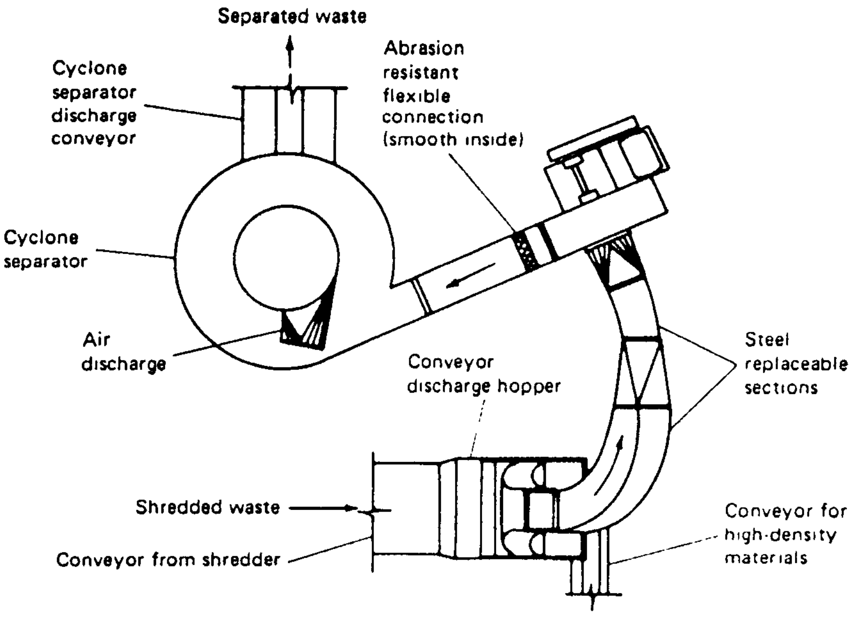


Figure 5.2 Rotary Drum Screen (Triple/s Dynamics System Inc.) (from Tchobanoglous et al (1977))

Figure 5.3 Internal View of Rotary Drum Screen (from Tchobanoglous et al (1977))

Air Separation

The use of air separation or classification has been adopted for solid waste disposal from its use in industrial applications. It is primarily used to separate lighter, usually organic material,



Plan

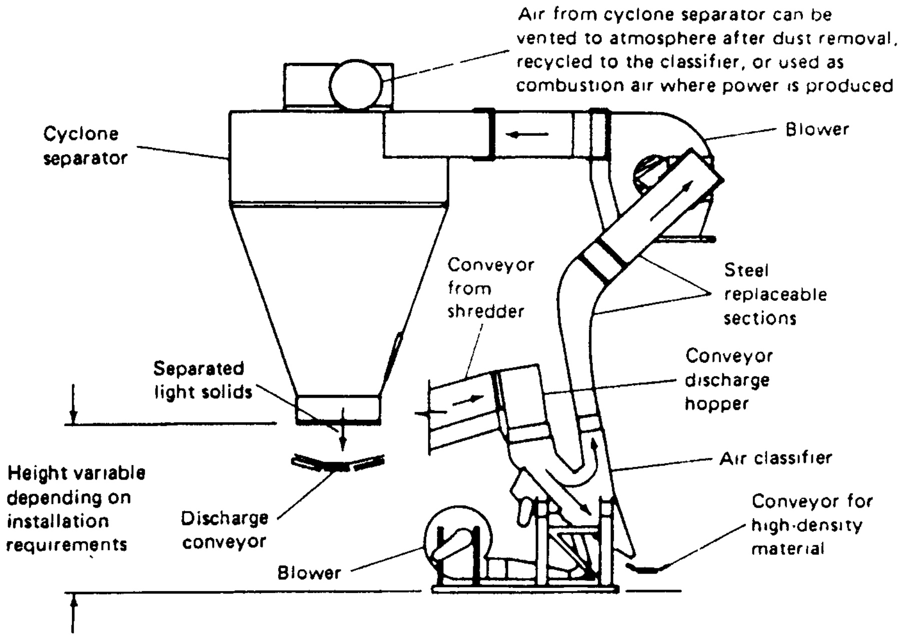


Fig. 5.4 Typical air classifiction system for solid wastes (Triple/S Dynamics Systems Inc.)
Source: Tchobanoglous (1977)

from heavier, usually inorganic material. The lighter material may include plastics, paper and paper products and other organic materials.

Air separation equipment types include:

- simple upward air flow chute types, where the lighter material is carried by the airflow to the top, and heavier materials fall to the bottom of the chute.
- various types of patented means to improve on the basic chute-types, through additions of vibrating equipment, agitators, and additional high velocity air streams at strategic points.

Normally there is also a need to separate the light fraction of organic material from the conveying air streams, which is usually done in a cyclone separator. The heavy fraction is removed from the air classifier to the recycling stage or to land disposal, as appropriate. The light fraction may be used, with or without further size reduction, as a fuel incinerators or as compost material.

Magnetic Separation

This method is most common to recover ferrous materials from the solid waste stream. Magnetic recovery of ferrous material may happen singly, or in conjunction with other separation techniques (shredding, air classifying, incineration).

Suspended magnets over a rotating belt conveying the solid wastes is one form of equipment used. Magnetic pulleys and drums are other forms. Consult local manufacturers for details.

Optical Separation

This is used mostly to separate glass from the waste stream. It can be accomplished by identification of the transparent properties of glass to sort it from opaque materials in the waste stream. It can also be used to separate mixed coloured glass. Removal of identified glass is accomplished by compressed air blast. Such machinery is complex and expensive. Abert (1985) describes such a process in two installations in Doncaster (U.K.) and Nancy (France)

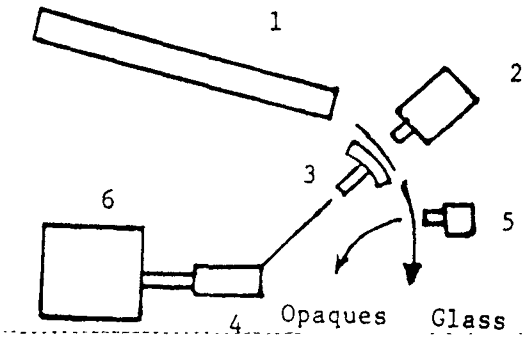


Figure 5.5 Simplified Scheme for Electronic Sorter for Separating Glass from Opaques

5.3.4 Moisture Content Reduction through Drying and Dewatering

Drying and dewatering operations are used primarily for incineration systems, with or without energy recovery systems. They are also used for drying of sludges in wastewater treatment plants prior to their incineration or transport to land disposal. The purpose is to remove moisture to make a better fuel. Sometimes the light fraction is "pelletized" after drying to make the fuel easier to transport and store prior to use in an incinerator or energy recovery facility. Ranges of moisture content for municipal solid waste components are given in Table 5.7.

Table 5.7 Typical data on Moisture Content Of Municipal Solid Waste Components

Component	Moisture, percent Range	 Typical
Food wastes	50 - 80	70
Paper	4 - 10	6
Cardboard	4 - 8	5
Plastics	1 - 4	2
Textiles	6 - 15	10
Rubber	1 - 4	2
Leather	8 - 12	10
Garden trimmings	30 - 80	60
Wood	15 - 40	20
Glass	1 - 4	2
Tin cans	2 - 4	3
Nonferrous metals	2 - 4	2
Ferrous metals	2 - 6	3
Dirt, ashes, brick, etc.	6 - 12	8
Municipal solid wastes	15 - 40	20

source: Tchobanoglous (1977)

Drying

The heat required for drying can be applied by the following methods:

- Convection drying, where hot air is in direct contact with the wet solid waste stream
- Conduction drying, where the wet solid waste stream is in contact with a heated surface, which has been heated
- Radiation drying, where heat is transmitted directly to the wet solid waste stream by radiation from the heated body.

The first of these, convection drying, is used mostly. A rotary drum type dryer, adopted from the cement industry, is shown in Fig. 5.6.

The time in the rotary drum is about 30-45 minutes. The required energy input will depend on the moisture content. This may be about 20-30% for municipal solid wastes in developed countries, and considerably greater in developing countries. An estimate of about 715 kJ/kg (or 1850 Btu/lb) of water evaporated allows calculations of energy input required for drying.

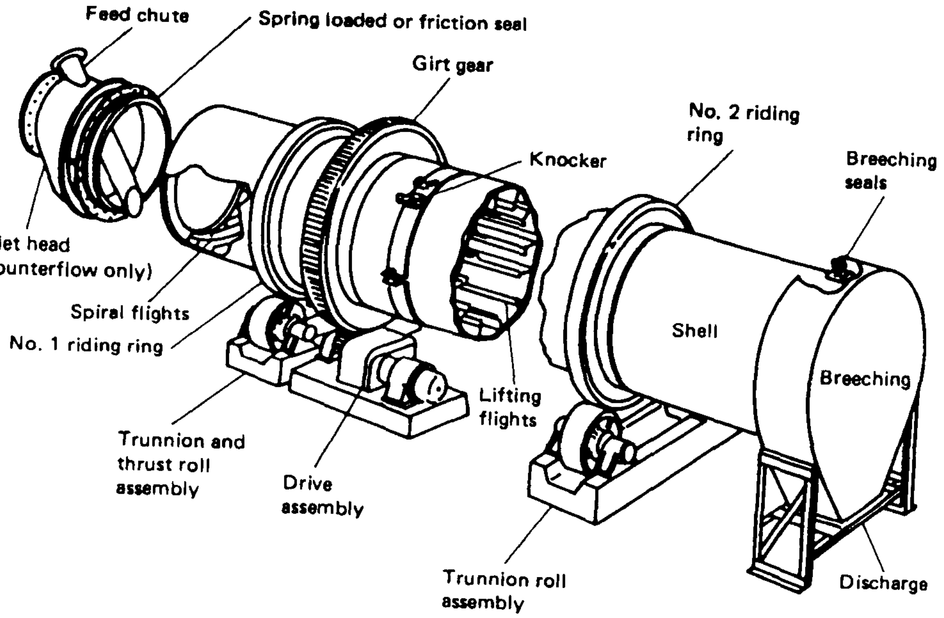


Figure 5.6 Countercurrent direct-heat rotary drum dryer (Bartlett-Suvo)

Source: Tchobanoglous et al (1977)

Dewatering

Dewatering is more applicable to the problem of sludge disposal from wastewater treatment of plants, but may also be applicable in some cases to municipal/industrial waste problems. When drying beds, lagoons or spreading on land are not feasible, other mechanical means of dewatering are used. The emphasis here is often on volume restriction through the elimination of water from sludges, before mixing sludges with other solid wastes. The processes used most frequently are vacuum filtration in large drums, pressure filtration in filter presses, and centrifigation. Sludges with solids contents of a few percent can be thickened to about 10-15% in centrifugation and vacuum filtration, and to perhaps 20-30% in pressure filtration.

5.3.5 Problems/Case Studies

Problem 5.1

The town of Iqaluit, Northwest Territories, Canada has a population of about 3,000 people. A waste composition study by hand sorting was carried out with the results shown below in Table 5.8.

Table 5.8 Waste Composition of Iqaluit, NWT, Canada

Waste Component	Percent by Weight, % (as discarded)	Estimated Moisture Content, %	Calculated* Dry Weight, kg
Food	21.4	65	7.5
Cardboard	14.4	}	}
Newsprint	5.0	}5	}23.7
Other paper products	18.5		
Cans	5.4		
Other Metal Products	4.0	3	9.1
Plastic, Rubber, Leather	13.3	4	12.8
Glass, Ceramics	3.1	2	3.0
Textiles	3.5	10	3.2
Wood	4.5	20	3.6
Dirt	3.4	8	3.1
Diapers	3.5	50	1.8
TOTAL	100	?	67.8

Source: Wong and Heinke (1990)

* based on an as-delivered weight of 100 kg.

No information is available from the field study on moisture content, as drying facilities were not available. From literature information the moisture content of various waste components is shown above. Calculate the probable moisture content of the municipal waste of the town.

Calculation:

* Moisture Content (%) = $\frac{a - b}{a} \times 100$

where a = initial weight of sample of waste as delivered
b = weight of sample after drying

* Dry weight of waste component, kg = (100% - moisture content, %) x as delivered weight

Based on an as delivered waste sample of 100 kg the dry weight of each component can be calculated e.g.

food waste component, kg = (100% - 65%) x 21.4 kg = 7.5 kg
(dry weight)

From the completed table above the total dry weight of all waste components is 67.8 kg.

Therefore

Moisture Content of waste sample % $= \frac{100 - 67.8 \times 100}{100} = 32.3$

This is a fairly typical value for a small community in a developed country. Note the high value for cardboard and other paper products, caused by shipping material to the isolated community of Iqaluit.

Case Study: Herten, Germany: RZR Recovery Center Ruhr *(Abert, 1985)*

This resource recovery plant is designed to process up to 300,000 tons of municipal solid waste per year. The technology has been developed by MVU corporation (Mannesmann Veba Umwelt technik GMBH), after extensive pilot plant development. The principal recovery objective of the plant is a refuse-derived fuel, trade-marked ECO-BRIQ.

Table 5.9 Average Composition of German Waste at Herten

Waste Component	Percent by Weight
Paper, cardboard	28
Wood	5
Vegetables, garbage	16
Yard rubbish	2
Plastics, rubber, leather, textiles	7
Glass, ceramics	16
Metal (mostly Fe)	5
Fines, others	21
Total	100
Moisture Content	25-40%

The flow diagram of the plant is shown in Fig. 5.7

After being discharged from the transport vehicle, the material is conveyed to the first separation device. This is a large trommel screen with 60 mm holes. The -60 mm material, which includes most of the glass in the refuse, thus bypasses the primary shredder, as only the +60 mm oversize is shredded. The oversize, after shredding, is combined with the -60 mm material and passes under a magnet, which attracts the ferrous fraction. Up to this point the process is fairly conventional. However, the primary trommel contains some special fittings that selectively reduce the size so that most of the plastic, particularly streamers, stays in the overflow so that it will be shredded in the hammermill. Conversely, the big pieces of glass are broken in the trommel so that they will pass through the 60 mm holes.

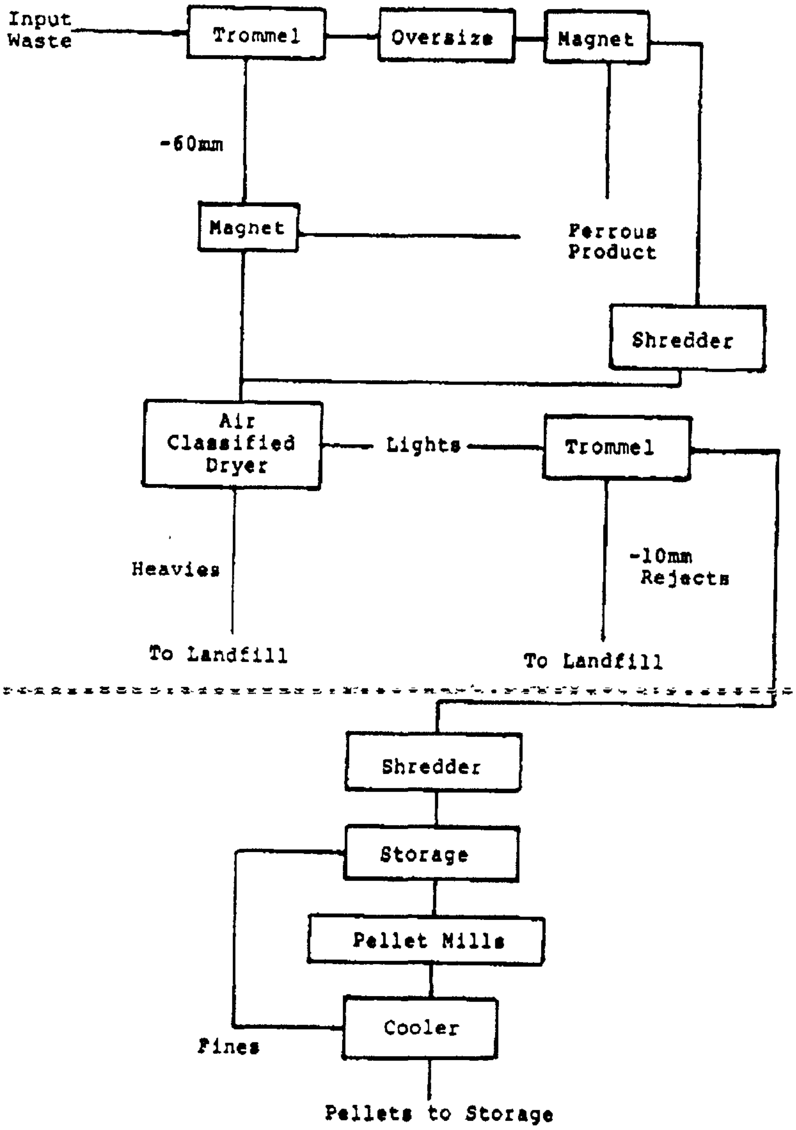


Fig 5.7 Herten: Recovery Center Ruhr, Germany (Abert 1985)

What is unique about the MVU process is the combination of air classification and drying, which occurs after magnetic separation. Fed to the air classifier-dryer by an auger airlock, the material which has an initial moisture of about 35 to 40 percent, is dried to 10 to 15 percent. Simultaneously, the light fraction is separated from the heavy fraction. The inlet temperature of the drying air is between 250°C and 300°C. The air classifying drying device is almost four stories high, making it perhaps the tallest air classifier in the world.

The heavy fraction is drawn off from the bottom of the air classifier through a rotary valve into a residual material bunker. This fraction is transported to landfill. It consists largely of inorganic waste, or of materials high in water. A cyclone filters the light material from the classifying air. The exhaust air is filtered in order to remove dust and then is partly recirculated to the air heater in order to conserve energy. The light fraction after the deentrainment is again trommel-screened. The hole size in this trommel is 10 mm. At this point the plant produces a fluff in the size range plus 10 mm - 60 mm. This material undergoes a second shredding step. The shredded light fraction goes to a storage bunker, from where it is conveyed to a series of pelletizing mills (Kelb presses). The presses are rated at 6 tons/hr. After pelletizing, the material enters a cooler and then is conveyed to storage. A certain amount of flaking takes place in the cooling process and this fine material is recycled back to the storage hopper and then to the pelletizer. The 10 mm undersize from the secondary trommel contains 8400 to 10500 kJ/kg which is too high to discard. As a consequence, a provision is made to screen this material at 4 mm and to recycle the oversize into the pelletizing process. Table 5.10 shows the expected outputs for the plant.

Table 5.10 Herten Plant Outputs

Product	Percent by Weight
ECO-BRIQ	45
Ferrous Scrap	5
Residues (15% by volume)	30
Moisture driven off during drying process	20
TOTAL	100

The Herten case study indicates the complexity of a modern mechanized resource recovery facility utilizing a number of the processing techniques and equipment described in this section. The energy recovery aspect of the Herten plant is further presented in Section 5.4.

5.4 INCINERATION AND ENERGY RECOVERY

5.4.1 Overview

Incineration is a well established industrial process. It has been used for decades for solid waste disposal in urban areas to substantially reduce the volume of solid waste through burning, prior to land disposal of the ashes. Air pollution control requirements have necessitated the treatment of emissions in the more recent past. Because solid wastes constitute a low-grade fuel it has become practice in recent years, whenever possible, to recover part of the energy content of the waste, which can be used to provide for the energy requirements of the facility itself, for district heating, power generation and other energy uses. Incinerators and Waste to Energy (WTE) facilities, including recovery of certain materials for reuse before incineration, are bprimarily applicable to urban areas of industrialized countries. As has been pointed out in Section 5.1, solid wastes in developing countries usually have a high moisture content, and a relatively low content of burnable material, such as paper and paper products, which weighs against the incineration option. Because of the greater emphasis in this manual on developing countries Section 5.4 is kept quite brief.

Increasing environmental concerns in all countries make it more and more difficult to locate sites for incineration and WTE facilities within the urban areas themselves. If plants are too far from the region which generates the wastes, transportation costs will become high and may tip the balance towards landfilling of wastes, provided that landfill sites can be found. Incinerators and WTE facilities generally have higher capital and operating costs than landfilling. The cost effectiveness of any method must be established locally.

5.4.2 Combustion Waste Materials

The objectives of incineration are to combust solid wastes so as to reduce their volume to about one-tenth, and without producing offensive gases and ashes.

Solid wastes contain the following major elements:

Elements		End Products (Gases)
Carbon C		Carbon dioxide, CO_2
Hydrogen H	Combustion Process	Water, H_2O
Oxygen O		
Nitrogen N		Nitrogen N_2
Sulphur S		Sulphur dioxide, SO_2 other gaseous compounds and inert material (ash)

Table 5.11 provides information for the several components of solid waste mixtures on the combustible components.

If energy values (in kJ/kg or BTU/lb) are not available they can be calculated approximately from the data in Table 5.10 and the Dulong Formula:

$$\text{Btu/lb} = 145.4\,C + 620\,(H - 1/8\,O) + 41S$$

where C, H, O and S are in percent by weight (dry basis) and can be converted to kJ/kg by: BTU/lb x 2.326 = kJ/kg

TABLE 5.11 Typical Data on Ultimate Analysis of the Combustible Components in Municipal Solid Wastes

	Percent by weight (dry basis)					
Component	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Food wastes	48.0	6.4	37.6	2.6	0.4	5.0
Paper	43.5	6.0	44.0	0.3	0.2	6.0
Cardboard	44.0	5.9	44.6	0.3	0.2	5.0
Plastic	60.0	7.2	22.8	--	--	10.0
Textiles	55.0	6.6	31.2	4.6	0.15	2.5
Rubber	78.0	10.0	--	2.0	--	10.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Garden trimmings	47.8	6.0	38.0	3.4	0.3	4.5
Wood	49.5	6.0	42.7	0.2	0.1	1.5
Dirt, ashes, brick, etc.	26.3	3.0	2.0	0.5	0.2	68.0

Source: Tchobanoglous et al (1977)

Principles of combustion, Mass-Burn Design and Equipment for Incinerators and WTE facilities are beyond the scope of this manual. The reader is referred to Corey (1969), Pfeffer (1912) and other textbooks on these subjects.

The air requirements for combustion of solid wastes are very considerable. Approximately 5000 kg of air are required for each tonne of solid wastes burned. Complete incineration of solid wastes will produce a virtually inert residue, which constitutes about 10% of the initial weight and perhaps an even larger reduction in volume. The residue is generally landfilled.

5.4.3 Use of Incinerators, WTE Facilities and Resource Recovery Centres

Much has been written in the popular press and also in technical journals about recycling vs burning or landfilling. The public often thinks of these as *either-or* issues, when in fact they are all part of a waste management strategy. As discussed in Section 5.1 *recycling* makes sense only if *recovery and reuse* occurs through the relevant industrial/commercial markets. Reduction in solid wastes produced and recycling of as much as possible may take care of as much as 25% to 50% in industrialized countries sometime in the future. The other 75 to 50% will still have to be disposed of in some way.

In urban areas of developed countries incineration remains an important component, particularly when combined with resource recovery facilities and energy recovery (WTE) facilities.

Data on inert residue and energy content of municipal solid waste components (as discarded) are provided in Table 5.12.

TABLE 5.12 Typical Data on Inert Residue and Energy Content of Municipal Solid Wastes (as Discarded)

	Inert residue, percent (after complete combustion)		Energy, Btu/lb (as discarded)	
Component	Range	Typical	Range	Typical
Food Wastes	2 - 8	5	1,500 - 3,000	2,000
Paper	4 - 8	6	5,000 - 8,000	7,200
Cardboard	3 - 6	5	6,000 - 7,500	7,000
Plastics	6 - 20	10	12,000 - 16,000	14,000
Textiles	2 - 4	2.5	6,500 - 8,000	7,500
Rubber	8 - 20	10	9,000 - 12,000	10,000
Leather	8 - 20	10	6,500 - 8,500	7,500
Garden trimmings	2 - 6	4.5	1,000 - 8,000	2,800
Wood	0.6 - 2	1.5	7,500 - 8,500	8,000
Glass	96 - 99+	98	50 - 100	60
Tin cans	96 - 99+	98	100 - 500	300
Nonferrous metals	90 - 99+	96	--	--
Ferrous metals	94 - 99+	98	100 - 500	300
Dirt, ashes, brick, etc.	60 - 80	70	1,000 - 5,000	3,000
Municipal solid wastes			4,000 - 5,500	4,500

Considerable information is available on European practice of the use of combined resource and energy recovery facilities. Abert (1985) provided an extensive and detailed report on European practice, from which a case study is reported in Section 5.3.5. Johnke (1992) reports on the European and particularly on the German experience on incineration and energy recovery. Table 5.13 shows that as of 1991 there were 629 plants in Europe. The percentage of wastes incinerated in the European countries ranges from zero to 80% of the municipal solid wastes (MSW) produced in that country. Incinerators with energy recovery systems now predominate. In Germany virtually all of the 49 incinerator plants use the heat generated. However, their contribution to energy production to save resources of primary energy is relatively small at 0.6%. However, in some regional situations such as large cities up to 4-9% of the total power demand might be supplied in future from waste incineration (Johnke, 1992).

TABLE 5.13 Comparison of MSW Incineration in Europe (1991 data)

European countries	Amount of waste incinerated (Mg x 10^3 per year)	Percentage (%)		
		Incinerated	Incinerated with energy recovery	No. MSW incinerators
Austria	300	18	18	2
Belgium	720	21	7	27
Denmark	1500	70	70	48
Finland	np	np	np	1
France	6350	40	13	260
Fed. Rep. of Germany*	9300	23	22	49
Greece	15	np	np	1
Ireland	--	--	--	0
Italy	2000	10	4	54
Luxembourg	140	78	78	1
Netherlands	2805	46	36	11
Norway	440	23	13	50
Portugal	--	--	--	0
Spain	697	6	43	22
Sweden	1550	55	55	22
Switzerland	2300	80	60	48
United Kingdom	2780	10	3	33
Total				629

* Original and new federal states.
n.p. = not published.
Source: Johnke (1992)

In North America, despite a history of incineration going back to 1885 (New York City), incineration, with or without heat recovery, only deals with about 5 to 10% of solid wastes, landfilling remaining the predominant option. In some jurisdictions (Ontario, Canada for example) the current government has put a temporary freeze on the construction of incinerators in order to "force" the reduction of solid wastes produced and the amount to be recycled. The largest MSW incinerator in the U.S. in Detroit is undergoing a complete $150 Million retrofit including up-to-date environmental controls. The project will be completed by 1995.

In Japan WTE plants account for about 25% of solid waste disposal. In Hong Kong and Singapore, as well as in other major cities in Asia, incineration is an important part of waste disposal because of the scarcity of land which could be used for landfilling. As has been pointed out earlier, because of the low content of burnable material and the high moisture content in solid wastes of most developing countries, incineration is not a viable option there.

5.4.4 Incinerators, WTE Facilities and Resource Recovery Centres

The newer municipal incinerators are usually the continuously burning type, and may have "waterwall" construction in the combustion chamber in place of the older, more common refractory lining. Corrosion of waterwall units can be a problem (See Figure 5.8 in Henry & Heinke (1989)).

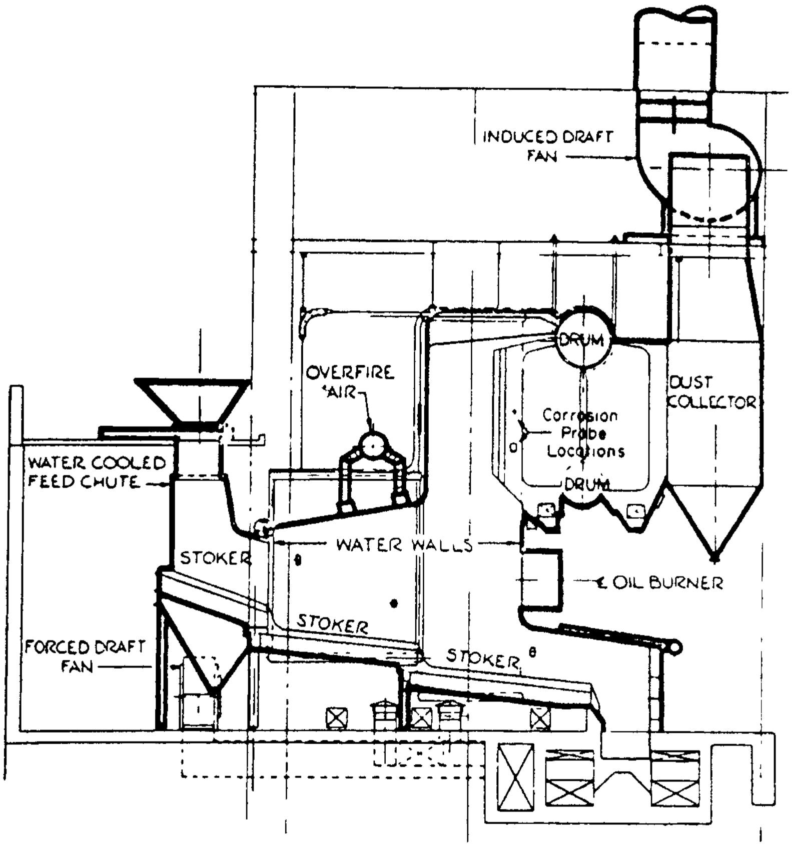


Fig. 5.8 Section through a waterwall incinerator

The combustion temperatures of conventional incinerators fuelled only by wastes are about 760°C in the furnace proper (insufficient to burn or even melt glass) and in excess of 870°C in the secondary combustion chamber. These temperatures are needed to avoid odour from incomplete combustion. Temperatures up to 1650°C, which would reduce volume by 97% and convert metal and glass to ash, are possible with supplementary fuel. Wastes burned solely for volume reduction may not need any auxiliary fuel except for start-up. When the objective is steam production, supplementary fuel (usually gas) must be used with the pulverized refuse, because of the variable energy content of the waste or in the event that the quantity of waste available is insufficient.

Markets for steam must be close to the waste-burning incinerators for these combustion systems to be competitive with other heating sources (1.6 to 3.2 km). As fuel costs rise this distance will increase.

The emission of air pollutants from incinerators and WTE facilities are an environmental concern. Therefore air pollution control is now required. Removal of fine particulates and toxic gases are of greatest concern. The emission of combustible, carbon-containing pollutants can be controlled by optimizing the combustion process. Oxides of nitrogen and sulphur and other gaseous pollutants have not been a problem because of their relatively small concentration. Other concerns related to incineration include the disposal of the liquid wastes from floor drainage, quench water, and scrubber effluents, and the problem of ash disposal in landfills because of heavy metal residues. (Henry and Heinke, 1989)

Because of the large and increasing paper component in municipal solid waste, particularly in developed countries, refuse derived fuel (RDF) can be a useful supplementary fuel for combustion processes and utility boilers. A simplified flow diagram for a typical resource recovery plant is shown in Figure 5.9, employing several of the techniques outlined in Section 5.2.

Problem 5.2

The Town of Iqaluit (Section 5.2.5 Problem 5.1) wishes to investigate the use of an incinerator for the disposal of its solid wastes rather than the current landfilling method. Calculate the energy value contained in the town's wastes, and compare to published values for municipal wastes.

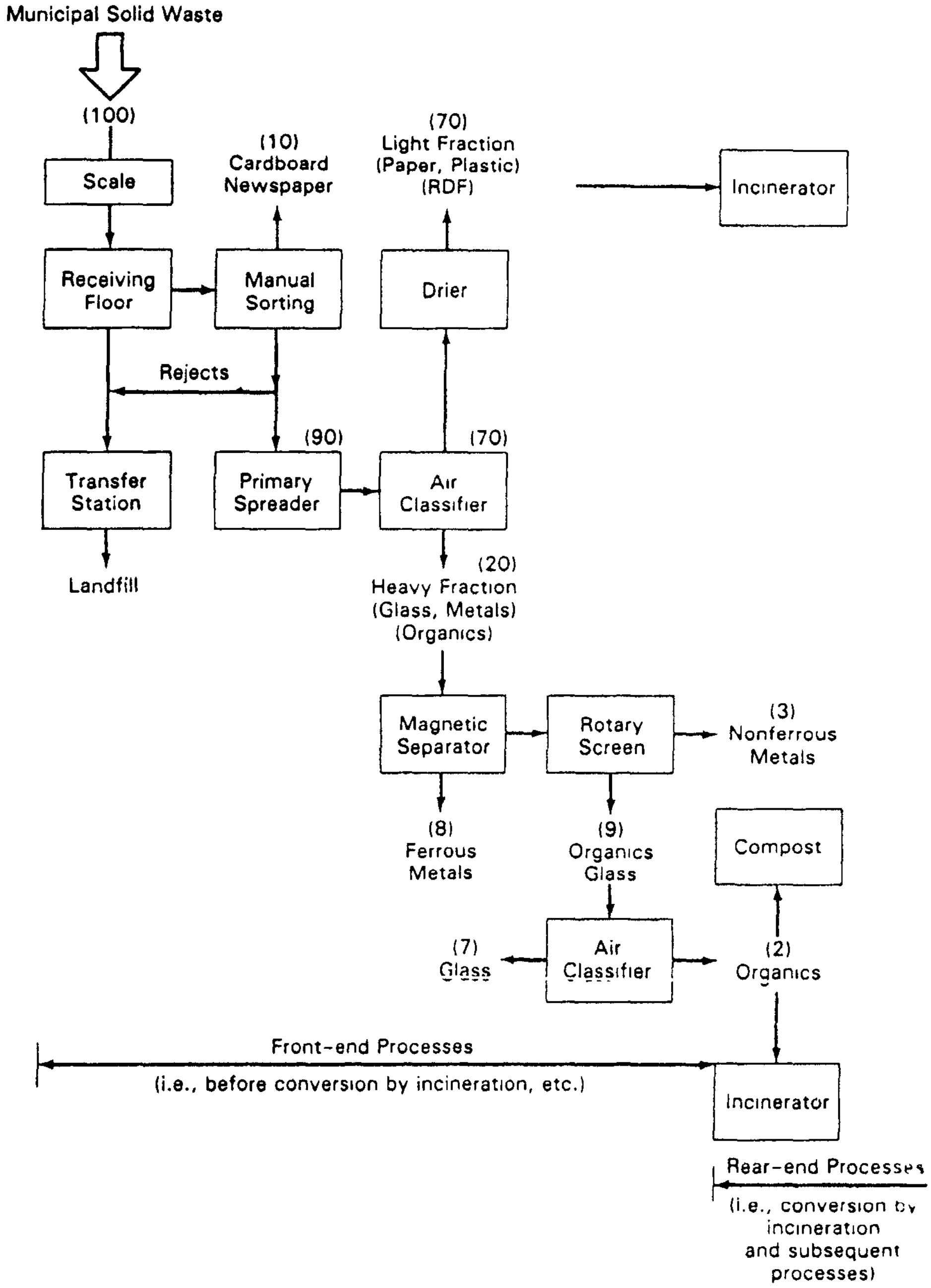


Fig. 5.9 Flow diagram for a typical resource recovery plant

Based on a sample of 100 lbs.

Waste Component	Weight, lbs. (as discarded)	Energy Value* Btu/lb	Calculated Energy Value Btu
Food	21.4	2000	42,800
Cardboard, paper and other paper products	37.9	7000	265,300
Cans	5.4	300	1,620
Other Metal Products	4.0	300	1,200
Plastics, rubber, leather	13.3	11,000	146,300
Glass, ceramics	3.1	60	200
Textiles	3.5	7500	26,250
Wood	4.5	8000	36,000
Dirt	3.4	3000	10,200
Diapers	3.5	3500	12,250
TOTAL	100.0		542,120

* From Table 5.12

$$\text{Energy Content, Btu/lb} = \frac{542{,}120\ \text{Btu}}{100\ \text{lb.}} = 5420\ \text{Btu/lb}$$

Energy Content, kJ/kg = 5420 x 2.326 = 12,600 kJ/kg

Note that the energy value of Iqaluit waste is on the high end of the range given in Table 5.12. This is so because of the high component of paper and packaging material necessary to ship goods to the town. Although this may allow consideration of an incinerator option, it is highly unlikely that this would be the actual choice. High cost of installation, high operating costs and consequence of breakdown would tend to staying with the current landfilling operation.

Case Study: Herten, Germany: RZR Recovery Center Ruhr (Abert, 1985)
(See also Section 5.2.5)

The energy aspects of the Herten case study are presented here. The ECO-BRIQ fuel represents about 45% of the total weight output of the Herten plant. Their heat value is about 14600 to 18800 kJ/kg. They can be stored quite easily up to one year without effect on stability, moisture content or heat value. The briques produced are used in a nearby cement kiln.

Overall the process at Herten RZR Recovery Center is energy efficient. After deducting processing losses and the losses involved in converting the ECO-BRIQ fuel to electricity, the net yield is a positive 25% taken in relation to the energy value of a tonne of input waste. This is shown in Fig. 5.10

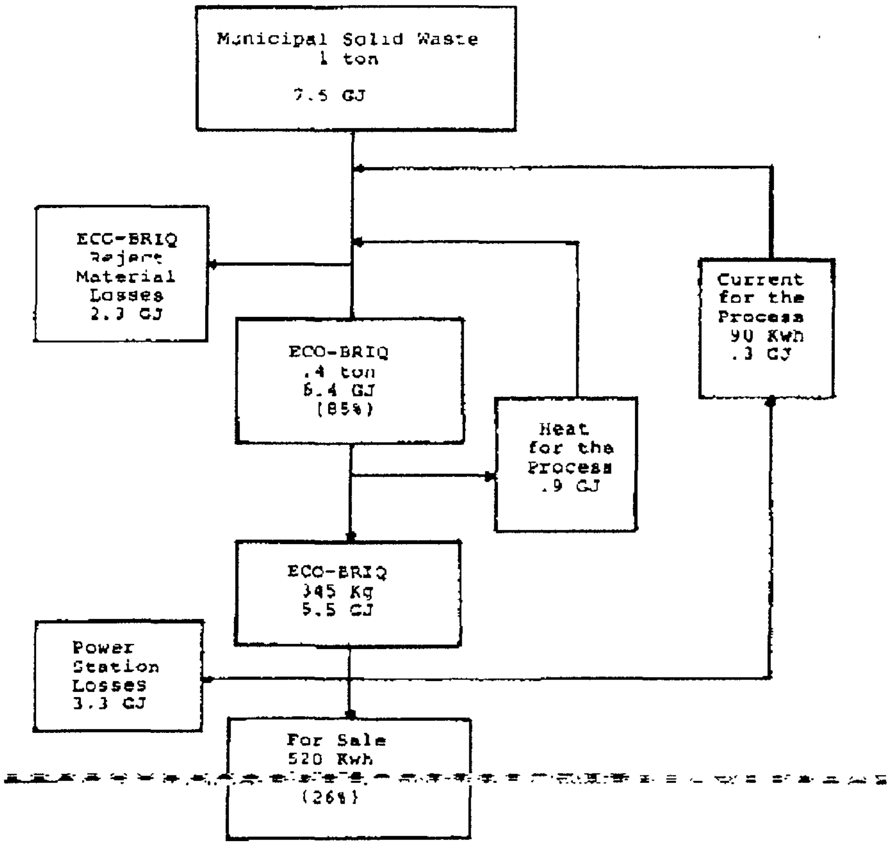


Figure 5.10

The energy diagram of the incineration plant is shown in Fig. 5.11

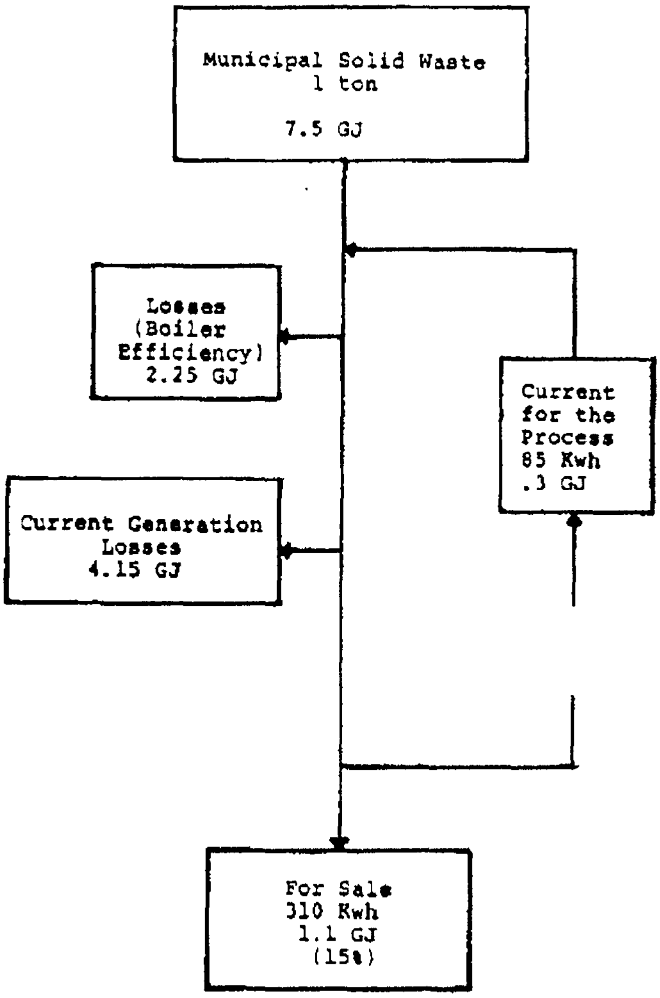


Figure 5.11

For further information on developments on this plant contact Mr. Peter Schmidt, Dipl. Ing., Marketing Mannesmam Veba Umweltstechnik GMBH, Sued str. 41, D4690 Herne 2, Germany.

SAQ 5.4

Write a 1,000 word short report to your Chief Engineer indicating the advantges and disadvantages of landfilling and of incineration in general and for your community in particular.

SAQ 5.5

What are the pollutants of major concern in the operation of an incinerator WTE facility with respect to air, water and land pollution?

5.5 COMPOSTING AND BIO-GAS PRODUCTION

5.5.1 Overview

Composting is a controlled **aerobic** process carried out by successive microbial populations combining both mesophilic and thermophilic activities, leading to the production of carbon dioxide, water, minerals and stabilized organic matter (Pereira-Notta, 1987). Generally, composting is applied to solid and semi-solid organic wastes such as nightsoil, animal manures, agricultural residues, and municipal solid waste. The end product from composting is a **soil fertilizer**.

Biogas is a by-product of **anaerobic** decomposition of organic wastes, as above, and is a **source of energy**. The biogas can be used in small family units for cooking, heating and lighting, and in larger institutions for heating or power generation. (Polprasert, 1989)

Composting

Farmers and gardeners have practised *composting* in some of its primitive forms for many centuries. Night-soil, vegetable matter, animal manure, household garbage, etc. were placed in piles or pits located in a convenient place and allowed to decompose as conditions would permit until the material was ready for the soil or the farmers were ready to apply it to the land. This process involved little or no control, required long periods in the pile to provide a good humus, might or might not conserve maximum nitrogen, and certainly did not provide sanitary treatment. (Gotaas, 1956)

Starting in the 1930s important advances in the practice of composting were made. Howard (1938), van Vuren (1949), Scott (1952) Waksman (1952) and many others made significant advances in practical applications and understanding of the process. Developments were geographical centred on India, China, Southeast Asia and East and South Africa. The Indore process, and modifications thereof, were applied in many places. It involved stacking organic matter from many sources (night soil, animal manure, sewage sludge, garbage, straw, leaves and other organic wastes) to a height of about 1.5m, or placing them into specially constructed pits up to 1m deep. The pile was turned once or twice during the composting period of six months or longer. Therefore short periods of aerobic conditions were likely followed by long periods of anaerobic decomposition. More frequent turning in later applications would have increased the length of aerobic decomposition leading to more rapid decomposition and shortening of the composting period.

These advances were of considerable importance but, because the decomposition was mostly anaerobic, it did not normally provide for high enough temperatures (greater than 60°C) to destroy pathogenic bacteria. The often long composting period of six months or more may compensate for lower temperatures. However, while a good natural fertilizer was produced, the health of workers and of goods produced from the farming operations may not have been assured. Flies, which are an important vector in the transmission of faecal-borne diseases, are difficult or impossible to control in wastes composted anaerobically in open stacks, particularly during warm weather. Special care and attention to protection of workers, and washing of farm products before use, can reduce the risk of infections greatly.

In the early 1950s Gotaas and his associates conducted research on some of the basic aspects of composting mixed municipal refuse containing garbage, both with and without additions of sewage sludge, in the United States. Their investigations have furnished some basic information on the effects of some of the different variables encountered in aerobic composting, namely: (1) temperature; (2) moisture; (3) aeration by turning and by others means; (4) the C/N ratio of the organic materials; (5) the use of special biological inocula, and (6) grinding or shredding the material. Their studies also yielded data on the types of organisms present in composting techniques for judging of the compost during and after the operation, the insulating and heat-retention characteristics of compost materials, and process-design considerations. (Gotaas, 1956)

In Europe and elsewhere several investigators were focussing their attention on mechanizing the composting process, particularly for use as a method for the treatment and sanitary disposal of the garbage and refuse from cities. Their higher land costs and labour costs, and the existence of sewage collection systems and treatment facilities, including digestion of sewage sludge with subsequent farm land disposal, provide the rationale for such a focus in these largely developed countries. Various patented processes were developed, such as Beccari in Italy, Frazer in U.S.A., the Dano process in Denmark, the VAM process in the Netherlands, the Bangalore process in India, and many others are described by Gotaas. Many large mechanized composting plants are now in operation in many countries. While it is not possible to generalize the many different forms of mechanized composting plants, they are generally capital and equipment intensive, use compact and enclosed facilities, mechanical means of turning of wastes, increased temperatures leading to increased aerobic decomposition resulting in much reduced composting periods and greater sanitary efficiencies.

Biogas Production

Biogas is a by-product of the anaerobic decomposition of organic matter. It is a source of energy. It consists mainly of methane (65%), carbon dioxide (30%) and trace amounts of ammonia, hydrogen sulfide and other gases. The approximate calorific value of biogas is about 21000 kJ/m^3 (about 600 BTU/ft^3).

Interest in biogas as a source of fuel is longest in developing countries, particularly in China. There the use of various forms of organic wastes from household and farms is for the production of compost fertilizer and for biogas production for household cooking, heating and lighting. These household biogas digesters may be as small as 1-5 m^3 in size. Examples of applications in China are given by McGarry and Stainforth (1978). In developed countries the creation of large wastewater treatment plants for control of water pollution necessitated the use of anaerobic digestion of removed solids, called sewage sludge, in large covered digesters. The biogas produced is used as fuel for heating boilers for further digester heating or building heating, as well as a fuel source for gas engines for pumps and other uses within the treatment plant. In smaller wastewater plants in the past the biogas was simply burnt off, as oil based energy sources were used for operating the plant. In the last few decades the much greater emphasis on resource conservation and on development of alternative sources of energy has provided a renewed interest in recycling of organic wastes as an energy source. The relatively drier municipal solid wastes in developed countries are leading to increased use of incineration of burnable wastes for production of energy for central district heating plants (see Section 5.3). The wetter municipal solid wastes in developing countries lend themselves more to the use of biogas digestors for energy recovery from municipal solid wastes. Polprasert (1989) is a prime source of up-to-date information on both composting and on biogas production facilities.

5.5.2 Characteristics of Organic Wastes

The quantities, characteristics and composition of municipal solid wastes have been dealt with in Chapter 2. Added here is additional information on the organic wastes contained in municipal solid wastes, as well as on other organic wastes that may be used in co-disposal facilities of a variety of organic wastes for the production of compost fertilizer and for biogas.

Organic wastes from municipal solid wastes, from human wastes (night soil), and from animal wastes will be dealt with. Wastewater sludges from treatment plants and industrial organic wastes from a number of agro-industrial enterprises will not be dealt with, but references such as Peavy et al.(1985) , Metcalf and Eddy (1979) and, Polprasert (1989) and others should be consulted where these wastes are contributing sources for composting or biogas facilities under consideration. These may include sugar refineries, breweries, slaughterhouses and meat processing plants, fruit and vegetable canneries, cooking oil industries, rice and tapioca plants, as well as many others.

Because the quantity and composition of solid wastes can vary considerably between countries and within countries, it is best if a field investigation is carried out on the wastes of the community for which a facility is to be designed. Chapter 2 provides some information on how this is best carried out on a representative sample of the waste stream.

Municipal Solid Wastes

The applicable tables in Chapter 2, as well as Tables 5.1 and 5.3 should be reviewed, together with the comments made there. Additional information of comparative solid waste analysis in several countries are provided in Tables 5.15, 5.16, and 5.17 below.

Table 5.15 Comparative Solid Wastes Analysis - %

	Bangkok Thailand	Calcutta, India	Cairo, Egypt	U.K.	U.S.A.
Food wastes (organic)	39.2	36	70	17.6	15
Paper and cardboard	13.6	3	10	36.9	44
Metals	1.9	1	4	8.9	9
Glass	1.1	1	2	9.1	8
Textiles	4.8	4	2	2.4	2
Plastics and rubber	14.5	1	1	1.1	3.5
Miscellaneous incombustible	3	50	10	21.9	4
Miscellaneous combustible	21.9	4	1	3.1	15.5
Bulk density,kg/L	0.28	--	--	0.16	0.18-0.41

Source: Polprasert (1989) from other sources

Table 5.16 Refuse Content From Various Municipalities in Developing Countries (Weight Percent)

Constituents	Iraq	Algiers, Algeria	Hong Kong	Abu Dhab UAE	Accra Ghana	Cairo Egypt	Alexandria Egypt	Sao Paolo Brazil
Vegetables	68.6	72.0	46.2	22.5	87.1	65.0	43.8	46.9
Textiles	3.8	2.6	9.0	0.3	1.2	2.5	3.0	3.4
Paper/carton	10.2	16.0	25.7	42.4	5.7	23.0	9.2	25.9
Straw	1.0	0.1	--	0.4	--	--	7.7	--
Timber	1.1	1.0	2.5	2.9	--	--	2.5	1.9
Leather/rubber	1.8	1.2	0.3	--	--	--	0.9	1.5
Horn/bones	1.2	0.2	0.3	2.9	--	0.5	1.3	0.1
Plastics	2.1	2.5	8.1	6.3	1.3	0.25	2.0	4.3
Metals	2.3	2.5	1.9	14.0	2.6	1.75	3.0	4.2
Crockery	5.5	0.7	0.4	3.8	1.4	--	24.7	9.7
Glass	2.4	1.2	5.6	4.4	0.7	2.25	1.9	2.1
Organic fines	--	--	--	--	--	4.75	--	--
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Moisture of crude refuse	58.5	60.0	44.7	30.0	50.0	--	30-40	62.0
Compostable portion	87.7	90.0	77.9	73.5	94.9	--	87.3	84.6

- not measured

Source: Reported in Obeng and Wright (1987) from Weber (1983) and Hughes (1986).

From these tables it is clear that the food wastes of developing countries (organic) are quite high, correspondingly moisture contents are high, and particle sizes are quite small. All these characteristics make them suitable for composting/biogas production.

The quantity of solid wastes is higher in developed countries through greater consumption and less household waste recovery. More than 2 kg per capita daily may be applicable for cities in North America at this time, hopefully to be reduced in future through greater conservation and recycle measures there, and as low as 0.4 to 1.0 kg per capita per day in cities of developing countries.

While it would be advantageous to have food wastes separately stored and collected for composting and biogas production, this is generally not possible. Therefore methods discussed in Section 5.2, such as component separation, mechanical size reduction and others need to be employed before composting operations. On farms and small villages much of the edible food wastes are fed to animals making the organic content of household wastes quite small, about 0.2 - 0.4 kg per capita per day. There may be insufficient organic matter left in garbage for composting unless other wastes from animals and plant matter are added.

Based on a study by Heinke and Wong (1990) and Quaye and Heinke (1992) the quantity of uncompacted solid wastes typically disposed at landfill sites in communities of the NWT, Canada averages at 0.014 m^3 per person/day. The field sampling was carried out according to the modified cone and quartering technique with a minimum size of 90 kg (200 lbs.) sample. Figure 5.12 shows part of this work.

Fig 5.12 Field Sampling, Northwest Territories, Canada

TABLE 5.17 SOLID WASTE COMPOSITION IN SELECTED COMMUNITIES OF THE NORTHWEST TERRITORIES, CANADA (% by weight)

Component	Tuktoyaktuk (Forqie, 1974)	Iqaluit (Heinke/ Wong, 1990c)	Pangnirtung (Heinke/Wong 1990c)	Broughton Island Heinke/ Wong 1990c)	Inuvik	Fort McPherson	Arctic Red
Food	15.9	21.4	19.3	15.9	18.7	21.4	20.9
Cardboard	6.4	14.4	12.1	9.3	8.7	12.1	8.6
Newsprint	--	5.0	0.4	0.3	6.0	0.6	0.5
Other Paper Products	26.8	18.5	15.2	14.0	15.8	10.2	18.3
Cans	11.7	5.4	5.5	5.0	3.9	6.7	2.5
Other Metal Products	2.5	4.0	3.9	6.5	6.6	4.6	7.4
Plastic, Rubber, Leather	10.1	13.3	8.8	8.9	14.3	13.7	14.1
Glass and Ceramics	13.6	3.1	2.6	1.7	4.4	6.1	6.5
Textiles	4.4	3.5	4.1	3.3	4.1	4.4	2.8
Wood	5.3	4.5	13.4	20.0	9.1	10.0	10.6
Dirt	3.3	3.4	3.1	4.8	4.5	2.5	
Diapers	--	3.5	11.6	10.3	3.8	5.7	5.3
Total	100	100	100	100	100	100	100

Source: Quaye end Heinke (1992)

Human Wastes

The composition of human faeces and urine is shown in Table 5.18 and 5.19. Night-soil is the commonly used term employed when no sewer facilities or septic tank type systems are used. Collection of nightsoil by truck or cart from bucket type toilets is used.

Table 5.18 Composition of Human Faeces and Urine*

	Faeces	Urine
Quantity (wet) per person per day	100-400 g	1.0-1.31 kg
Quantity (dry solids) per person per day	30-60 g	50-70 g
Moisture content	70-85%	93-96%
Approximate composition (percent dry weight)		
organic matter	88-97%	65-85%
Nitrogen (N)	5.0-7.0%	15-19%
Phosphorus (as P_2O_5)	3.0-5.4%	2.5-5.0%
Potassium (as K_2O)	1.0-2.5%	3.0-4.5%
Carbon (C)	44-55%	11-17%
Calcium (as CaO)	4.5%	4.5-6.0%
C/N ratio	~6-10	1
BOD_5 content per person per day	12-20 g	10 g

* Adapted by Polprasert (1989) from Gotaas (1956) and Feachem et al (1983)

Table 5.19 Characteristicsof Human Waste

	Honey-bag waste		Black water waste*	
	Average	Range	Average	Range
Volume (L per person per day)	1.3	--	8.5	--
pH	--	8.6-8.9	--	7.85-8.40
Alkalinity (mg/L)	14900	11900-17000	1947	1800-2280
Total solids (mg/L)	78140	65990-85030	8957	7800-12200
Volatile solids (% of total solids)	77.53	71.53-80.18	72.6	70.8-76.0
Dissolved solids (mg/L)	39290	32500-53620	--	--
COD (mg/L)	110360	80750-134820	10210	8400-18180
Supernatant COD (mg/L)	48510	39980-61280	5060	3780-7000
TKN (mg/L)+	8070	7280-9520	830	790-1040
N in NH_3 (mg/L)	3920	3470-4060	555	520-590
Organic N (mg/L)	4150	3696-5520	285	270-450
Phosphorus (PO_4) (mg/L)	3730	3400-4250	--	--
Volatile acids (mg/L)	2490	2300-2670	1504	1080-1870

*Toilet waste diluted by about 1L per flush.
+TKN = total Kjeldahl nitrogen.

Source: Heinke and Prasad (1980)

The information contained in Table 5.19 comes from work in communities of the Northwest Territories. 'Honey bag' wastes refer to faeces and urine from bucket toilets. 'Blackwater' wastes refer to waste from lowwater use toilets, which flush into a holding tank below the toilet, which is pumped out weekly by pumper trucks. Because the C/N ratio of faeces (6-10) is lower than that required for composting and anerobic digestion other organic matter high in carbon content need to be added, such as food wastes, leaves, rice straw etc.

Where septic tanks and tile fields, or cesspools are used, there is a need to occasionally remove the contents. They can be disposed of after further treatment at wastewater treatment plants, at wastewater lagoons and other similar facilities. In concentrated form it might be used in composting or biogas production facilities. (Tables 5.20 and 5.21)

Feachem et al (1983) found the quantities of faeces produced in developed countries to be between 100-200 g (net weight) per capita daily, but higher in developing countries (about 130-520 g (net weight)). This may also result in higher quantities of septage generated in developing countries, as compared to the few reported data of 200-400 k per capita yearly in developed countries.

Animal Wastes

Information on the quantity and composition of animal wastes is provided in Tables 5. 22, 5. 23 and 5. 24.

As for other wastes these figures should be used as a general guideline only, and field measurements of the actual farm or similar type of farm should be carried out.

Animal wastes may be used in conjunction with human wastes, garbage and plant matter for small scale composting/biogas facilities on a farm or a collection of farms. In fact in many cases the addition of animal wastes is necessary to provide sufficient nutrients.

5.5.3 Composting

Composting

Composting of a mixture of organic wastes can take place under anaerobic or under aerobic conditions.

Anaerobic conditions

In the absence of oxygen, anaerobic bacteria decompose organic matter as follows:

Organic Matter + anaerobic bacteria $\rightarrow$ Ch_4+CO_2+H_2S+NH_3 + other end products + energy (COHNS)

If air is introduced to the composting pile through frequent manual or mechanical turning, or through blowers, aerobic conditions will prevail.

Organic Matter + 0_2 + Aerobic Bacteria $\rightarrow$ CO_2 + NH_3 + H_2O + other
(COHNS) end products + energy

Table 5.20 Physical and chemical characteristics of septage as found in the literature, with suggested design values a,b (EPA, 1984)

Parameter	United States				Europe / Canada				EPA mean	Suggested design value
	Average	Minimum	Maximum	Variance	Average	Minimum	Maximum	Variance		
TS	34,106	1,132	130,475	115	33,800	200	123,860	619	38,800	40,000
TVS	23,100	353	71,402	202	31,800	160	67,570	422	26,620	25,000
TSS	12,862	310	93,378	301	45,000	5,000	70,920	14	13,000	16,000
VSS	9,027	96	51,500	542	29,900	4,000	52,370	-	-	-
BOD5	6,480	440	78,600	179	8,343	700	25,000	36	5,000	7,000
COD	31,900	1,500	703,000	469	28,975	1,300	114,870	88	42,850	15,000
TKN	588	66	1,060	16	1,067	150	2,570	17	677	700
NH3N	97	3	116	39	-	-	-		157	150
Total P	210	20	760	38	155	20	636	32	253	250
Alkalinity	970	522	4,190	8						
Grease	5,600	208	23,368	112	-	-	-	-	9,090	8,000
pH	-	1.5	12.6	8	-	5.2	9 0	-	6.9	-
LAS	-	110	100	2	-	-	-	-	157	150

a Values expressed as mg/L, except for pH

b The data presented in this table were compiled from many sources. The inconsistency of individual data sets results in some skewing of the data and discrepancies when individual parameters are compared. This is taken into account in offering suggested design values.

Table 5.21 Characteristics of septage in Asia[a]

	Japan[b]	Bangkok, Thailand[c]
pH	7-9	7-8
TS	25,000-32,000	5,000-25,400
TVS	--	3,300-19,300
TSS	18,000-24,000	3,700-24,100
VSS	50-70% OFTSS	3,000-18,000
BOD_5	4,000-12,000	800-4,000
COD	8,000-15,000	5,000-32,000
Total N	3,500-7,500	--
NH_3--N	--	250-340
Total P	800-1,200	--
Total coliform, no./100 ml	10^6-10^7	10^6-10^8
Fecal coliform, no./100 ml	--	10^5-10^7
Bacteriophages, no./100 ml	--	10^3-10^4
Grit (%)	0.2-0.5	--

Source: Polprasert (1989) from sources below

a Values expressed as mg/L, except for pH and those specified
b Data from Magara et al. (1980)
c Data from Arifin (1982) and Liu (1986)

Table 5.22 Bioengineering parameters of animal wastes (Taiganides, 1978)

Parameter	Symbol	Units	Pork pigs	Laying hens	Feedlot beef	Feedlot sheep	Dairy cattle
Wet waste	TWW	% TLW/day	5.1	6.6	4.6	3.6	9.4
Total solids	TS	% TWW	13.5	25.3	17.2	29.7	9.3
		% TLW/day	0.69	1.68	0.70	1.07	0.89
Volatile solids	TVS	% TS	82.4	72.8	82.8	84.7	80.3
		% TLW/day	0.57	1.22	0.65	0.91	0.72
Biochemical oxygen demand	BOD_5	% TS	31.8	21.4	16.2	8.8	20.4
		%TVS	38.6	29.4	19.6	10.4	25.4
		TTLW/day	0.22	0.36	0.13	0.09	0.18
$COD:BOD_5$ ratio	$COD:BOD_5$	Ratio	3.3	4.3	5.7	12.8	7.2
Total nitrogen	N	% TS	5.6	5.9	7.8	4.0	4.0
		% TLW/day	0.039	0.099	0.055	0.043	0.036
Phosphate	P_20_5	% TS	2.5	4.6	1.2	1.4	1.1
		%TLW/day	0.017	0.077	0.008	0.015	0.010
Potash	K_20	% TS	1.4	2.1	1.8	2.9	1.7
		% TLW/day	0.010	0.035	0.013	0.031	0.015

Table 5.23 Waste production by various animals

Animal	Average weight of animal, in pounds (kg)	Total waste[a] in pounds/ head/day[b] (kg/head/day	BOD_5 in pounds/head/ day[b] (kg/head/day)
Beef cattle	800(363)	40-60(81-27)	1.0-1.5(0.45-0.68)
Dairy cattle (milk cows, replacement heifers, breeding stock)	1,300(590)	96(44)	2.0(0.19)
Swine	100(45)	--	--
Chickens			
Broilers[c]	--	0.5 lb/lb/day	0.0044 lb/lb/day
Laying hens	--	0.059 lb/lb/day	0.0044 lb/lb/day
Sheep and lambs	--	15.5(7.0)	0.35(0.16)
Turkeys	15(6.8)	0.90(0.41)	0.05(0.023)
Ducks	3.5(1.59)	--	0.011-0.065
Horses[c] pleasure, farm racing)	--	82(37)	0.8(0.36)

Source: Polprasert (1989) adapted from Lohani and Rajadopal (1981)

[a] Total excreta including feces and urine

[b] All units for waste and BOD_5 production are in pounds (kilograms)/head/day except for those for chickens (broilers and laying hens) in pounds/pound of bird/day as indicated

[c] Manure for broilers and horses is mixed with bedding material or litter

Table 5.24 Annual Production (kg nutrient per year) of fertilizer nutrients from average weight animals and per AU[a] (Taiganides, 1978)

Nutrient	Symbol	Dairy cow		Feedlot beef		Pork pig		Laying hen		Feedlot sheep	
		400 kg cow	Per AU	300 kg steer	Per AU	55 kg pig	Per AU	2 kg hen	Per AU	50 kg sheep	Per AU
Total nitrogen	TN	53	66	60	100	8	71	0.7	181	8	78
Phosphates	P	14	18	9	15	3	31	0.6	141	3	27
Potash	K	22	27	14	24	2	18	0.3	64	6	57

[a] Animal unit (AU): animals whose total live weight is 500 kg

Aerobic conditions for organic waste decomposition are preferred because of a faster rate of decomposition and greater release of heat. Anaerobic conditions result in a much slower process, requiring therefore longer composting periods, and can result in bad odours. The heat release is also smaller, resulting in lower and less effective destruction of pathogenic organisms.

However, because anaerobic composting requires little operations, it is used in many places for the production of humus on farms and in individual households for use in gardening. In practice, small composting operations with occasional turning of the pile operate at times and in parts of the pile in both the anaerobic and aerobic mode.

In wastewater treatment plants there is a need for treatment of the removed solids, called sludges. This can be achieved under either anaerobic or aerobic conditions. Large diameter digesters, with or without heat addition, are used to decompose the sludges. The final disposal of liquid sludges, sometimes concentrated by various means, are often disposed on farmland. Where industrial wastes are part of the wastestream, removal of various toxic materials may be required before land application.

Pathogenic organism are destroyed if the temperature in the compost reaches about 60°C for at least one day, or longer at lower temperatures. For further information on the temperature-time effect on various pathogenic organisms consult Feachem et al (1983). Inactivation of pathogenic bacteria is essential for the humus to be used as a fertilizer and soil conditioner.

The composting process can only progress satisfactorily if suitable organisms are present which are capable of decomposing the organic wastes in the compost. Such organisms are naturaly present in some of the organic wastes added to the compost pile, such as night soil, animal wastes and wastewater sludges. Whether seeding of a compost with organisms is required depends on the mixture of organic wastes. The microbiology of composting is beyond coverage possible in this manual. The reader is referred to textbooks on soil microbiology and composting.

Environmental Conditions

As in all biological process, certain environmental conditions must be present for organisms to work most effectively. The environmental conditions of importance to composting are:

- Nutrient balance,
- Temperature and pH,
- Moisture content,
- Oxygen supply (Aeration),
- Particle size.

Nutrient Balance

The carbon to nitrogen ratio, C/N, is most important. For composting a C/N ratio of about 25/1 is desirable. Table 5.25 provides C/N ratios of various wastes and their nitrogen content.

Table 5.25 C/N Ratio of Various Wastes

Material	Nitrogen (% dry weight)	C/N ratio
Nightsoil	5.5-6.5	6-10
Urine	15-18	0.8
Blood	10-14	3.0
Animal tankage	--	4.1
Cow manure	1.7	18
Poultry manure	6.3	15
Sheep manure	3.8	--
Pig manure	3.8	--
Horse manure	2.3	25
Raw sewage sludge	4-7	11
Digested sewage sludge	2-4	--
Activated sludge	5	6
Grass clippings	3-6	12-15
Nonlegume vegetable wastes	2.5-4	11-12
Mixed grasses	2.4	19
Potato tops	1.5	25
Straw, wheat	0.3-0.5	128-150
Straw, oats	1.1	48
Sawdust	0.1	200-500

From Golueke (1972)

Temperature and pH

The main objective is to control temperature levels at about 55±5°C in compost piles. At this temperature breakdown of organic material and pathogen activation will be optimum. Temperature control can be achieved through varying moisture content and aeration. pH is normally neutral under aerobic conditions but will drop somewhat under anaerobic conditions.

Moisture Content

This is important to achieve optimum microbial decomposition. 60 ± 10% is optimum. Often materials for composting have a higher moisture content, in which case dry bulky materials can be added. Some agricultural products have lower than 60% moisture content and require the addition of water.

Oxygen Supply (Aeration)

In simple compost systems aeration is achieved through periodic manual turning of the wastes. Forced-air aeration is used for larger systems. Low oxygen supply leads to anaerobic conditions requiring longer times for the compost to mature. Too much aeration through mechanical means does not achieve better results.

Particle Size

The smaller the size of the waste the better it is for effective composting in general. Therefore shredding of wastes and straw etc. is practised, where necessary. Sometimes bulky organic materials need to be added to increase the carbon content and to provide support for the compost pile by creating voids for aeration. Sawdust, rice straw and domestic refuse can accomplish this.

Composting Systems

Polprasert (1989) provides a detailed description of the many simple, onsite composting systems, as well as the complex, mechanical composting plants, which are normally off-site from where the wastes are generated. Three examples are provided in Fig. 5.13, 5.14 and 5.15.

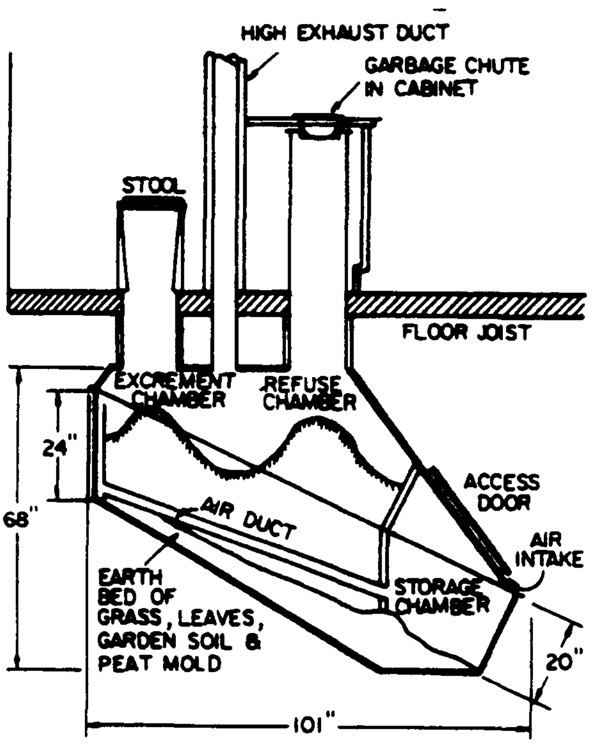


Figure 3.7 The Clivus Multrum (Rybczynski *et al.*, 1978 reproduced by permission of the International Development Research Centre, Canada)

Fig. 5.13 Aerobic Composting Toilet

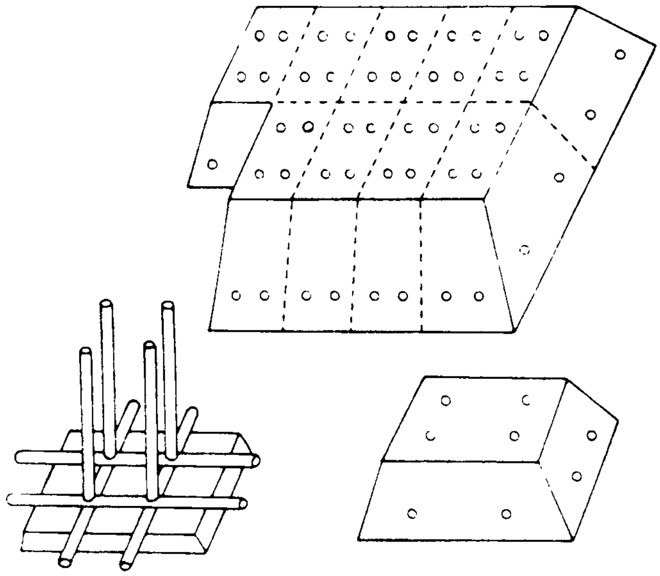


Fig. 5.14 Chinese ground-surface aerobic composting pile (McGarry & Stainforth, 1978)

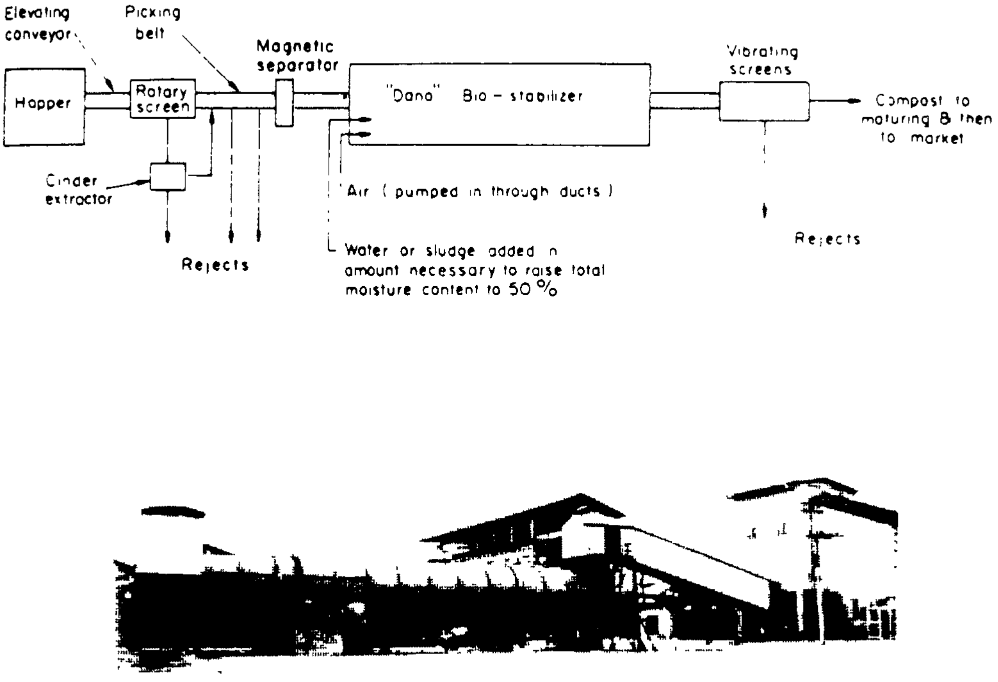


Fig. 5.15 Typical Dano plant - diagram and Bangkok plant

5.5.4 Biogas Production

Biogas is produced as a by-product of anaerobic decomposition of organic matter. Its main components are methane (55-65%), carbon dioxide (35-45%), and small amounts of nitrogen, hydrogen and hydrogen sulphide. Methane has a high heating value (about 9000 kcal/m^3. (Polprasert, 1989).

The main benefits of biogas production are:

- production of an energy source
- stabilization of the waste
- reclamation of nutrients, mainly N, P and K
- inactivation of pathogenic organisms

When comparing composting and biogas production, the main benefit of the latter is the production of energy. The other cited benefits are accomplished better through composting. The advantages and disadvantages of biogas technology are shown in Table 5.26.

The process of anaerobic digestion is often described by a very simplified chemical reaction equation (see 5.4.3), although in reality it is much more complex. It occurs in three general stages of decomposition (Polprasert, 1989).

1. liquefaction or polymer breakdown
2. acid formation
3. methane formation

For further information on the details of this process refer to Section 4.3.2 and to Polprasert or other text books.

Environmental Requirements

As with composting, a number of environmental factors influence the process. They are:

- Temperature
- pH and alkalinity
- Nutrient concentration
- Loadings
- Presence of toxic compounds
- Mixing

For start-up,a good seed, such as digested sludge,is required in amounts of about 50% of the feed stream at the start, and reduced gradually over the first month.

Table 5.26 Advantages and Disadvantages of Biogas Technology

Advantages	Disadvantages
Produces large amount of methane gas; methane can be stored at ambient temperature Produces free-flowing, thick, sludge.	Possibility of explosion. High capital cost (however, if operated and maintained properly, the system may pay for itself).
Sludges are almost odourless, with the odour not being disagreeable. Sludge has good fertilizer value and can be used as a soil conditioner. Reduces organic content of waste materials by 30-50 percent and produces a stabilized sludge for ultimate disposal.	May develop a volume of waste material much larger than the original material, since water is added to the substrate (this may not be a disadvantage in the rural areas of developing countries where farm fields are located close to the village, thus permitting the liquid sludge to be applied directly to the land, serving both for irrigation and fertilization).
Weed seeds are destroyed and pathogens are either destroyed or greatly reduced in number.	Liquid sludge presents a potential water pollution problem if handled incorrectly. Maintenance and control are required.
Rodents and flies are not attracted to the end-product of the process; access of pests and vermin to wastes is limited. Provides a sanitary way for disposal of human and animal wastes.	Certain chemicals in the waste, if excessive, have the potential to interfere with digester performance (however, these chemicals are encountered only in sludges from industrial wastewaters and therefore not likely to be a problem in a rural village system).
Helps conserve scarce local energy resources such as wood.	Proper operating conditions must be maintained in the digester for maximum gas production.
	Most efficient use of methane as a fuel requires removal of impurities such as CO_2 and H_2S, particularly when the gas is to be used in internal-combustion engines.

Source: National Academy of Science (1977)

Table 5.27 compares biogas technology and composting

Table 5.27 Comparative analysis of Biogas Technology and Composting

Operating conditions	Composting (aerobic/anaerobic)	Biogas technology
Materials added to nightsoil or animal manure for C/N ratio and moisture adjustments	Vegetation	Water + vegetation
Temperatures	50-70°C	Ambient
Period of operation	6-8 weeks (including-maturation & curing)	4-8 weeks
Nitrogen loss	Low to high	High
Space required	Same	Same
Modes of operation	Range from traditional to complicated	Complicated
End-product	**Composted materials**	**Digested slurry**
Weight	Reduced due to water loss	Increased in density due to biomass production
Water content	40-50%	88-92%
Humus content	Abundant	Less than composted product
Pathogen destruction	Good	Moderate
Transport	Easier (solid matter)	More difficult (liquid matter)
Further handling	Not necessary	Drying usually needed
Storage	Easy, little loss of nitrogen	Difficult, with possible loss of nitrogen

Source: Polprasert (1989), adapted from Tam and Thanh (1982)

Temperature

A temperature range of about 25-40°C (mesophilic) is generally optimal. It can be achieved in many regions without additional heating, thus being very economical. In some cases additional energy input is provided to increase temperatures to 50°-65°C (thermophilic range) for greater gas production. In some parts of the world heating of the feed stream during winter is necessary. Often digesters are constructed below ground to conserve heat.

pH and Alkalinity

A close to neutral pH is optimum. At lower pH values (below 5.5) some of the bacteria carrying out the process are inhibited. Excess loading and presence of toxic materials will lower pH levels to below 6.5 and can cause difficulties. When pH levels are too low, stopping the loading of the digestor and/or use of lime is recommended. The presence of alkalinity between 2500-5000 mg/L will provide good buffering against excessive pH changes.

Nutrient concentration

C/N ratios of about 25-30/1 are recommended, as is the case with composting. Other elements such as P, Na, K and Ca are important.

Loadings

Of concern are two types of Loading:

- organic loading, kg COD or VS (volatile solids)m^3-d

ccc
- hydraulic loading, or retention time

There are two types of anaerobic digesters with the following optimal organic loading rates (Polprasert, 1989)

-dispersed growth	1-4 kg VS/m^3-d	
or	1-6 kg COD/m^3-d	
-attached growth		
anaerobic filters		1-15 kg COD/m^3-d
up-flow sludge blanket		5-30 kg COD/m^3-d

for hydraulic detention time:

dispersed growth	10-60 days
attached growth	
anaerobic filters	1-10 days
up-flow sludge blanket	0.5-6 days

Types of Biogas Digesters

A detailed coverage of the various batch, semi-continuous and continuous biogas digesters is beyond coverage in this manual. The several references included here, but particularly Polprasert (1989) should be consulted. Coverage given here is restructured to a brief overview only of dispersed-growth digesters. A comparison of popular Chinese and Indian designs is provided by Tam and Thanh (1982). Figures 5.17 and 5.18 provide a schematic of a low-cost biogas digester and a fixed-dome digester.

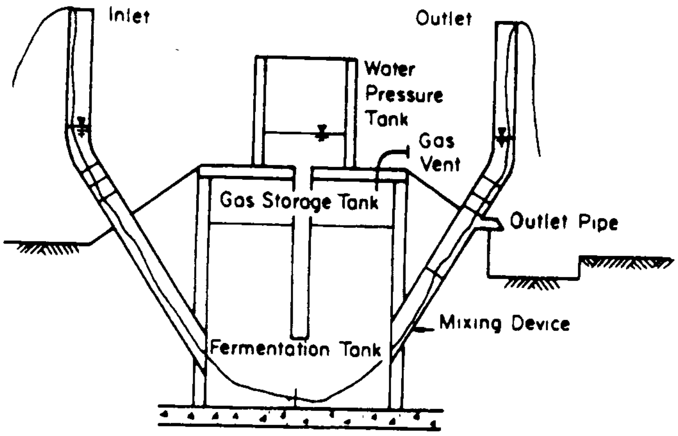


Figure 5.16 Low Cost Biogas Digester

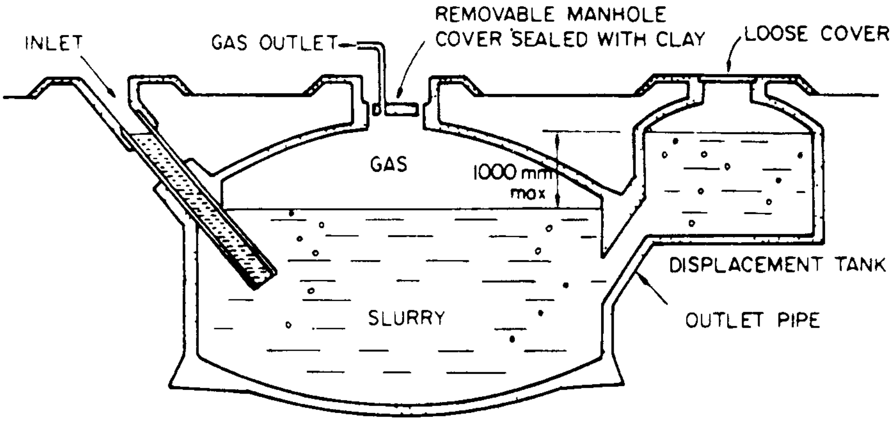


Figure 5.17 Mixed Dome Biogas Digester

Toxic Compounds

Table 5.28 provides information on common inhibitors.

Table 5.28 Inhibitors of Biomethanation

Parameter	Inhibiting concentration (mg/L)
Volatile acids	>2,000 (as acetic acid)[a]
Ammonia nitrogen	1,500-3,000 (at pH>7.6)
Sulfide (soluble)[b]	200; >3,000 toxic
Calcium	2,500-4,500; 8,000 strongly inhibitory
Magnesium	1,000-1,500; 3,000 strongly inhibitory
Potassium	2,500-4,500; 12,000 strongly inhibitory
Sodium	3,500-5,500; 8,000 strongly inhibitory
Copper	0.5 (soluble metal)
Cadmium	150[c]
Iron	1,710[c]
Chromium +6	3
Chromium +3	500
Nickel[d]	2

[a] Within the pH range 6.6-7.4, and with adequate buffering capacity, volatile acids concentrations of 6,000-8,000 mg/L may be tolerated

[b] Off-gas concentrtion of 6 percent is toxic

[c] Millimoles of metal per kg of dry solids

[d] Nickel promotes methane formation at low concentrations. It is required by methanogens

Source: EPA (1979)

SAQ 5.6

Contrast the conversion of domestic/agricultural/industrial wastes into compost and biogas. Outline what is common and what is different about the two processes.

5.6 SELECTED MATERIALS RECOVERY

The following materials have been selected for special coverage in this section because of their importance to the waste stream, their current substantial level of recovery and reuse, or their potential for much increased recycling.

5.5.1 Paper and Paper Products
5.5.2 Plastics
5.5.3 Metals
5.5.4 Glass
5.5.5 Automobiles

Recycling through recovery from the waste stream and reuse of the recovered material to make new products or recover energy is a rapidly changing scene. Therefore up-to-date information cannot usually be found in archival journals or books. A number of privately sponsored 'magazine-type' publications have appeared in recent years devoted to the topic of informing the public and professionals on the latest developments in recycling worldwide. One of these publications is WARMER BULLETIN, published in the United Kingdom. WARMER stands for **W**orld **A**ction for **R**ecycling **M**aterials & **E**nergy from **R**ubbish. It is published four times a year free of charge. Its publications of the last three years have provided helpful resource material for this section.

5.6.1 Paper and Paper Products (WARMER BULLETIN, November '91)

Paper and paper products are the largest single component of the waste stream. They have also the longest history and close to highest percentage of recycling success.

"Paper making depends on the single fact that wet cellulose fibres bind together as they dry under pressure. Paper recycling just reverses this process, -- making the cellulose very wet and agitating it so that the fibres are separated and can be reconstituted. (WARMER BULLETIN, November 1991)."

Recycling vs. Incineration Option

"Recycling paper saves trees. It can also save energy, because pulping and processing paper requires less energy than pulping and processing trees. But if the energy used in processing the waste paper comes from fossil fuels (as in Netherland, Denmark and U.K.) and the energy used in processing the trees comes from the residues from the logging, sawing and pulping operations (as in Sweden), the net environmental benefits are not so obvious. Indeed, using recovered fibre as fuel might actually turn out to be more environmentally benign". (M. Flood in WARMER BULLETIN, November 1991). The Netherlands obtain 69% of the fibre used in paper and board from recycled material, whereas in Germany it is 48%, and in Sweden lower still. In the United States about 20-25% comes from recycled paper.

A dry tonne of salvaged paper produces somewhat less recycled fibre because of the loss of filler, broken fibres, glue, laminate and other items which are washed out in the processing of waste paper. Newsprint may produce 0.85-0.90 (dry) tonnes of pulp; printing, computer paper and other papers perhaps 0.65-0.70 (dry) tonnes. Fibres can also not be recycled more than five times other than for non-renewable products such as toilet paper.

The necessary detailed information required to choose between the recycling option (fibre reuse) and the incineration option (fuel reuse) is beyond this manual. It will also depend on whether other conditions in the country favour incineration and waste-to-energy plants or landfilling. In any case paper and paper products are a valuable resource and should be recovered from the waste stream, regardless of whether fuel or fibre is recovered.

Types of Paper and Paper Products and Uses

Pfeffer (1992) reports that the types of paper and paper products recycled are distributed as follows by weight:

•	Corrugated containers	47%
•	Newsprint	18%
•	Mixed papers	12%
•	High-grade papers from print shops and offices	23%
	Total	100%

The major sources of recycled paper have been and continue to be the industrial and commercial users, but in future the individual householders are expected to contribute more because of the greater emphasis on public education. Of all items separated by householders, newspapers have the greatest success.

As far as the opportunity to reuse fibre in the production of paper and paper products, paper (card) board uses the most, but construction paper and tissue paper use the highest percentages of recycled fibre, at close to 50%. Cardboard follows at about 33%, whereas fine papers may be as low as 5%.

Markets and economics remain the most important influences on the recycling of paper, as for other materials.

5.6.2 Plastics

Plastics are perhaps the most important new material of the current century that have impacted the daily life of people. Use of plastics in the second half of this century has grown enormously to a current 100 million tonnes used world wide. They have replaced other materials in products and been used for new products. Grocery bags, bags for waste disposal, as protections for cleaned clothes, soft drink bottles, toys, insulation material, packaging for foods and industrial products and many other uses are part of everyone's daily life, particularly in the developed world. Plastics are light in weight, and the products are often high in volume as compared to their low weight. They are durable and versatile.

The disposal of plastics can cause difficulties whether landfilling, incineration or recycling is used. Only about 7% by weight, but about 20% by volume of household wastes are due to plastics. Because of their high-volume low weight characteristic, and because of the need of separating the several types of plastic materials, the sorting and the transportation to reuse plants is relatively expensive. Therefore on the whole recycling of plastic materials has not been as successful as for other materials, -- overall less than 10% of plastics produced.

Types of Plastics and Use

The great majority of modern synthetic plastics are derived from petroleum or natural gas. About 4% of all oil uses goes to plastics use. The two main types of plastic are (WARMER BULLETIN, February 1991):

1. **Thermoplastics** - soften when heated and hardens again when cooled. Most plastics produced are of this type. Plastic bags are one example.

2. **Thermosetting** - hardened by curing and cannot be remoulded, for example a melamine table top.
   There are many types of thermoplastics (Howell, 1992 and WARMER BULLETIN, February 1992)

• PET	(**p**oly**e**thylene **t**erephthalate) for carbonated soft drink bottles
• HDPE	(**h**igh **d**ensity **p**olyethylene) for bottles for household chemicals, bottle caps, milk containers
• LDPE	(**l**ow **d**ensity **p**olyethylene) for bags, sacks, squeeze bottles and bin liners
• PVC	(**poly**vinyl **c**hloride) for blister packs, food trays and bottles
• PS	(**p**oly**s**tyrene) for egg cartons, cups for vending machines and household use
• PP	(**p**oly**p**ropylene) for packaging film, margarine containers and other food packaging uses

- "Engineering plastics" characterized by higher strength, resistance to heat and impact, for use in automobiles, airplanes, appliances and industrial products, often replacing metals previously used.

The PET^{S} (from clear soft drink bottles) and the HDPE's (from milk containers) are receiving the major attention for recycling.

The end-use of plastics for Western Europe is given as follows(WARMER BULLETIN, February 1992)

Packaging	33%
Furniture, toys, houseware, etc.	25%
Building/Construction	20%
Electrical/electronics	10%
Automotive/transportation	7%
Agriculture	5%
Total	100%

Recycling Operations (WARMER BULLETIN, February 1992)

Sorting at the household or centrally into the different types of plastics must take place. To aid householders special codes have been developed for each type of plastic by American plastics manufacturers, and now accepted elsewhere. Other schemes, including returnable deposits, have been developed in several European countries. Special curbside collections for many types of recyclable materials, including plastics are now common in many cities world wide. At central processing plants automatic separation techniques, sorting plastics electronically, by floatation and by X-ray techniques, are used. Because plastics cannot be easily sterilized, plastic bottles are normally not refilled for hygienic reasons, and are instead shredded for reprocessing. Separation of mixed plastics may not always be feasible. Processes have been developed for converting mixed plastics into 'plastic wood' for fencing and garden furniture. Howell (1992) and several issues of WARMER BULLETINS (November 1991, February 1992, November 1992 and February 1993) provide case studies in various parts of the world on the use of recycling facilities.

Unless there are markets for collected and reprocessed plastics recycling cannot take place. This issue is not yet successfully resolved. It may well be that the environmental burden of transporting lightweight material long distances for cleaning and remanufacture is greater than that imposed by using virgin materials. Recycling of plastics components from cars and other transportation products may become more feasible in the future.

Energy Recovery

Plastics are of a high-calorific value, varying between 22,000 and 43,000 kJ/kg, making them equivalent to wood (16,000 kJ/kg) at the low end, and to heating oil (44,000 kJ/kg) at the high end. Therefore in incineration, in WTE plants and in the production of energy, plastics together with other combustible components of the waste can be used productively.

Degradability

Most plastics are not biodegradable (broken down by soil bacteria). Some plastics have been produced which are photodegradable, ie. broken down by sunlight. Although development of such products was once looked at as a possible solution for the disposal problem this has not been found to be feasible on a large scale and may have led to increased use and discarding of plastic products.

Outlook

The increasing use of plastics and the resulting buildup of plastic waste products is a problem. Through industrial initiatives, government legislation and public education the problem can be made smaller. The extent of effective recycling through the existence of viable markets for plastic waste products is as yet unclear.

5.6.3 Metals

Covered here are aluminium and ferrous metals.

Aluminium

Aluminium recycling, especially for cans, is often given as an example of success of recycling in general. The production of aluminium from bauxite is a highly energy intensive process. The relative environmental impact of this production process will depend on the source of energy used. Water power will be most benign, brown coal most damaging, particularly with respect to the CO_2 production and the greenhouse effect. In any case, recycling aluminium products makes sense, particularly cans. Recycling of other aluminium products such as packaging products and foil is more difficult to achieve.

The use of aluminium cans for all kinds of beverages has risen greatly over the last thirty years, mostly replacing small glass bottles. The extent of recycling varies, reported as over 50% in the U.S., considerably less in Europe. The future of aluminium, plastic and glass containers may in part depend on the reality as well as the image with respect to recycling.

Ferrous Metal

The separation of ferrous metals from the waste stream can be quite easily achieved by magnetic separation. In the past there was a market for tin cans, which is now very small. However, tin-coated steel cans, sometimes with interior plastic coatings, are used for fruit and vegetable products.

Together with other metal products in the waste, ferrous metals are brought to scrap dealers. Appliances and other enameled fixtures discarded from households are also handled by scrap dealers. They are used together with metal products from automobiles and industrial discards by steel producers which include a percentage of scrap metal in their production. Because the removal of metals from the waste stream is desirable for operation and maintenance reasons for the subsequent waste processes, it is generally carried out even if the price for scrap metal is low.

5.6.4 Glass (Pfeffer, 1991)

Glass containers and bottles were choice for all kinds of fruit and vegetable products and beverages of many kinds through to the 1950s. Since then they have lost much of the market share for soft drinks to aluminum cans and plastic bottles, but still have the major share for certain products such as jams, preserves, pickles and other vegetable products. They also retain a virtual monopoly for wine and liquor, and a considerable share of the beer market. In the latter substantial deposits assure a high return of empty beer bottles.

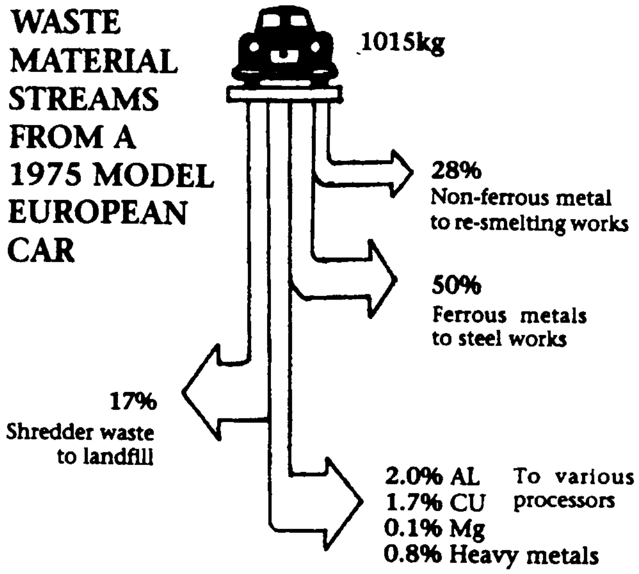
The reuse of glass for the production of new glass products necessitates the separation of glass according to colour. Furthermore metal or plastic caps, and labels must be removed. Then the glass is crushed to reduce the volume and thereby shipping costs. There is often an imbalance of market and supply for certain coloured glass. Meade (WARMER BULLETIN, November, 1991) reports of a large oversupply of green and other coloured glass, making their recycling not possible. She also reports on other possible uses for crushed glass: "glassphalt" for paving streets by replacing other asphalt aggregates with glass in part; crushed glass fillers for waste treatment plants.

5.6.5 Automobiles (WARMER BULLETIN, May 1991 p. 17 and November 1992 p. 15)

While most of the public believes that 'automobile graveyards' are the final resting place for the several tens of millions of cars which are scrapped worldwide each year, in fact the scrap metal dealers have been doing a pretty good job of recycling and are making a good living out of it. Nevertheless more can be done. Governments, manufacturers and scrap dealers are collaborating to improve the reclamation of more reusable parts from old automobiles. Some car makers are developing technologies to use recovered materials such as thermoplastics from cars for new automobile production. Several countries are developing ordinances which would require manufacturers of components, spares, accessories and automobiles to ensure lifespan maximization, ease of dismantling, and reusable or recyclable components. Some automobile companies are planning to construct vehicle disassembly plants. In Germany, a consortium has been formed to recover precious metals from cars, such as platinum and rhodium used in the production of catalytic converters.

Figure 5.18 shows the proportion of recoverable material and waste from a 1975 European car. Since the average lifespan of a car is about 10 to 12 years, this information is only a few years out of date.

In attempting to increase the reuse of automobile components it is also important to remember other important issues: the safety, reliability and durability of the car while it is on the road; ease of disassembly for recovery of parts versus the ease of disassemby by car thieves and safety on impact.



Source: WEKA Fachverlag für technische Führungskräfte

Figure 5.18 Material streams from a 1975 Model European Car

5.7 CASE STUDIES

A number of case studies on specific recycle projects across the world are briefly cited here to provide a brief overview of what is happening across the world and to provide the opportunity for follow-up, where desired. Most case studies were selected from WARMER BULLETINS (WB).

1. **Eastern Europe and Mediterranean Countries**
   "Perestroika: Making use of what 550 million people throw out"
   WB Summer 1989, p. 10-13
   Reports on resource recovery in nine countries (Portugal, Poland, Hungary, Romania, Yugoslavia, Turkey, Israel, Egypt, Malta)

2. **Russian Recycling (WB Autumn 1989, p. 9)**
   Landfilling is the primary method, at waste generation of 200 kg/person/year. 12 energy-from-waste plants in the Soviet Union, recovering waste heat for steam heating. A few mechanical composting plants. Recycling programs for newspapers, corrugated board, textiles and food wastes.

3. **Shanghai, China, Recycling (WB Winter 1989, p. 23)**
   The Resource Recovery and Utilization Company of Shanghai has 24,000 full-time and 13,000 part-time staff. More than 1.35 million tons of recyclables were collected in 1982, including 240,000 tonnes from the estimated 1.6 million tonnes of household refuse generated by the population of almost 12 million. Source separation is encouraged by 502 stations which buy material, plus door-to-door collections and nearly 1,500 buyers in the rural fringes, who work on a commission basis.

4. **Recycling in Hong Kong (WB Spring 1990 p. 3)**
A new waste management system is being established to cope with near-full landfills. The 450 tonnes per day compost plant is now used only as a transfer station, because of low quality output. New landfills are to be constructed further from urban centres, with transfer stations sited locally. The three incinerators which together handle 1,900 tonnes of waste daily are "yesterday's technology" and the government wants to close them. Waste incineration with energy recovery is a preferred option. Recycling is already in existence, but collection schemes will be difficult to organize with 90% of Hong Kong's residents living in high-rise accommodation. At present, only 1% of glass is recycled, but more than 50% of paper and even higher proportion of metals.

5. **Rio de Janeiro Recycling (WB Spring 1990)**
Companhia Municipal de Limpeza Urbana (COMLURB) is the public corporation formed in 1975 to handle street cleaning, waste collection, disposal and waste treatment for Rio de Janeiro. COMLURB also has the responsibility of drafting regulations in those areas. It reports directly to the city's public works department, which in turn is responsible to the mayor.

Each of the city's six million inhabitants produces an average of 285 kg of waste per year. Collection is made more difficult by the absence of standardized waste bins. Illegal dumping is common, despite regulations and threats of heavy fines. There are six transfer stations, two of which are equipped with waste compactors. The city's one recycling plant treats 300 tonnes each day: materials sold include paper, plastics, glass (sorted into clear and coloured), ferrous and non-ferrous metals. There is still considerable scavenging at landfills.

Additionally, Rio has a composting plant handling 100 tonnes of waste per day. Operating costs of both the recycling and compost plants are covered by the sale of compost and recovered materials, as well as by savings from reduced transport and landfilling costs. The three landfills operated by the corporation have until recently accepted a mixture of household, commercial and industrial wastes, but stricter controls are now being considered. Landfill gas recovery from the city's former tip is providing vehicle fuel and gas, which after cleaning, is fed into the state gas network.

6. **Singapore Recycling (WB August 1990 p. 3)**
Singapore is a small (625 sq km) but crowded (2.65 million people) island. Like most major cities in the world, Singapore has a great deal of rubbish to dispose of, and its hot and humid climate makes rapid disposal essential. Land suitable for refuse disposal is scarce, and incineration is the preferred disposal method. The island's two incineration plants handle 60% of the refuse daily. The first, at Ulu Pandan, was commissioned in 1979 and has a capacity of 1,600 tonnes per day. The second, Tuas, has a capacity of 2,000 tonnes per day, and began operation in 1986. A third incinerator which is now being built at Senoko, is due for completion in 1992. It will process 2,400 tonnes a day.

It is planned to incinerate 85% of the island's total waste, recovering ferrous scrap and generating electricity, revenues from which will cover operating costs of the plants.

7. **Fiji Waste Treatment (WB August 1990 p. 3)**
In January 1990 the French Company Novergie, signed a letter-of-intent with the Government of Fiji to set up a $14 million garbage treatment plant in Sura. The French company will be granted a 25 year monopoly in the industry. The plant will cover 2.0 hectares and employ 20 people and treat the garbage from the Greater Suva area. The rubbish will be processed to separate the organic fraction; this will be moved to concrete fermenting towers and eventually used to make compost. 18,000 tonnes of household waste and 27,000 tonnes of garden waste will be processed each year, although the completed plant will be able to handle up to 100,000 tonnes per year. Completion is scheduled for 1991. Suva's rubbish is currently disposed of in the Lami rubbish dump; this is near the coast, and studies have indicated that the marine environment near the dump is significantly polluted by mercury, lead, zinc and organic waste. The French company originally proposed an incinerator-based process for the garbage, but decided that the compost option was better suited for Fiji. The Lami dump has a new base of life; it is now expected to become the site of a $20 million 'cultural village'.

8. **Taiwan Waste Management and Resource Recovery (Philip Patrick, WB November 1990 p. 8)**
Taiwan has experienced tremendous economic growth in its 40 years as an independent state, but the rate of industrial development has caused serious environmental problems in the major cities, not least those associated with solid waste management. Taipei, the capital city, has a population of 4.7 million. Waste disposal has traditionally been by landfill, but land is becoming increasingly difficult, in some areas impossible to find.

Incineration with heat recovery for electricity generation is the choice of the future. 15 plants are planned for Taiwan, with 5 plants for Taipei.

Where landfill has to continue, high design and operation standards will be required. The landfill at Futeking in Taipei City could serve as a model for the rest of the world. It receives 2,600 tonnes of waste per day and is engineered to the highest standards, with comprehensive environmental protection features: leachate collection and treatment, gas collection, drainage systems, design features to allow for earthquakes and typhoons, and landscaping of the surrounding area.

Since Taiwan has few indigenous resources, conservation and reuse of materials forms an important part of the economy, and materials recovery and recycling are a major industry. Activities are carried out almost entirely by the private sector with no formalized industrial structure. Collection of materials ranges from private individuals sorting cardboard, bottles, etc. from waste put out on the street for collection or operators with tricycles collecting from shops and businesses, to the classification and baling of salvaged materials in large sorting yards from which materials are sold to industry for re-use.

An organization promoting the recycle of materials provides large colourful containers ("igloos") in streets and other public places for reception of glass, plastics and metal. The contract calls for 4,000 tonnes of PET containers over a 5 year period for processing and reuse by the plastics industry. A further example is the recycling of aluminium cans, extensively used for soft drinks and beer. Recycling rate is estimated to be around 50%. A law is being drafted requiring manufacturing of various items, including bottles, aluminium cans, pesticide containers and mercury batteries, to take back these used materials.

9. **Recycling in Cairo (Lois Jensen, WB May 1991 p. 5)**
Manchiet Nasser, at the northern edge of Cairo, is the workplace and home of more than 10,000 Zabbaleen, or garbage collectors. Its air is laced with the smoke of smouldering rubbish and the odour of rotting organic wastes. There is a hidden order to the chaos here. Mountains of garbage have been carefully sifted into piles of paper, plastic, glass, metal and bone. Manchiet Nasser and six other settlements on the outskirts of Cairo are part of one of the oldest and most extensive recycling operations in the world. Today, this traditional system -- which relies on donkey carts and thousands of small entrepreneurs who buy used materials -- is being brought into the twentieth century.

Today, Ahmed Moustafa El Rakabawy is chairman of the board of directors of the Environmental Protection Agency (EPC), which includes representatives from both the Wahi and Zarrab communities, and recently won a bid to mechanize part of Cairo's household garbage collection system. Its 20 trucks now cover two residential areas, where 40 donkey carts once operated, in considerable less time.

With over 10 million inhabitants the old systems had to be modernized. Attempts to bypass the age-old system by a municipal run system failed. It did not service Cairo's needs and was too expensive to operate. It would have ruined the livelihood of many people and wiped out many small shops and businesses. Thus the decision was made to modernize the existing system. Other private sanitation systems were created to provide competition to the existing Zabbaleen company.

10. **Source Separation in Developing Countries (C. Furedy, WB August 1991 p. 12-13)**
Dr. Furedy reviews the resource recovery systems in a number of southeast Asian countries and China, and reflects on the decline of recovered materials when standards of living rise making the work required for collecting and transporting recovered materials to shops or government operated stations less attractive.

11. **The Recylers of Harare, Zimbabwe (J.B. Keeling, WB November 1991 p. 4)**
Harare, capital city Zimbabwe, has a population of about 1.25 milliion people, increasing at an annual rate of 6%; 3% by birthrate and 3% by influx. In 1990 approximately 130,000 tonnes of domestic waste and 90,000 tonnes of industrial wastes were generated. Plastic, paper and glass, together with metal, hessian sacks, rags and bones have been salvaged from city sites since the early 1970s.

Harare offers contractors the right to remove a given waste for a tendered sum over a two-year period. Other Zimbabwean towns and cities have similar arrangements. Tip scavengers collect reusable refuse and sell it to the contractors' representative on site.

Special uses of recovered materials include:

- tyre sandals and mats made from old tyres
- heat sealing of plastic sheets and salvaged bags result in new plastic bags for fruit and vegetable sellers
- Cotton lint from stripping cotton seed is used for upholstery, filling cricket balls, for fuel and cattle feed

12. **Recycling in Vietnam (WB November 1992 p. 2)**
Hanoi and Ho Chi Minh City (Saigon), Vietnam's two largest cities, have highly labour-intensive recycling systems in daily operations. In a country where labour is cheap and materials, when available, too expensive for the average person, nearly all waste is reclaimed for further use by private enterprise in its simplest form. An army of scavengers swarms continually over the piles of discarded rubbish which ring the cities. Anything reusable is either kept for personal use or rushed to one of the many stalls which bear signs offering to buy waste of all kinds. Scavengers reckon to make about 10,000 dong (= U.S. 90 cents) a day for their work, apart from items they keep for themselves. There are about 2,000 scavengers in Hanoi. The human scavengers help to relieve Hanoi's overburdened waste collection system.The simple act of removing inorganic waste from the refuse piles allows for more effective composting of organic waste.

5.8 PROBLEMS/QUESTIONS

The following questions/problems are designed to test your knowledge with regard to Chapter 5, and to the Manual as a whole. Some questions/problems may require the reading/assistance of other textbooks in the field. If there is missing information, state your assumptions made and why you made them.

1. Paper and paper products are an important part of domestic and industrial/commercial wastes. Estimate for your household and for the building/business you work in the annual quantity of paper/paper products of different categories.

2. Write a 1,000 word short report to the new mayor of your community outlining what the current role of the municipal government and of private companies/citizens is in the role of resource and energy recovery in your community.

3. Write a 1,000 word short report to the new mayor of your community about the existing legislation in your country, state and community affecting resource and energy recovery in your community.

4. Write a 1,000 word short report to the new mayor of your community outlining your recommendations about necessary changes in the situations described in questions 6 and 7, recommended by you, and the difficulties the mayor may face in accomplishing these changes.

5. Your community is planning to construct a resource recovery plant of the kind outlined in Figure 5.9. You are in charge of solid waste management. Consult with companies in your community or country/state which supply some of the necessary equipment. Indicate, where necessary, what types of equipment required will need to be imported. With the assistance of the suppliers prepare a brief technical report to the Chief Municipal Engineer on your findings.

6. An experimental 200 tonnes/d resource recovery plant, salvaging the proportions noted in Figure 5.9, has markets for RDF, ferrous metals, and glass, each at $20 per tonne. If capital and operating costs for the plant amount to $50/tonne). If capital and operating costs for the plant amount to $50/tonne, what annual subsidy must be provided to keep the plant operating?

7. Write a 1,000 word short report to the head of an environmental action group who vigorously opposes the siting of a new landfill operation and of a new incinerator for waste disposal in your community. Use layman's language.

8. Assess the current practice of recycling/reuse of various components of wastes in your community. Pay particular attention to markets (availability, costs and steadiness of demand). What changes, if any, do you recommend for the next five years?

9. The recycling of paper and paper products has historically and currently been the largest success. What are some of the reasons for this? Are there lessons to be learned for other possible materials to be recycled?

10. Assess the present state of recycling of automobile products in your community/country. Include in this all parts (body, tires, batteries, plastics etc.). Assign a grade of 0 (worst) to 10 (best) for the possible opportunities in your community. If the mark is less than 5, indicate what changes should be contemplated and how this could be achieved.

11. Repeat question 9 for the following products:

    a) bulky goods, such as appliances, off-road vehicles, snowmobiles etc.
    b) discarded lumber and wood products
    c) plastics
    d) aluminum (cans and other consumer products)

e) ferrous metals

Pay particular attention to the question whether private industry or government action is desirable to improve the current situation.

12. Investigate the use of composting in your community (at the individual household, farm commune, or private/municipal level) and write a brief report on it. If the practice is not common, give the reasons why this is so, and suggest possible ways to increase composting if this makes sense.

13. Repeat question 11 for biogas production.

14. The treatment of sludges from wastewater treatment often involves anaerobic digestion, one form of biogas production. Investigate whether the local wastewater treatment plant uses this form of sludge treatment and write a brief report on it. If not, prepare a brief report on this topic from literature information.

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ANSWERS TO SELF ASSESSMENT QUESTIONS

SAQ 5.1

See Section 2.3.2 Field Investigation (p. 13) for assistance.

Quantity of Waste

- Choose a sample period (one week, or 3 days per week, etc.)

- Count the number of municipal truck loads (assumed here of equal size/weight) during each sample period.
- Weigh each full truck, and also the empty truck, to establish total load delivered.
- Do the same for private truck loads

Note: If the available scale is too small to weigh a truck, choose up to three truck deliveries, dump and weight contents in smaller batches. Count truck loads as full, half full etc. and estimate total weight delivered in sample period that way.

Quantity of waste, kg/person/day:

$$\frac{\text{Total Weight delivered of no. of sample days(kg)}}{\text{no. of days x 5000 persons}}$$

Waste Composition

- Choose a sample size of about 100 kg from a dumped truck load (by quartering method of pile).
- Separate the materials into pre-determined components (e.g. metal, glass/ceramics, etc. (Table 2.2)), and put into containers, such as used oil drums.
- Weigh each container, full and empty to obtain weight of component.
- Calculate each component as a fraction (%) of the total sample of 100 kg.
- Repeat up to 5 times on different days and average the results to obtain the composition of solid wastes.

Equipment Needed

Scales (for truck (if available)), and for smaller samples
Containers
Rubber gloves, coats, face masks, first-aid kit
Shovels
Sorting table

Check your results with appropriate values in Tables 2.2, 2.3 and 5.1.

SAQ 5.2

Given: Summer Camp: 100 children, 25 staff
Solid wastes: bottles and cans = 20% (removed)
(by weight) paper = 40% (burned)
food (kitchen) = 30% (collected)
misc (cabins) = 10% (collected)

Assumptions

1. Waste quantity = 1.1 kg/capita, day
2. Food wastes (30%) have a density of 300 kg/m^3
3. Miscellaneous wastes (10%) have a density of 160 kg/m^3

Solution

$$\text{Food volume/week} = 0.3 \times \frac{125 \times 1.1\ \text{kg}}{300\ \text{kg/m}^3} \times 7 = 0.96\text{m}^3$$

$$\text{Misc volume/week} = 0.1 \times \frac{125 \times 1.1\ \text{kg}}{160\ \text{kg/m}^3} \times 7 = 0.60$$

Total volume to be picked up = $1.56m^3$
= $(2\ yd^3)$

SAQ 5.3

1. Use 100 kg of solid waste as a basis for calculations.
2. Use typical values for moisture content and density (Tables 2.3, 5.1 and 5.7) and energy content (Table 2.6 or 5.12)

Solution

Components		Moisture		Dry Solids		Density	Vol
Type	kg	%	kg	%	kg	kg/m^3	m^3
Food	15	70	10.5	30	4.5	300	0.05
Yard	10	60	6.0	40	4.0	160	0.06
Other	10	20	2.0	80	8.0	160	0.06
Metal	10	3	0.3	97	9.7	480	0.02
Glass	10	2	0.2	98	9.8	160	0.06
Ash	10	8	0.8	92	9.2	480	0.02
Total	100		22.3				0.71

(a) Moisture Content = 22.3%

(b) Density = 100 kg/0.71 m^3 = 141 kg/m^3

Component		Energy kJ/kg	
Type	%	Component	Solid Waste
Paper	35	16,300	5700
Food	15	5,800	870
Yard	10	5,800	580
Other	10	5,800	580
Total			7730

(c) Fuel Value 7730 kJ/kg refuse

SAQ 5.4

Consult Chapters 4 and 5 to prepare your brief answer.

SAQ 5.5

The waste streams from incinerators and WTE facilities are:

- dry ash in the bottom residue
- liquid waste from floor drainage
- fly ash with the flue gases.
- quench water
- scrubber effluents
- flue gases

Each has pollutants which are of environmental concern, although in varying degrees of severity.

Air Pollution

Pollutants are emitted as fine particulates and toxic flue gases.

Concentrations of heavy metals in particulates, particularly lead, zinc, mercury and cadmium, may be significant and care must be exercised in their removal and disposal. The most important of flue gas pollutants are sulphur dioxide (SO_2) and hydrogen chloride (HCl), the agents of acid rain. They may be eliminated by wet scrubbers. Hydrogen fluoride and oxides of nitrogen are also produced but are not normally a problem because of low concentrations.

Water Pollution

The liquid wastes of incineration - floor drainage, scrubber effluents and quench water - have the potential for the pollution of surface waters and aquifers, if they are discharged as waste effluents without treatment.

Land Pollution

Dry ash in the bottom residue and fly ash captured from flue gases in electrostatic precipitations or bag filters contain heavy metals and will pollute the land unless treated or disposed of at special hazardous waste landfills.

SAQ 5.6

Composting and bio-gas production are processes used in the decomposition of organic solid wastes - domestic, agricultural, industrial - to produce useful end products: soil fertilizer in the former, bio-gas (methane) in the latter.

Common Characteristics

- both use organic wastes as the raw material input
- similar space requirements
- the period required for completion of the process - 4 to 8 weeks
- both use biological agents for decomposition

Differences

- end products
- environmental conditions: aerobic for composting, anaerobic for bio-gas production
- water content
- storage of residual end-products - relatively easier for composting
- transportation requirements
- weight, volume and density changes during the process
- temperature: 50° - 70°C for composting, ambient for bio-gas.

Refer to Section 5.5 for details.

6 HAZARDOUS WASTE TREATMENT AND MANAGEMENT

6.1 INTRODUCTION

Hazardous waste is generally defined as waste that can be harmful to the health of humans, other organisms or the environment. However, various more precise definitions are in use.

In Ontario, Canada, the following definition is given: "Hazardous waste means waste that requires special precaution in its storage, collection, transportation, treatment and disposal to prevent damage to persons or property, and includes explosive, flammable, volatile, radioactive, toxic and pathological wastes".

In the USA, the EPA (Environmental Protection Agency) gives a similar definition and also provides a list of hazardous wastes that includes the following:

- spent halogenated solvents used for degreasing (trichloroethylene, methylene chloride);
- spent non-halogenated solvents, such as xylene, acetone;
- wastewater treatment sludges from electroplating.

On the other hand, domestic sewage, animal manures and fly ash are excluded from the list. Nuclear and radioactive wastes are also excluded, because they are controlled separately under the Atomic Energy Act (1954).

In Belgium (Flanders) a distinction is still made between toxic and hazardous waste. Toxic waste is regulated and defined by a National (Belgian) Law (of 22nd July 1974) whereas hazardous waste is governed and defined by the Flemish Law (decree 2nd July 1981) and by VLAREM (Flemish regulations regarding the environment).

Modern science and technology have made possible the production of many new products which have greatly changed our lives from those of our ancestors. A few examples are: television sets, aerosol cans, pesticides, plastic materials used for packaging and the manufacture of toys. Production of such goods creates many industrial waste by-products which may be hazardous if mismanaged. Degreasing compounds, waste preservatives, pesticides, heavy metals, and other toxic contaminants discharged with liquid industrial wastes can have long-term effects on human health.

Concern over hazardous waste is a rather recent phenomenon. Legislation to control hazardous wastes evolved only in the mid-seventies in most developed countries. Most hazardous wastes cannot be handled by the environmental processes used in municipal wastewater treatment plants. Faced with an increasing waste disposal cost, industries will try to recycle more of their waste and to minimize the quantity of waste to be removed off-site. Large industries are sometimes able to solve their own waste problems, but smaller companies will have to make use of off-site facilities for treatment and disposal of hazardous waste.

The organic chemicals of most concern are those that persist in the environment, which means that they are only slowly degraded and, being fat soluble, accumulate in the food chain. Examples are PCBs (polychlorinated biphenyl) and some pesticides. Many inorganic elements, such as Hg, Pb, Cd, As, are biological poisons even at low concentrations and may accumulate in organic matter in soil and sediments and are taken up by plants. They can build up to toxic levels in organs and tissues of the human body.

Of course, it is impossible, within the limitations of this module, to consider the full range of hazardous wastes. Therefore we will discuss just two examples:

- asbestos, the health problems of which are now fully understood, and which present some special treatment and management problems.
- pesticides, which may sometimes end up together with household waste on landfills, although they are very toxic. Some special treatment methods for such materials will be briefly discussed.

This section will be followed by a discussion of physical and chemical treatment methods of some other hazardous wastes such as special sludges, acids and bases, emulsions and waste streams from surface treatment containing chromate and cyanide.

Finally solidification-stabilization will be discussed. This is a method for the treatment of hazardous (mainly metal containing) waste that cannot be recycled and for which no other treatment technology is available. An example of hazardous waste that can be treated by solidification-stabilization is nuclear waste. This field is however so broad and specialised, that it cannot be discussed in detail in this module. Developing countries are strongly cautioned against importing radioactive waste, for which they lack the technology of treatment and control. Particular care must also be taken in the disposal of hospital waste that may contain radioactive materials. In some developing countries serious problems have been encountered with old radioactive sources, used for cancer therapy, that were not properly disposed of and resulted in high radiation doses to sanitation workers and scavengers.

Efficient management of hazardous waste must not only include appropriate removal methods (incineration, landfilling of physicochemically treated waste), but also waste minimization and prevention. Again this is a very broad area which cannot be covered completely in this module. Only some general considerations will be presented and some examples, both from industrialised and from developing countries, will be discussed.

Objectives

The objectives of this chapter are:

- to define the term hazardous waste.
- to illustrate the techniques of management, treatment and minimization of hazardous waste using asbestos and pesticides as examples.
- to describe physical and chemical treatment methods used to treat hazardous waste.
- to describe the solidification / stabilization technique for stabilizing hazardous waste and bringing it to a solid state prior to landfill disposal.

- to emphasize the importance of waste minimization and prevention in the management of hazardous waste and to describe the principal levels of activity of a waste minimization and prevention programme.
- to present a number of case studies of industries in which waste minimization and prevention have been successfully applied.

SAQ 6.1

Compare some typical definitions of hazardous waste.

6.2 ASBESTOS

Asbestos is a fibre material with several interesting properties such as non-flammability; resistance against heat, corrosion, acids and bases; low electric and heat conductivity; high absorbing and insulating capacities. It has found many applications, for example, as a construction material, as an insulating material and as a sealing material, and it has also been used in paints, lacquer and heat resistant textile fibres.

In recent years the use of asbestos has drastically decreased in most developed countries because of the severe health problems that it may cause. Long-term exposure to asbestos can indeed lead to cancer, asbestosis, and several other diseases - Zielhuis (1977).

Considering these effects, asbestos has been eliminated and replaced in several applications. Therefore, a major problem at the present time is the removal of asbestos from existing buildings and the disposal of asbestos containing waste. Several methods are suggested in the following section (6.2.1). One must however be aware of the fact that the disposal of asbestos is very expensive, and therefore priority should be given to using alternatives to asbestos, so that it can be eliminated at the source - Albracht and Schwerdtfeger (1991).

6.2.1 Methods for the removal of asbestos containing waste

Big-Bag Method

In the Big-Bag method, asbestos-containing waste is packed in plastic bags, followed by discharge at a landfill. The method is still frequently used, but the risk of damaging the plastic bags by discharging them at the landfill is not negligible, and this may result in intolerable asbestos concentrations at the landfill site, as well as in the soil and in the air. Therefore, this method is no longer recommended.

Discharge in Pits

This method consists of the mixing of asbestos-containing waste with water, followed by discharging the mixture in suitable pits, and covering with cement. Immediate covering of the wet asbestos with cement can however not always prevent the emission of intolerable amounts of asbestos. Therefore, the use of this method should also be discouraged.

Double-barrel Method

An inner barrel of about 100 litres, containing the asbestos, is placed in an outer barrel of 200 litres and the annular space in the outer barrel filled with concrete.

Since the concrete jacket is not fully durable, this method may not always be sufficiently safe for the disposal of asbestos containing waste.

Block or Cube Method

The asbestos-containing waste is mixed with cement and, after hardening, is stored in a pressure-tight aggregate cube. Subsequently, the cube is covered with a polyethylene coating. The treated product thus obtained can be discharged at a class II or III landfill (landfill for household waste and inert waste respectively).

Using this method is certainly a move in the right direction of ecologically sound technologies; its cost ranges from US $80 to US $600 per m^3 of asbestos-containing waste.

Vitrifix Process

When heated at 1400°C the fibre structure of asbestos is degraded, resulting in a glasslike product which has practical uses, for example as an additive in concrete. This is the safest most ecologically sound technique, but also the most expensive. The cost ranges from US $650 to US $1200 per m^3 of asbestos-containing waste, depending on the application of the treated waste.

6.3 PESTICIDES

Insects are the most numerous of living organisms and the nearly one million described species constitute approximately 70% of all species. Of these, about 1% are considered to be significant pests. They attack humans and their domestic animals, transmit human, animal, and plant diseases, destroy structures and compete for available supplies of food and fibres. In the United States, at least 600 species of insects are important pests. Estimates suggest that the total annual loss to agriculture in the U.S. is about 10% of production, and worldwide agricultural losses are about 14% of production - Othmer (1984). Therefore, it is obvious that pesticides, and more specifically insecticides, are used extensively (more than 2 million tons/year).

The usefulness of any pesticide is dependent upon its proper application and this is determined by the properties of the pesticide, the habits of the pest, and the site of the application. Essential concerns in pesticide management include residues in food and the impact of such residues on humans. Pesticides (especially chlorinated pesticides) are one of the major problems regarding soil pollution, and therefore, constitute a great threat to public health. These compounds are extremely resistant, both chemically and biochemically; moreover, they concentrate in the food chain (bio-accumulation: e.g. DDT), particularly in fatty tissues - Buckens (1975). The toxicity of pesticides varies from one species to another. Some pesticides are carcinogenic and/or mutagenic. Full toxicological reports are not yet available but the public is generally aware of the fact that pesticides may damage health severely.

Pesticides can be subdivided into several classes: insecticides (against insects), herbicides (against plants), fungicides (against fungi and mould), rodenticides (against rodents), nematocides (against nematodes), acaricides (against mites),molluscocides (against snails). The first three categories are the most important ones, especially considering the amounts produced. Pesticides are commonly formulated as dusts, water dispersions, emulsions and solutions - Menis (1983).

The range of persistence of pesticides varies from that of tetraethylpyrophosphate, which is destroyed by moisture within a few hours, through that of nicotine, pyrethrin and rotenone, which are decomposed by light and air within a few days, to the more stable carbamates, pyrethroid, organo-phosphorus, and organochlorine insecticides, which may persist for weeks. Most persistent are inorganic substances, such as lead arsenate and cryolite, which are removed only by weathering or washing - Kirk Othmer Encyclopedia of Chemical Technology (1984).

Since the chlorinated cyclic pesticides are very persistent, and, therefore, constitute a large disposal problem, some of the available treatment methods for chlorinated waste will be discussed - Buckens (1975).

6.3.1 Deep-well Disposal

The liquid is stored in an underground, porous layer which is isolated by an impermeable layer (clay). This method is not recommended, since it is almost impossible to be absolutely sure that all pesticides will remain in the wells. If not, the contamination of the soil can be disastrous.

6.3.2 Incineration

The incineration of chlorinated waste produces CO_2, H_2O and HCl. When the flue gases are cooled slowly, Cl_2 can be formed, according to the Deacon reaction:

$$2HCl + \frac{1}{2}O_2 \Leftrightarrow Cl_2 + H_2O + \text{heat} \qquad (1)$$

The formation of Cl_2 should be avoided, as it is more difficult to remove by washing than HCl. This can be realized by working at high temperature (>1200°C) and low oxygen excess. Sometimes HCl can be recovered as a dilute solution which can be used to control the pH in biological treatment plants - Broen (1992). In order to remove HCl by absorption in water, the gases must be quenched rapidly to avoid Cl_2 formation. Several processes are available for rapid cooling of the flue gases, among them the UCAR-process (flue gases are cooled by injection of a cold acid stream), and the NITTETU process (immersed incineration). Sometimes the flue gases are quenched in a graphite quench.

6.3.3 Chlorolysis

Chlorolysis is a destructive chlorination process, resulting in the production of commercially valuable products, such as tetrachloromethane (CCl_4), tetrachloroethylene ($CCl_2 = CCl_2$) and hexachloroethane (C_2Cl_6). The reaction can take place in the liquid phase (low temperature, high pressure) as well as in the gas phase (high temperature).

SAQ 6.2

Discuss the use of asbestos. Why is asbestos being replaced by other materials in several of its applications? State what methods are available for the removal of asbestos wastes.

6.4 PHYSICAL AND CHEMICAL TREATMENT OF SOME HAZARDOUS WASTES

Several physical processes, including filtration, centrifugation, flotation and sedimentation, are used for solid-liquid separation. Membrane processes, for example, reverse osmosis or electrodialysis, can also sometimes be employed. Stripping and distillation are also useful physical processes for removing particular components.

Chemical treatment is an essential part of most hazardous waste treatment operations. Therefore, this chapter will concentrate on examples of the chemical treatment of hazardous waste.

6.4.1 Dehydration of waste-containing sludges

Wastes, such as different sorts of sludges that contain high amounts of water, are unsuitable for landfilling because of the obvious stability problems they may cause at the landfill site. Solid particles may be separated from the liquid phase by using a filter press. The filter cake, which may contain high concentrations of heavy metals, is sent to a landfill, while the effluent is treated in a wastewater treatment installation - De Bruycker (1992).

6.4.2 Neutralisation of acids and bases

Waste acids and bases should on no account be disposed of in small containers at a landfill site. Instead, they should be neutralised before discharge.

*acid + $Ca(OH)_2$
*base + HCl, H_2SO_4, H_3PO_4

The sludge that may be formed as the pH changes is separated by a filter press. If the concentration of heavy metals in the sludge becomes too high, the sludge must be subjected to further treatment. The effluent is sent to a water-treatment installation.

In general, one clearly observable tendency is that, nowadays, waste products contain a higher concentration of heavy metals and, moreover, a higher organic loading. The COD (Chemical Oxygen Demand) of the acids and bases can run up to 150,000 mg/l. This COD is primarily produced by the presence of detergents and other organic components which are very difficult to remove - De Bruycker (1992).

Whether a waste product can be processed or not can only be decided after a preliminary analysis of the waste, followed by a laboratory test which is focused on the properties of the filter cake and the effluent. The filter cake must meet the criteria for disposal; if not it must be subjected to further treatment. The effluent must also meet the environmental standards.

6.4.3 Emulsion breakdown

In a unit provided for breakdown of an emulsion, the oil or latex phase of the emulsion is separated from the water phase in which the former components are emulsified. The degree of contamination determines whether the oil phase can be regenerated or should be incinerated. The water phase must be treated in a water purification installation.

Emulsion breakdown can be realized by means of several processes - Hartinger (1991):

- chemical treatment
- physical treatment
- thermal treatment
- mechanical treatment

One of the chemical treatment methods is the addition of acids in degreasing baths containing an emulsion. The tensides, which are added in these baths to remove the oil phase, do not form stable emulsions. By adding acid the tensides release the oil components, which float and can be simply removed from the surface of the wastewater.

Physical treatment methods are mainly based on adsorption properties. Emulsions are adsorbed at the surface of materials such as zeolites and activated carbon.

Another technique is electrophoresis. The addition of electrically charged colloids makes the emulsion electrically conductive. When an electric field is applied, the positively charged particles move towards the negatively charged electrode and vice versa. At the electrode the particles are discharged, and phase separation (removal of the oil-phase) is possible.

In thermal processes, the light phase, mostly water is evaporated by applying a high temperature. The oil phase can be removed when the solution is supersaturated.

Mechanical processes can also be applied for emulsion breakdown. The processes often use membrane techniques such as ultrafiltration, tangential microfiltration, or are based on the flotation principle.

In general the quality of the emulsions is significantly improved, emulsions are better stabilized, have a longer lifetime and give better results. This improved performance is obtained by the use of an increasing number and quantity of additives. The treatment of the waste products becomes, however, much more difficult.

6.4.4 Reduction of Chromate

This method is based on the reduction of the very hazardous Cr(VI) to Cr(III), that can be precipitated as a slightly soluble hydroxide.

The reduction can be accomplished by using sulphite or iron(II) hydroxide.

$$2Cr_4^{2-} + 3SO_3^{2-} + 10H^+ \rightarrow 2Cr^{3+} + 3SO_4^{2-} + 5H_2O$$

(2)

$$CrO^{2-}_4 + 3Fe(OH)_2 + 4H_2O \Leftrightarrow Cr(OH)_3 + 3Fe(OH)_3 + 2OH^-$$

(3)

Cr^{3+} can also be precipitated with calcium hydroxide ($Ca(OH)_2$) as $Cr(OH)_3$ at pH = 8.5 - Hartinger (1991).

6.4.5 Oxidation of cyanide-containing waste

Cyanide-containing waste is mainly produced by the electroploting industry. During the process of cyanide destruction, liquid and soluble solid cyanide-containing waste products are oxidized to cyanate-containing products (over 1000 times less toxic). Mostly, hypochlorite is used as the oxidizing agent. The oxidation must be fully controlled, according to the highest safety standards - Hartinger (1991).

$$CN^- + OCl^- \rightarrow OCN^- + Cl^- \quad (pH = 11)$$

Apart from the risks of working with cyanide, the smallest disturbance of the process will lead to unacceptable concentrations in the sludge formed in this process. With existing legislation and the availability of suitable analytical techniques, it has been found that the threshold of 250 mg/kg DS (dry solid) (Belgian Legislation) is often exceeded and the waste is considered to be toxic. A thermal post treatment of the sludge is then the only allowable solution although it is quite expensive.

6.5 SOLIDIFICATION - STABILIZATION OF HAZARDOUS WASTE

In hazardous waste management, the term solidification/stabilization (S/S) is normally used to designate a technology that makes hazardous waste non-hazardous or acceptable for land disposal by mixing the waste with stabilizers. The waste may be treated to bind the toxic elements into a stable, insoluble form (stabilization) or to entrap the waste products in a solid, crystalline matrix. S/S employs selected stabilizers (e.g. cement, fly ash, lime, etc.) to alter the physical and chemical characteristics of the waste stream prior to disposal. Heavy metals are bound in a silicate structure, which results in an unleachable product. The product can then be dumped at a landfill site without any problem. Even with new and improved waste pretreatment methods, there will continue to be need for this technology for safe land disposal of toxic wastes. This technique should only be used, however, when no other technology is available, for example, waste reduction, recycling or incineration.

Three goals can be achieved by using S/S:

- reduction of the solubility of the contaminating components, and conversion into a less toxic product
- reduction of the surface of the waste so that transfer or leaching of the components is hampered
- improvement of the physical properties and processability of waste

These goals can be realized by the production of a monolithic block with a high structural integrity (solidification), and the application of processes to reduce the solubility and toxicity of the contaminants (stabilization). In the second step the physical properties of the waste matter can be altered or improved.

6.5.1 Terminology for solidification/stabilization

Solidification: A process in which materials are added to the waste (liquid or solid in powdered form) to produce ideally a monolithic block with high structural integrity. The process may or may not involve chemical bonding between the toxic contaminant and the additives.

Stabilization: In this process a waste is converted into a more chemically stable form. The term may include solidification, but also the use of a chemical reaction to transform the toxic components to new non-toxic substances.

Mobility: Mobility includes not only leaching of the contaminants towards the water phase, but also towards the air via vapourisation.

Encapsulation: The encapsulation process involves the complete coating or enclosure of a toxic material or waste agglomerate with a new substance, for example, the S/S additive or binder. Microencapsulation is the encapsulation of individual particles, whereas macroencapsulation is the encapsulation of an agglomeration of waste particles or micro-encapsulated materials.

6.5.2 Types of waste treatable by S/S

Three types of waste products can be treated using the S/S-method. Firstly, some wastes can be mixed with filling and binding agents to obtain a dischargeable product. This rather simple treatment can only be used for waste with chemical properties already suitable for landfilling, but with physical properties which make the waste stream not suitable for landfilling. This process thus only changes the physical properties of the waste matter.

Secondly, besides the addition of a filling and binding agent to change the physical properties of the waste, pH-correction may be carried out. As a result of this, the percolate may be less contaminated.

Finally, the most important application is the solidification of metal-containing waste. The purpose of this method is to convert the soluble metals to compounds with a low solubility by addition of the proper reagents, binding agents and filling agents. The product is a solid concretelike substance which can be discharged, without any danger, at a class I landfill (suitable for hazardous waste).

The ability of a solidified/stabilized waste product to retain/contain a given hazardous constituent depends primarily on its resistance to leaching (or volatilization) of its waste constituents and on its long-term durability.

Considering the complexity of the chemical and physical reactions, the processability of the waste matter must be investigated experimentally.

6.5.3 Categorization of S/S processes

S/S technology may be categorized according to the binder used, to the binding or containment mechanism or to the process type - Wiles (1987).

Binders

S/S processes can be subdivided into two groups according to the binding material:

- inorganic processes
- organic processes

As the cost-price is an important consideration in the selection of the binder, it is usually advantageous to use, when possible, other waste materials as binders. Inorganic binding systems include varying combinations of cements, lime, pozzolana, gypsum and silicates.

Table 6.1 shows the most important inorganic binders and their properties.

Table 6.1: Inorganic S/S binding materials and properties

Portland Cement	**Pozzolana**
waste is mixed with Portland cement	waste is mixed with silicate- and aluminosilicate materials
addition of water to develop hydration reactions	concretelike substance when mixed with lime or cement and water
waste is incorporated in cement matrix, chemical or physical modifications are possible	mainly physical encapsulation of the contaminants
mainly formation of metalhydroxides	reactions are slower than with Portland cement
additives: fly ash, sodium silicate	additives: fly ash, slag

Organic binders in use or used experimentally include epoxy, polyesters, asphalt/bitumen, polyolefins (primarily polyethylene and polyethylene-polybutadiene) and urea-formaldehyde.

Organic binders are less frequently used because they are more expensive than the inorganic materials. The major advantage of these binders it that the volume increase of the waste is limited. Organic binding materials are mainly used with organic wastes.

In thermoplastic solidification, the waste is mixed with asphalt or polyethylene, and the process is mainly based on physical micro-encapsulation. No chemical reaction occurs between the waste and the binder. Advantages of the process are the stability of the product and its insolubility in water; disadvantages are the flammability of the product and the requirement of high mixing temperatures.

Organic polymerisation is also used in S/S. In this case, the process is based on the formation of polymers immobilising the contaminants. The most important polymer is urea-formaldehyde resin.

Combinations of inorganic and organic binder systems have been used as well, but are mostly more expensive. These include diatomaceous earth with cement and polystyrene, polyurethane and cement, and polymer gels with silicate and lime cement.

Binding mechanisms

Another categorization scheme, often used, is based on the waste containment or the binding mechanism. These mechanisms include:

Sorption: Sorption involves adding a solid to take up any free liquid in a waste. Examples of materials added are activated carbon, anhydrous sodium silicate, gypsum, clays, and similar particulate materials. Most sorption processes merely remove the liquid to the surface of the solid.

Fly ash-lime reactions: This process uses the fine, non-crystalline silica in fly ash and the calcium in the lime to produce low-strength cementation. Physical trapping of the contaminant in the cured pozzolana concrete matrix is the primary containment mechanism. Water is removed in hydrating the lime-pozzolana concrete.

Pozzolana-Portland cement reactions: In this process Portland cement and fly ash or other pozzolanas are combined to produce a relatively high-strength waste/concrete matrix. Water is removed in the hydration of the Portland cement. In variations of this technology, gypsum or aluminous cement may be used with or instead of Portland cement.

Thermoplastic microencapsulation: This process blends waste particulates with melted asphalt or similar materials. Physical entrapment is the primary containment mechanism for both liquids and solids.

Macroencapsulation: This process isolates a large volume of waste by covering with any acceptable material. A drum is a simple example. More sophisticated macroencapsulation processes with superior performance employing polyethylene or similar resins in the containment vessel have been investigated.

Vitrification: This process is a relatively new method to stabilise waste containing a large proportion of solids, and the process is carried out in-situ. Electrodes are placed in the contaminated soil, and the current, which flows between these electrodes, causes the soil to melt and organic components to be volatilized. This melted material is then quenched thus creating a stony material that immobilises the metals.

Knowledge of the binder system and the basic containment process allows an evaluation of potential for successfully employing S/S technology to manage a waste.

Process types

In drum processing: The S/S binders are added to the waste contained in a drum or other container. After mixing and setting, the waste-binder matrix is normally disposed of in the drum.

In plant processing = reactor processing: This process refers to a plant and/or process specifically designed for solidification/stabilization of bulk waste material. The process may be conducted within a plant for waste from an internal industrial operation or the plant may be specifically designed and operated to solidify/stabilize waste from external sources.

Mobile plant processing: S/S processes and equipment may be mobile or can easily be transported from one site to another.

In-situ processing: In this process the binders, that is, solidifying or stabilizing materials are added or injected directly to the contaminated sludge or soil.

Open-pit or trench mixing: This is the most simple and most often employed S/S method. The waste is placed in a well or a ditch and mixed with the binding material. The solidified material can be left on the spot after covering, or dug out and tipped elsewhere.

6.5.4 Inorganic binding materials

Since inorganic binders are in practice most frequently used in the S/S processes, it is appropriate to discuss some of these materials in more detail, the most important being cement, lime and pozzolanas. Some background information is necessary for a proper understanding of the factors controlling leaching and durability characteristics.

Cement

Cement-based S/S processes have as their main goal the binding of toxic waste constituents in a stable, insoluble complex (stabilization), or to entrap the waste in a solid cement matrix (solidification). Primarily, the free water is incorporated in the cement matrix via hydration reactions.

Portland cement contains several minerals, including: calcium silicate, calcium aluminate and iron oxides. The composition of the cement may be as indicated in Table 6.2.

Table 6.2: Composition of Portland Cement

tricalciumsilicate	54% (wt/wt)	C_3S
dicalciumsilicate	17%	C_2S
tricalciumaluminate	11%	C_3A
alumino-ferrite	9%	C_4AF
gypsum	4%	$CS'H_2$

($C = CaO$, $S = SiO_2$, $A = Al_2O_3$, $F = Fe_2O_3$, $S' = SO_3$, $H = H_2O$)

When cement is mixed with water, several chemical reactions occur, the most important reactions being:

$2(3CaO.\ SiO_2) + 6H_2O \Rightarrow 3CaO.\ 2SiO_2.\ 3H_2O + 3Ca(OH)_2$ (5)
$2(2CaO.SiO_2) + 4H_2O \Rightarrow 3CaO.\ 2SiO_2.\ 3H_2O + Ca(OH)_2$ (6)
$4CaO.\ Al_2O_3.\ Fe_2O_3 + 10H_2O + 2Ca(OH)_2 \Rightarrow 6CaO.\ Al_2O_3.\ Fe_2O_3.\ 12H_2O$ (7)
$3CaO.Al_2O_3 + 12H_2O + Ca(OH)_2 \Rightarrow 3CaO.\ Al_2O_3.\ Ca(OH)_2\ .12H_2O$ (8)

The dominant reaction in the global hydration and solidification process of Portland cement is the formation of calciumsilicatehydrate (CSH, reaction 5) and calcium hydroxide as a result of the hydration of tricalciumsilicate C_3S. CSH has a non-crystalline porous structure. It constitutes about 70% of the hydrated material in the solidified material and is responsible for the development of the strength. The formation of CSH is therefore of the utmost importance in the S/S process.

Hydration of C_3S takes place in three steps:

- when Portland cement is mixed with water, leaching of Ca^{2+} and formation of $Ca(OH)_2$ occurs; remaining cement particles contain mainly silica;
- reaction of $Ca(OH)_2$ from the solution (supersaturation) with the silicon-containing surface of cement creates a gely semi-permeable membrane around the cement particles; the gel initially decelerates the hydration reactions;
- as the osmotic pressure in the membrane increases, the membrane breaks, followed by the formation of new CSH between the cement particles.

The hydrates react with additional water in the mixture in order to form a crystalline hydrate structure. Gypsum is added to counteract the fast solidification as a result of the C_3A hydration. Water is thus retained in several ways:

- by chemical reaction in order to form hydrates: chemical bonding;
- incorporation of water in the crystalline structure during the solidification of cement - chemical bonding, less strong;
- adsorption on the surface and in the pores of cement - no chemical bonding.

As a consequence of these three mechanisms by which water is retained, one can find three types of pores/voids in solidified cement:

- The smallest voids, which occur within the calcium-silicate-hydrate gel structure are 0.5 to 2.5 nm in diameter and account for about 28% of the porosity of the solid product. These small voids have little effect on the strength and permeability of the final product, but appear to be important in drying shrinkage and creep.
- Capillary voids account for the larger volumes, not filled by solid components. In well-hydrated, low water/cement ratio mixtures, capillary voids range from 10 to 50 nm in diameter, but in high-ratio mixtures they may be as large as 3000 to 5000 nm. Pore size distribution and not simply

total capillary porosity is generally considered a better criterion for evaluating the characteristics of a cementitious product; capillary voids larger than about 50 nm are thought to be detrimental to strength and impermeability, whereas voids smaller than 50 nm are more important to drying shrinkage and creep. Capillary voids limit the strength of concrete by acting as "stress concentrators".

- The third type of void, called an "air void", is generally spherical and usually ranges from 0.05 to 0.2 mm in diameter, but may be as large as 3 mm in diameter. Air voids in this size range are usually introduced intentionally into the cement mixture to increase the resistance of the final product to freeze-thaw (frost) damage, even though they typically have an adverse effect on strength and impermeability.

The main parameter, influencing the strength, durability and porosity of solidified cement, is the water/cement ratio. The relationship between concrete porosity and strength is of great importance when predicting the ability of a given waste-cement mixture to contain the waste under leaching conditions. Water in the capillary voids may be eliminated and replaced by other materials to improve the properties of the cement and to hinder leaching. Compressive strength then may be an acceptable indicator of the resistance to leaching of a solidified/stabilized waste.

Chemical reactions occurring in the cement are not limited to hydration reactions. The waste may indeed also contain several components which may participate in chemical reactions, and in the solidified system several chemical and physical interactions may occur. One of the main questions concerns the location of the toxic components in the cement matrix.

Various interactions may take place:

- chemisorption, e.g. at charged locations at the surface
- precipation reactions e.g. with anions of cement or gypsum
- formation of inclusions in cement particles
- chemical incorporation in cement particles
- formation of a surface compound with a surface cement component

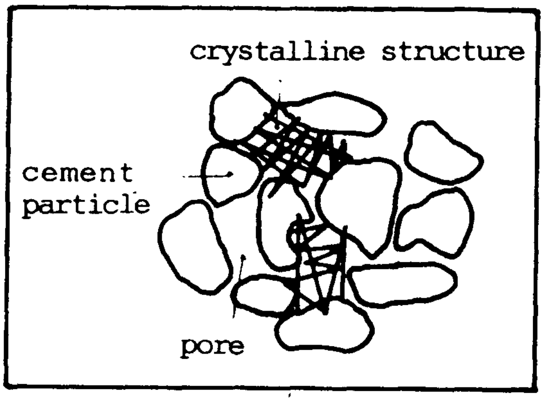

Figure 6.1: Structure of solidified system

Lime

Pure lime, $Ca(OH)_2$, does not give a concretelike matrix when mixed with water. However, lime easily precipitates many different metals as their hydroxides. When lime, mixed or not mixed with metalhydroxide, is in contact with air, CO_2 from the air is absorbed, which will lead to the formation of calcium carbonate $CaCO_3$ and other insoluble metal carbonates. Gypsum can be formed when sulphates are absorbed. These components can also be formed in contact with water containing dissolved sulphates or CO_2. Formation of carbonates is important for long-term stability.

Lime is always used in combination with other materials. Mixing lime and Fe- or Al-containing minerals results in a cementlike material. The velocity of solidification and the strength of the material are however lower than with cement. Lime can also be added to cement based S/S processes. Most often it is used for the treatment of acid waste for the following reasons:

- waste must be neutralized before solidification, and lime is less expensive than cement;
- metals which must be immobilized are less soluble in a basic medium

Pozzolanic materials

By definition, pozzolana are siliceous materials that display no cementing action by themselves but contain constituents that combine with lime at ordinary temperatures and in the presence of water to form cementitious compounds. The main pozzolanic materials used commercially, at present, are fly ash from coal fired power plants, furnace slag and kiln dusts from lime or cement kilns, volcanic glass and calcinated clays. Although pozzolanic reactions are not identical to cement reactions, they are thought to resemble them. Pozzolanic reactions are generally much slower than cement reactions, and set-times are usually measured in days or weeks instead of hours. Care must also be taken so that no additional contaminants are introduced through these waste byproducts. Mixing of pozzolanic materials with cement leads to products with high durability and improved sulphate resistance. When pozzolanic materials are used in addition to, or as a partial replacement for Portland cement, the rate at which the material acquires strength is lower, but the ultimate strength and impermeability are improved.

The composition of blast furnace slag resembles that of Portland cement because the main constituents of both products are lime, silica and alumina. Blast furnace slags contain practically no ferric oxide and less lime than Portland cement. They may also contain considerable amounts of magnesia, some ferrous iron and reduced sulphur compounds (CaS). A mixture of slags and cement gives the product a higher density; it contains more CSH and less $Ca(OH)_2$.

An alternative is to use, directly, blast furnace slag cements consisting of a finely ground mixture of Portland cement clinker and blast furnace slag; a small quantity of gypsum is added in order to control the setting time.

SAQ 6.3

Discuss the use of inorganic binding materials for solidification of hazardous metal-containing waste.

6.5.5 Physical and containment properties of the final treated waste

Several physical and containment properties should be considered in order to develop a suitable S/S treatment - Jones (1990).

Air entrainment

Additives causing air incorporation into the cement paste are universally deleterious to the ultimate strength and impermeability of the concrete, most likely because of the added large-pore space. The entrained air, however, greatly increases the resistance of the products to freezing, thereby increasing their durability under freeze-thaw conditions.

The durability/permeability relationship

Long-term durability of the stabilized/solidified waste product is a prime consideration in designing and specifying waste S/S systems. Predicting the long-term integrity of the final waste form requires consideration of all possible modes of failure. For cementitious stabilized/solidified products, water is generally involved in every form of deterioration; and in porous solids, permeability of the material to water usually determines the rate of deterioration. Internal movement and changes in the state of aggregation of water are known to cause disruptive volume changes of many types of products. Examples are water freezing into ice, development of osmotic pressures because of different ionic concentrations, and hydrostatic pressure buildup by differential vapour pressures. All of these can lead to large internal stresses within a moist solid and to its ultimate breakdown.

Cracking by crystallization in pores

Solidified/stabilized waste products often contain substantial amounts of salts, organic molecules, or both, with appreciable water solubilities. Concentration of these materials at or below the surface of the solid where vaporisation of pore water occurs, can cause super-saturated solutions to develop and salt crystals to form in the pores of the S/S product, which may disrupt its structure.

Wet-dry cycling

Wet-dry cycling of normal concrete products does not significantly damage its structure. If the total proportion of the cement is reduced or if the water/cement ratio is increased, as is often done in S/S practice for reasons of economy, wet-dry cycling may, however, lead to rapid deterioration of the solidified/stabilized waste product.

Freeze-thaw damage

Although there is generally a direct relationship between strength and durability, this does not hold in the case of frost damage. In a manner analogous to salt crystals, ice crystals forming at temperatures below the freezing point of water, can rapidly deteriorate water saturated concrete products.

Deterioration by chemical reactions

The effects of waste constituents as well as aggressive environmental agents on S/S waste products must be adequately known before the long-term stability of the S/S product can be assumed. The solid phase of a well-hydrated Portland cement paste exists in a stable equilibrium with the high-pH pore fluid. High concentrations of OH^-ions bring about a pH of 12.5 to 13.5 in the pore fluid. Natural CO_2, sulphates and chlorides common in ground and rainwater may bring about aggressive solutions below pH 6, which can be detrimental to the S/S product.

Cation-exchange reactions can occur between the external solution and the cement binder: Acids solutions with anions that form soluble calcium salts (such as calcium chloride, acetate and bicarbonate) will leach the calcium from the S/S product. This is particularly damaging because it increases the permeability of the concrete, thus increasing the rate of further exchange reactions.

Attack of waste-concrete products by sulphates can be a serious problem and is an important consideration in the S/S of sulphate-containing wastes in Portland cement. Concentrations of soluble sulphates greater than 0.1% in soil or 150 mg/l in water will endanger cement products, and soils of over 0.5% soluble sulphates or water containing over 2000 mg/l of sulphate can have a serious effect. Pozzolanic S/S systems are useful for S/S of high sulphate wastes, since they contain less free calcium hydroxide and, thus, are less reactive to sulphate.

Radiation and S/S products

Large doses of gamma radiation do not appear to affect setting properties or cause appreciable loss of strength or increased leachability in Portland cement solidified waste products.

6.5.6. Selection of a S/S process

The selection of a proper S/S process is based on several factors, among which are:

Characteristics of the waste: This is the most important factor in the selection of the S/S process. As already discussed, contaminants may affect the strength, durability and permeability of the solidified and stabilized waste, and inorganic wastes are more easy to treat than organic wastes. Physical characteristics, such as size and shape of the particles of the waste, as well as of the binder may also play an important role.

Process type: The selection of the process type must be adapted to the infrastructure and technical possibilities available, and may of course depend on the level of technological development of the country.

Product management: One must choose between disposal at a landfill, storage and transport to another site. These alternatives have differing regulatory requirements.

Economic considerations: S/S processes generally are rather cheap because of the use of cheap ingredients, but space is required in a landfill for hazardous waste, which increasingly is becoming a more important cost factor.

6.6 WASTE MINIMIZATION AND PREVENTION

Waste minimization in industry is not yet close to the ideal, although in most cases minor changes of the process, equipment and installations are sufficient to minimize the quantity of waste produced. Knowledge of the origin of the waste and the opportunities to avoid or minimize the production of this waste are therefore very useful. When the whole organization (which means people at all levels) pays attention to the waste problem, waste production can be substantially reduced - De Bruycker (1992).

In a waste minimization and prevention programme two levels of activity can be distinguished:

Level 1:
- sensitization of the whole organization to the problem
- suitable education of the personnel
- follow up and stimulation of contributions from all persons concerned

After this initial optimization period, further waste reduction will require more fundamental adjustments:

Level 2:
- adjustments of processes and products
- adjustments of the equipment

An indication of how and where solid waste is generated, is given in the simplified materials flow diagram shown in Figure 6.2. Solid wastes are already generated at the start of the process, beginning with the mining of raw material. Afterwards, solid wastes are generated at every step in the process converting raw materials into goods for consumption. It is apparent from Figure 6.2 that one of the best ways to reduce the amount of solid waste is to reduce the consumption of raw materials and to increase the recovery of the waste materials. Although the concept is in principle simple, effecting this change in a modern technological society has proved to be extremely difficult - Peavy et al (1985).

In many cases the cost of disposal or destruction of the waste is becoming higher than the initial raw material cost, and it will certainly increase further during the coming decades. The only alternative then is an aggressive environmental reduction programme, whereby pollution is prevented at the source. In fact this solution is now at the top of everyone's priority list: industrial managers, environmentalists, legislators and regulators.

Pollution prevention and minimisation will however require severe changes both in mentality and in techniques. Statements such as "The Polluter Pays" and "Pollution Prevention Pays" can be used to stimulate this process.

SAQ 6.4

What factors play an important role in the selection of a particular S/S process?

SAQ 6.5

Summarise the levels of activity that may be distinguished in a waste minimization programme.

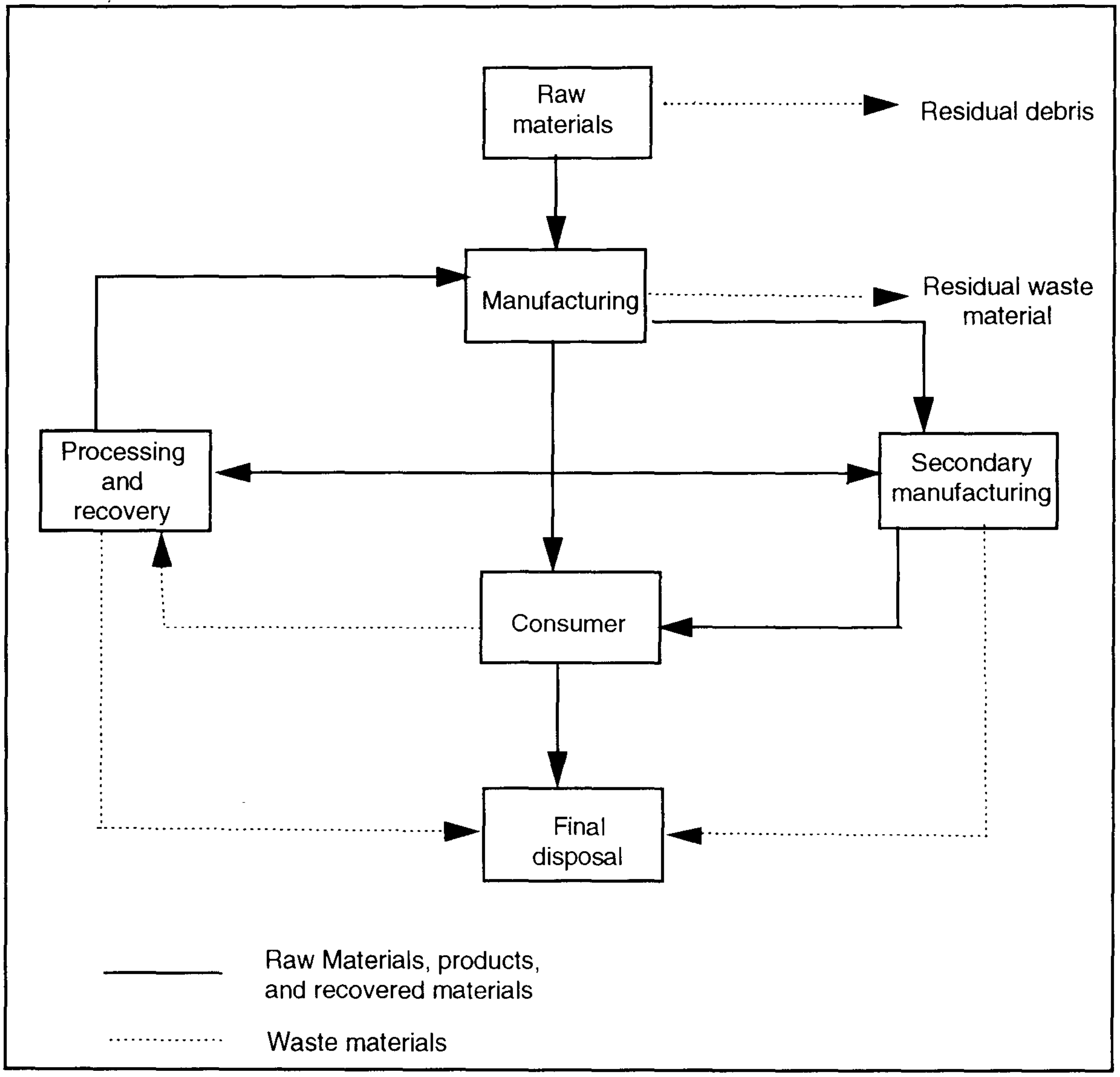

Figure 6.2: Generalized flow of materials and the generation of solid wastes in society - Peavy et al (1985)

Actual waste prevention can be realized by means of the following measures:

source directed measures:
- good housekeeping
- technological improvements of existing processes
- alternative production processes

internal reuse - recycle:

- recovery of waste as raw material after a suitable treatment
- treatment of waste with the aim of recovering valuable materials: e.g. organic solvents (white spirit, toluene, trichloroethane,...) by means of distillation; ferrous and non-ferrous waste,...

A method that can be used to investigate the possibilities of reducing or avoiding the production of waste is the mass-flow and mass-balance analysis (MF-MBA), which covers all input-output data as well as production techniques - Fleischer et al (1992).

The mass-flow of a production process can be described with a general scheme which includes all input and output data (Figure 6.3). The analyzed mass-flow at each process step, and afterwards for each production line are added. All the single mass-balances of the production lines are finally assembled in the overall mass balance.

After this qualitative analysis, a quantitative analysis of the substances and substance-flows is required in order to show where it is possible to reduce and avoid waste generation and emission.

In conducting a MFA in a factory, all input and output data, as well as process engineering are involved. This method shows a complete balance of all the essential environmental parameters, so that all the possibilities of preventing waste and emissions can be investigated.

With the help of the qualitative compilation of the input and output data of a production line, it is possible to make statements of importance concerning the ecology, as far as the toxicological effects are known. A report on the toxicology of the process substances is thus a completion of the MFA. Consideration of the qualitative and quantitative analyses reveals the production steps which have the most ecological weight and hence should receive highest priority in the waste prevention and minimisation program.

Unfortunately, a complete discussion of waste minimisation and prevention is beyond the scope of this course. Only a few representative examples will be discussed.

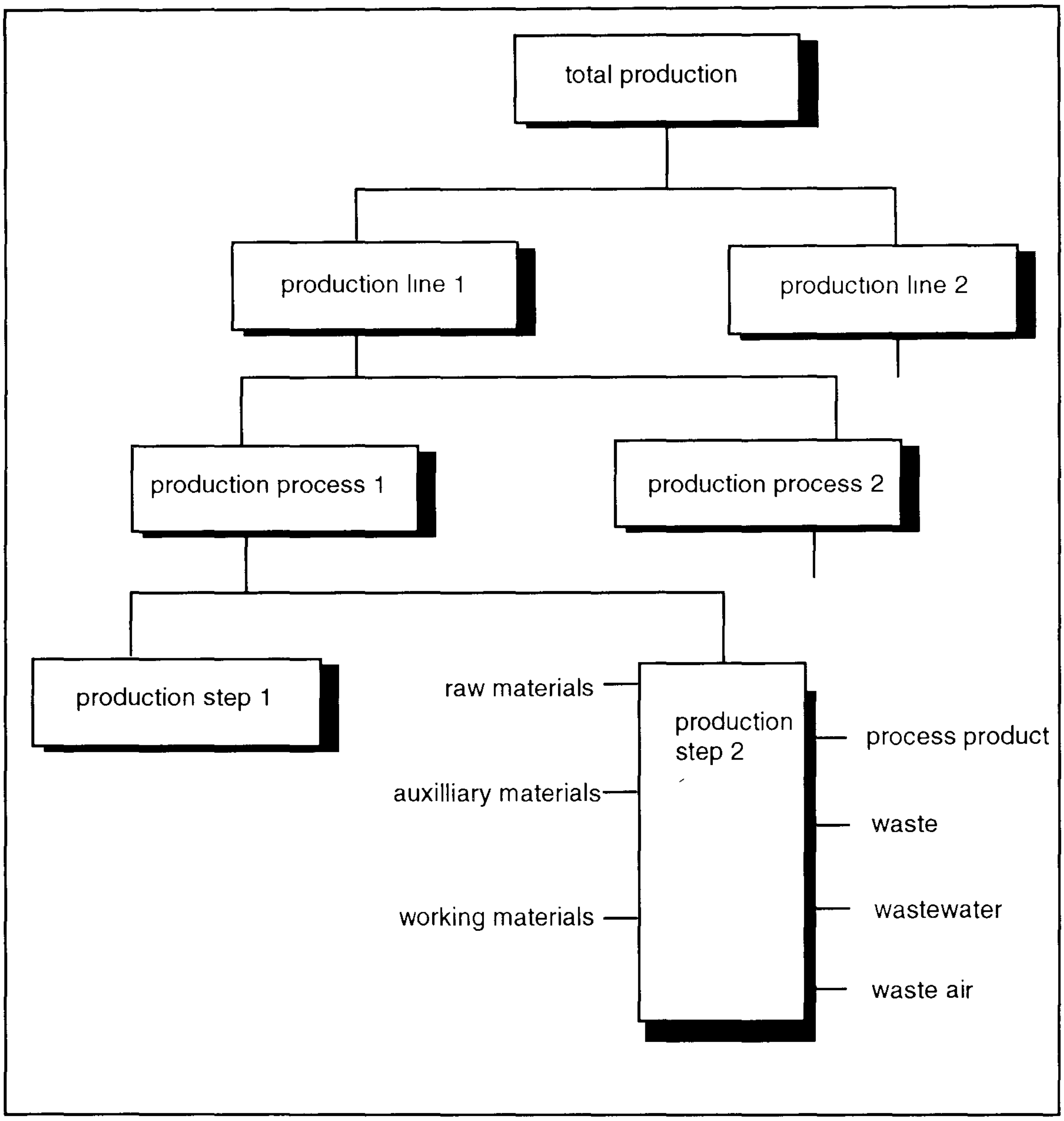

Figure 6.3 Systematic structure of the mass-flow balance related to production

6.6.1 TiO_2- production: substitution of the sulphate process by the chlorine process

Titanium dioxide or titania (TiO_2) has some very important properties which make this product essential for today's society, its most notable properties being its high covering capacity and high refractive index (2.69). These properties make TiO_2 more suitable as a whitener in comparison with other products such as zinc white and white-lead. Moreover TiO_2 is a non-toxic product. Table 6.3 shows the main industrial applications of TiO_2 - Van Cauwenberghe (1991). The annual worldwide production of TiO_2 is about 3,000,000 tons.

Table 6.3: Main Industrial Applications of TiO_2 - Nagels (1992)

Application	Proportion of Total
paints and printer's ink	60%
plastics	30%
paper synthetic fibres medicine cosmetics ceramic products	10%

Many existing production units are based on the sulphate process, which is schematically shown in Figure 6.4.

Ilmenite ore (45% of TiO_2) or titanium slags (85% of TiO_2) are dissolved with concentrated sulphuric acid.

$$TiO_2 + H_2SO_4 \rightarrow TiOSO_4 + H_2O$$

Other sulphates (e.g. $FeSO_4$) are also formed. Due to their high concentration, they crystallize into a porous cake. The cake is dissolved in water and titanium salts are precipitated as titanium hydroxide by means of hydrolysis:

$$TiOSO_4 + 2H_2O \rightarrow TiO(OH)_2 \downarrow + H_2SO_4$$

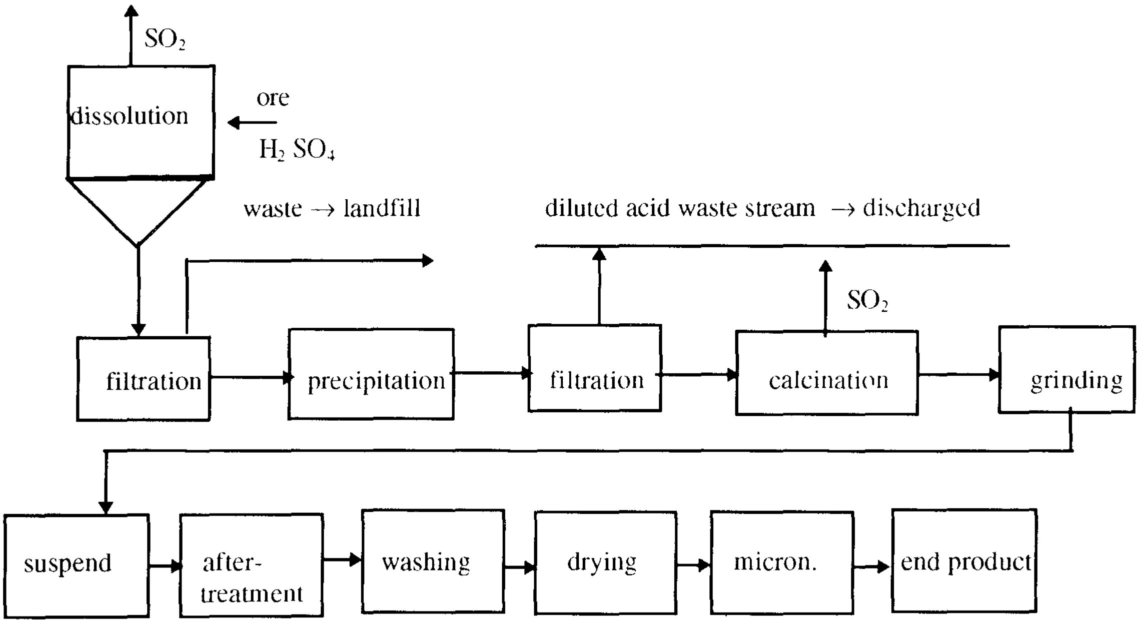

Figure 6.4: TiO_2-production by means of the sulphate process

This results in a suspension that is filtered in order to separate it from diluted sulphuric acid and iron sulphate.

To obtain the TiO_2-pigment the hydrate is calcinated, followed by a grinding step which is necessary to acquire the proper granulometry. The product is then subjected to post-treatment with SiO_2 and Al_2O_3 so as to stabilize the TiO_2-particles. Otherwise TiO_2 is easily degraded into Ti_2O_3 under the influence of ultra-violet radiation.

Finally, the product is washed (removal of salts), dried and ground (to reduce the TiO_2 particle size).

The use of the sulphate process results in some intolerable waste products:

- diluted sulphuric acid: filtration and washing of the pigment
- SO_2-emission: calcination of the pigment

Two alternatives are available for reducing these waste streams;

- reconcentration of the diluted sulphuric acid
- change-over to the chlorine process

1. Reconcentration of the diluted sulphuric acid

The diluted sulphuric acid can be reconcentrated up to a concentration of 91-92%. Apart from several logistic problems, high investments are necessary (about 75 million US$ for a production unit of 300,000 ton/year).

2. Change-over to the chlorine process

In this case the investment is even slightly higher (about 80 million US$) but at the end, a completely new installation, based on modern technology and resulting in an end-product of very good quality is secured.

Figure 6.5 shows the chlorine process.

In a fluid bed reactor, titanium ore is chlorinated in the presence of calcinated cokes at high temperature.

$$TiO_2 + 2Cl_2 + C \rightarrow TiCl_4 + CO_2$$

After cooling, the highboiling chlorides and some inert material such as SiO_2 are removed. It is possible to obtain a $FeCl_2$-solution out of this fraction, which can be used in water purification.

$TiCl_4$ (Bp=136°C) is then condensed and purified by means of distillation. The gas stream is sent to an absorption unit where HCl is removed by absorption in water resulting in a 30% HCl-solution. Subsequently, CO and COS (other waste gases of the chlorination step) are converted into CO_2 and SO_2.

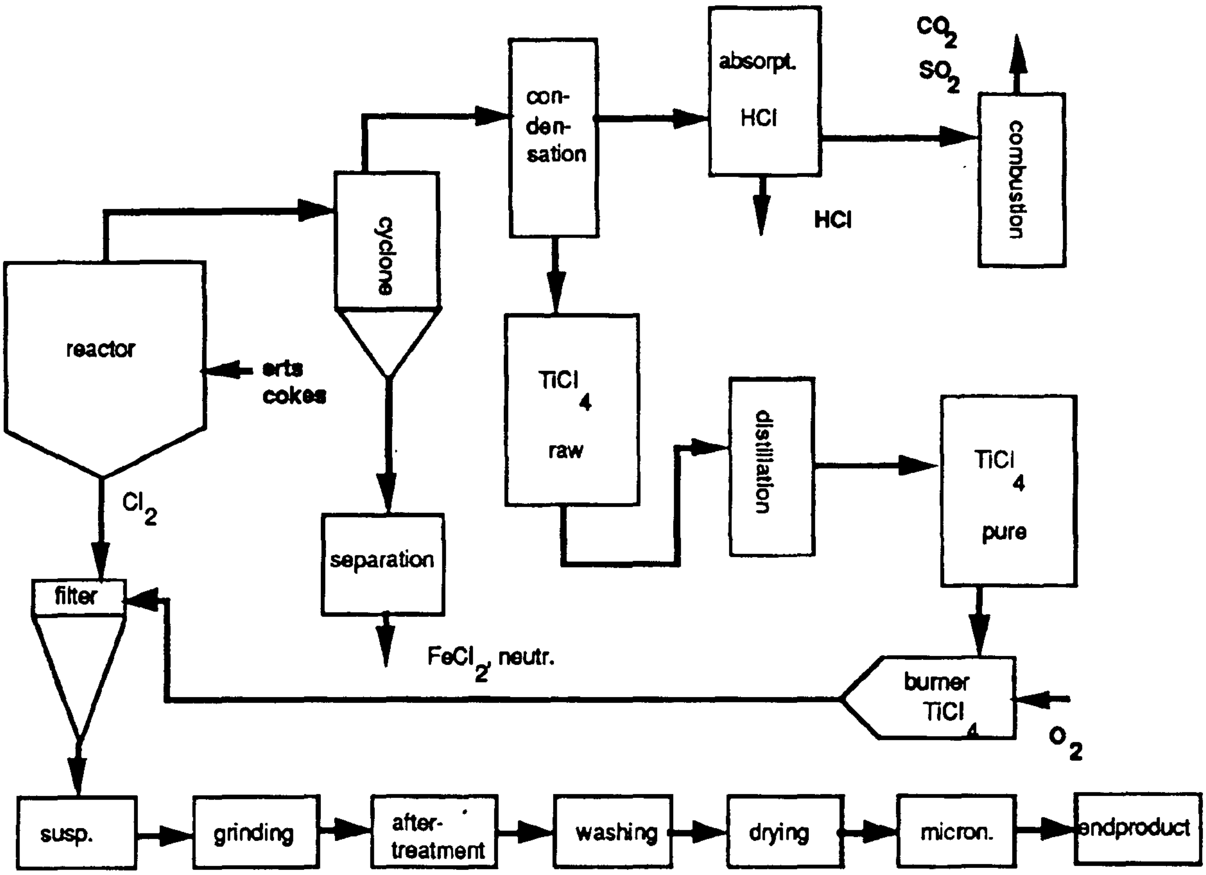

Figure 6.5: TiO_2-production by means of the chlorine process - Nagels (1992)

The purified $TiCl_4$ is then heated (1700-1800°C) with oxygen in order to obtain TiO_2 and chlorine. After separation of TiO_2 by means of filtration, chlorine is recycled to the reactor.

$$TiCl_4 + O_2 \rightarrow 2Cl_2 + TiO_2$$

The last part of the process is identical to the sulphate process.The use of the chlorine process for the production of TiO_2 results in a substantial reduction of waste. The acid waste streams no longer occur in the process and the emission of SO_2 is reduced by more than 90%.

Table 6.4 compares the two processes for the production of TiO_2 with respect to the waste production for an installation which produces 310,000 tons of TiO_2 per year.

Table 6.4 Comparison of the sulphate and the chlorine process - Van Cauwenberghe (1991)

Sulphate process	Chlorine process
waste acid: 320,000 ton/year	Cl_2: recycled $FeCl_2$: 40,000 ton/year (used for water treatment) HCl: 8,000 ton/year
SO_2-emission: 3,500 ton/year	SO_2-emission: <350 ton/year
discharge of acid waste stream containing heavy metals	discharge of neutral $CaCl_2$-solution

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SAQ 6.6

Compare the sulphate and chlorine processes for the production of TiO_2, from the standpoint of waste prevention and minimization.

6.6.2. Caustic soda and chlorine production: substitution of Hg-electrolysis and diaphragm electrolysis by membrane electrolysis

At the present time, caustic soda and chlorine are produced by three different electrochemical processes, which all start from the same raw material: sodium chloride.

Hg-electrolysis was the first industrially applied technique, and was mainly used in Europe. Later on, diaphragm electrolysis was developed, and was mainly applied in the United States. Both methods make use of components (mercury and asbestos) which are intolerable from an environmental point of view.

In the last twenty years, most of the caustic soda and chlorine-producing companies have succeeded in reducing the emission of mercury by up to about 95%, due to several expensive technological innovations - Paulus (1991).

Since 1980, a new technology, known as membrane electrolysis, which does not make use of polluting additives, has become available. Figure 6.6 shows the principle of this method which is in fact comparable to the principle of electrodialysis.

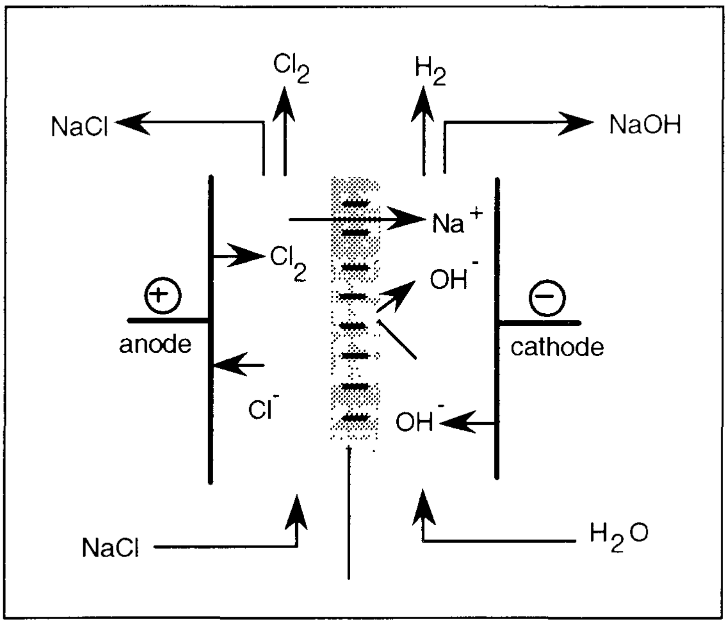


Figure 6.6: Schematic arrangement of the 'chlor-alkali" process

In electrodialysis, an electrical potential difference acts as the driving force, and use is made of the ability of charged ions or molecules to conduct an electrical current. If an electrical potential difference is applied to the salt solution, the positive ions (cations) migrate towards the negative electrode (cathode), whereas the negative ions (anions) move towards the positive electrode (anode). Uncharged molecules are not affected by this driving force. Ion exchange membranes are used to control the migration of the ions - Mulder (1991).

In the particular case of membrane electrolysis only cation-exchange membranes are used. The membrane cell consists of two compartments separated by a cation-exchange membrane (negatively charged).

A sodium chloride solution is pumped through the left-hand compartment and electrolysis of chloride ion to chlorine gas will occur at the anode (positive electrode). At the same time the sodium ions migrate towards the cathode (negative electrode). In the right-hand compartment, electrolysis of water occurs at the cathode and hydrogen gas (H_2) and hydroxyl ions (OH^-) are produced. The negatively charged hydroxyl ions migrate towards the anode but cannot pass the negatively charged cation-exchange membrane. In this way, chlorine gas is released from the left-hand compartment, whereas a sodium hydroxide solution (and hydrogen gas) is obtained from the other compartment.

$$2NaCl + 2H_2O \rightarrow 2NaOH + Cl_2 + H_2$$

The main advantages of this technique can be summarized as follows:

- an improved situation with respect to the environment (no Hg or asbestos emissions)
- less energy consumption

- lower investment cost
- less personnel required

The most important disadvantage is the requirement of a raw material with higher purity, which is of course more expensive.

Tables 6.5 and 6.6 summarize the applied technologies for the production of chlorine, worldwide and in Europe, respectively - Paulus (1991).

Table 6.5: Worldwide production of chlorine (1990)

Hg-electrolysis	40%
diaphragm-electrolysis	45%
membrane-electrolysis	15%

Table 6.6: Chlorine production in Europe (1990)

Hg-electrolysis	69%
diaphragm-electrolysis	24%
membrane-electrolysis	7%

6.6.3. Waste reduction in the electroplating industry

The electroplating industry produces rather small amounts of waste products and wastewater. This waste is, however, highly concentrated and toxic, as it contains heavy metals, cyanide, nitrites and some other salts, and thus requires rather sophisticated waste treatment techniques.

The wastewater of the electroplating industry is usually detoxified by addition of suitable chemical products, to remove mainly the heavy metals by precipitation, which results however in the production of toxic sludge. In view of stringent environmental legislation, the disposal of sludge is becoming very expensive, so that minimisation and prevention of waste production has become a top priority.

Several techniques have been proposed to reduce the amount of wastewater. Other techniques focus on the reduction of the consumption of toxic materials. Both techniques will be illustrated by some examples. To identify the possibilities of reduction and prevention of waste, check-lists are available. This methodology was developed by the U.S. Environmental Protection Agency.

Electroplating with trivalent chromium

The toxicity of hexavalent chromium Cr(VI) and the sometimes unfavourable performance of the chromic acid baths (e.g. high concentration, low current efficiency, high hydrogen production) have motivated the development of processes using trivalent chromium Cr(III). The major problem in such a process is the easy oxidation of Cr(III) to Cr(VI) at the anode. Even in the presence of very small quantities of Cr(VI) the current efficiency decreases drastically. Two alternatives are available - Nagels (1992):

- the application of baths containing complex forming agents, avoiding the oxidation of Cr(III) at the anode.
  - advantages:
    - no hexavalent chromium
    - lower chromium concentration:
      - Cr(VI)-process: 150-250 g/l
      - Cr(III)-process: 21-22 g/l
    - lower operating temperature:
      - Cr(VI)-process: 40-50°C
      - Cr(III)-process: 20-22°C
    - improved covering capacity
    - less hydrogen formation
  - disadvantages:
    - very microporous precipitate
    - dark colour, caused by traces of nickel, iron, copper or zinc
- the application of a membrane process(second generation)

  The anode is protected by a polypropylene membrane. The membrane is impermeable to Cr(III)-ions, and thus the oxidation of Cr(III) at the anode is inhibited (Figure 6.7).
  - advantages:
    - low chromium concentration:
      - Cr(VI)-process 150-250 g/l
      - Cr(III)-process: 5-6 g/l
    - no dark metal precipitation
    - very low sludge production in the water treatment (because of the low bath concentration)

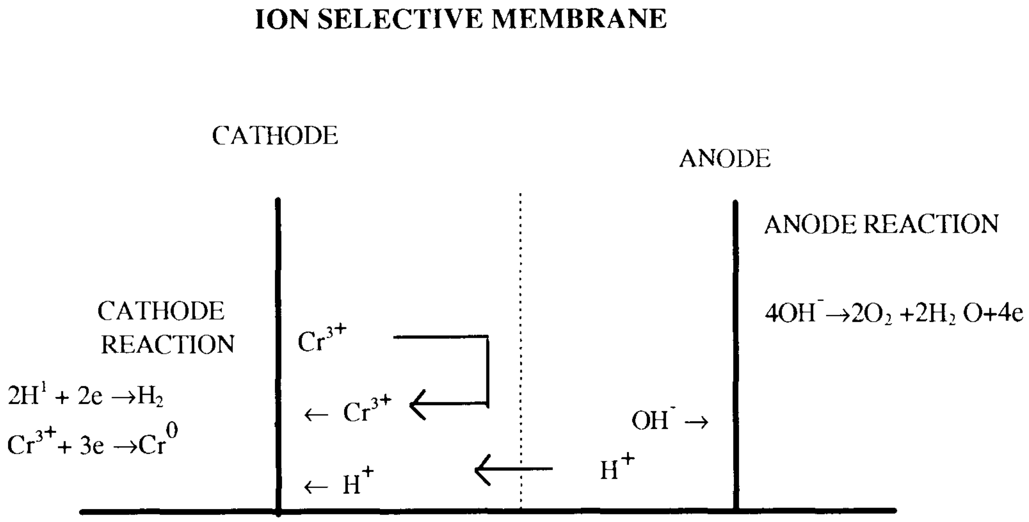


Figure 6.7 Ion transport in a second generation process

Passivation of zinc with trivalent chromium

The passivation of zinc and cadmium with trivalent chromium requires the use of hydrogen peroxide, which replaces hexavalent chromium. The pH of the bath solution at the zinc surface increases, resulting in a chromium hydroxide film. The combination of trivalent chromium with hydrogen peroxide is less aggressive than the usual combination of hexavalent chromium with sulphuric acid. With the conventional technique about 10% of the precipitated zinc is redissolved in the bath solution, whereas with the new combination only 1% is redissolved - Nagels (1992).

advantages:
- the use of less toxic chemicals
- no detoxification of hexavalent chromium required
- decreasing production time
- economization of the purification cost (because of the decrease of wasted zinc)

disadvantages:
- sensitivity of the colour when changing the pH
- corrosion protection has not improved with respect to the existing passivation solution

The application of cyanide-free baths

Cyanide ions are used in electrolytic baths and in aqueous solutions to complex metal ions and to keep them in the solution. The environmental impact of the cyanide baths is mainly caused by the detoxification of the cyanide containing wastewater. Traditionally, cyanide is detoxified by adding an overdose of hypochlorite. To avoid this aftertreatment, cyanide-free baths have been developed - Nagels (1992).

example: electrolytic zinc baths

- traditional cyanide-containing bath

Zn	50 g/l
NaCN	150 g/l
NaOH	81-90 g/l

- cyanide-free alkaline bath:

ZnO	10 g/l
$NaOH$	120 g/l

- cyanide-free acid bath:

$ZnCl_2$	70 g/l
NH_4Cl	180 g/l

Two major disadvantages of the use of cyanide free baths must be mentioned:

- cyanide must be replaced by a complexing agent that may cause other less severe environmental problems (ammonium, phosphate, EDTA)
- large amounts of tensides must be added (10 g/l)

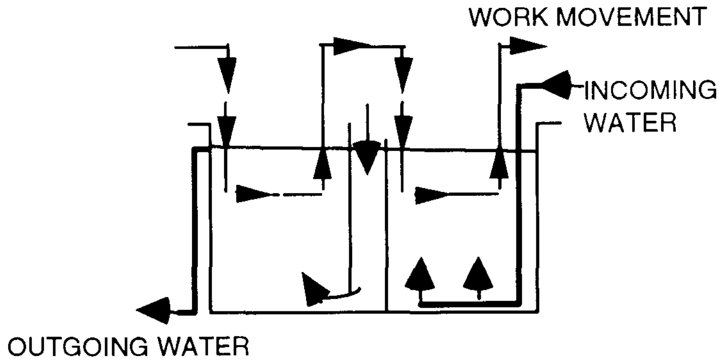
In conclusion one can state that cyanide-free baths do not always offer a better alternative. A temporary solution can be the use of low-cyanide-containing baths followed by a detoxification process using hydrogen peroxide.

Rinsing in several baths

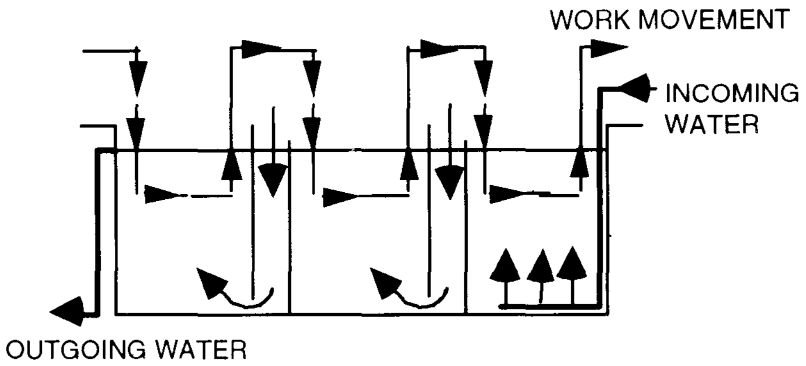
After each electroplating treatment, the components are rinsed in several baths. The general opinion concerning these rinsing baths is that there will be an improved result if sufficient amounts of fresh water are applied. However, this requires large investments, which are necessary for demineralisation plants (containing anion- and cation-exchanging resins). On the other hand, a well-designed rinsing-treatment will give the same results, but will require smaller amounts of fresh water. Moreover, when efficient recycling and detoxifying processes are applied, substantial amounts of the rinsing-water and of the chemical components can be recovered. Some techniques will be explained in more detail - Nagels (1992); Anon (1992)

Cascade rinsing is based on the counterflow principle. The bath consists of several compartments and the rinsing water moves in the opposite direction from the work (Figure 6.8). Fresh water is only added to the last rinsing bath. The 'loaded' water of this bath can be used in a preceding bath, since this bath contains more strongly contaminated components, which can be rinsed using less pure water. The required amount of rinsing water is drastically reduced by applying cascade rinsing. In order to obtain the same results, the water volume may be 10 times smaller than when cascade rinsing is not applied.

After the cascade treatment, the rinsing water can be sent to a cation-exchanging resin (for the removal of metal-cations) and to an anion-exchange resin (for the removal of cyanides). The rinsing water can thus be recycled, and when the resins are saturated, they can be regenerated, resulting in highly loaded regenerate streams. Because of this high concentration, valuable components can be recovered, for example, by electrolysis.



DOUBLE COUNTERFLOW RINSE



TRIPLE COUNTERFLOW RINSE

Figure 6.8: Double and triple counterflow rinse - Anon (1992).

6.6.4. Waste prevention and recycling in the photofinishing industry

The development of photographic films causes a significant amount of emissions and waste. Environmental problems caused by large-scale photofinishers are: the production of municipal and hazardous waste, the production of wastewater and a high water consumption. To avoid or reduce these emissions and the production of waste, a mass-flow and mass-balance analysis is carried out. The internal substance flow is shown in Figure 6.9. The film and paper developing processes are the steps of the production process with the most important environmental impact - Fleischer et al (1992).

The waste comprises municipal waste (50%), as well as hazardous waste which has to be declared. Figure 6.10 shows the amounts of the fractions which may be considered as municipal waste. The main fractions are desilvered photographic papers (31%), plastic waste (24%) and metals (20%). The waste group of desilvered photographic papers is mainly determined by the high level of production losses due to inaccurately printed negatives. The plastic fraction includes high-density polyethylene (containers for chemicals as well as film-cans) polystyrene (oneway cameras) and polycarbonate. The metal waste consists mainly of film cartridges.

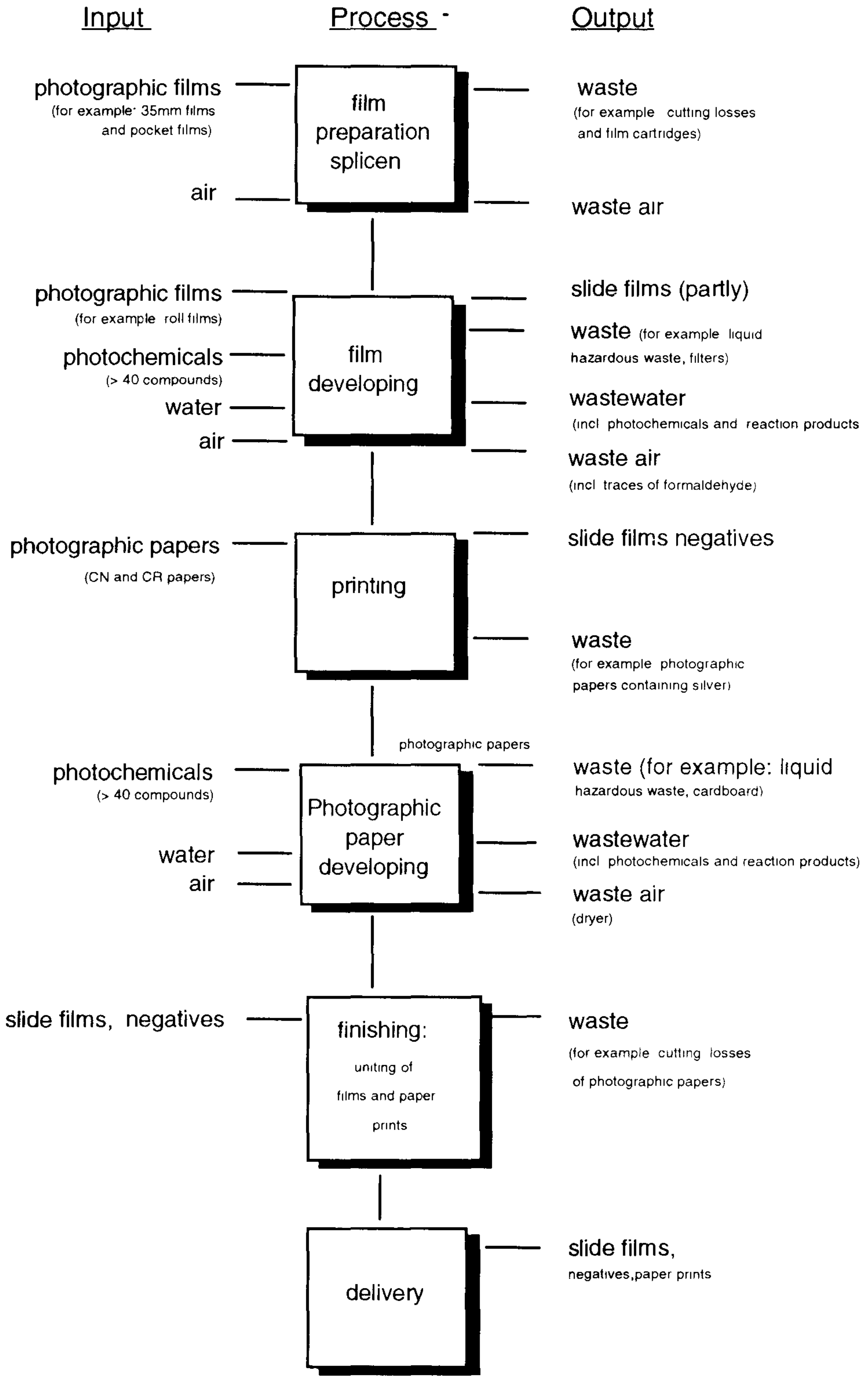


Figure 6.9: Internal substance flow

The hazardous waste is quantitatively dominated by the overflow of fixing (46%) and bleaching baths (46%). Another waste fraction consists of the filters used to clean the process baths in the developing machines (7%).

Based upon the results of the MFA, the present state of production techniques developed for the prevention of emissions can be described. Comparing this analysis with the general state-of-the-art techniques leads to the process engineering required for minimizing waste production and emissions.

Most of the waste is produced at a few sites within the production process. Introduction of some specific steps to collect waste separately would allow a large part of it to be recycled. Indeed, a mishmash of materials would be prevented and a mono retrieval of materials could be obtained. Figure 6.11 shows some possibilities for avoiding particular waste fractions.

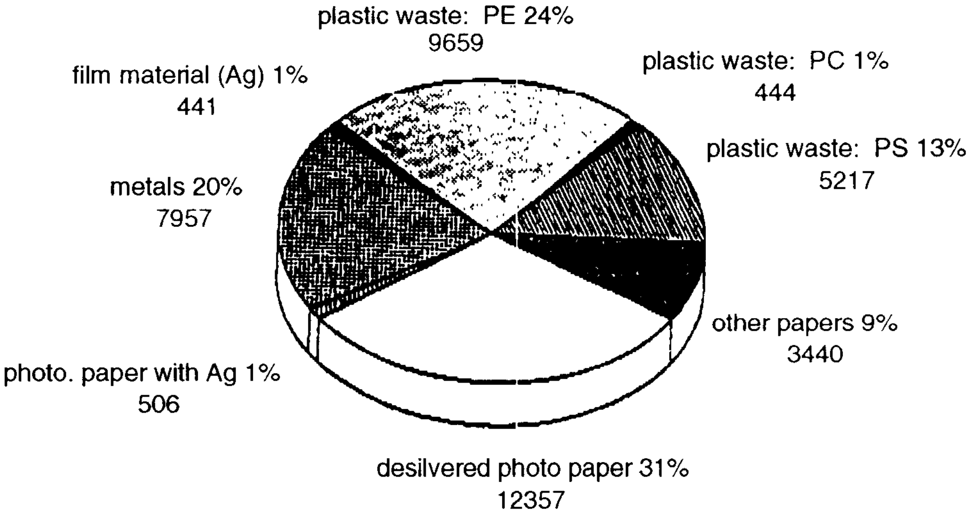
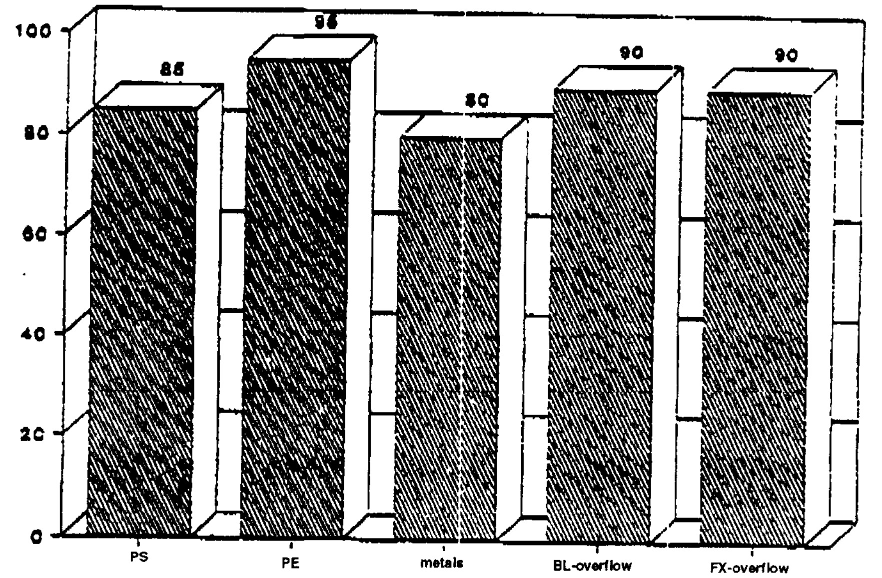


Figure 6.10: Municipal waste fractions - Fleischer et al (1992)

The polyethylene (PE) and polystyrene (PS) plastics of municipal waste are shown. The used film-cans and the empty and cleaned chemical containers from the PE-waste group could be reused as mono fractions. In the future, these PE elements could be redesigned in such a way as to be reusable for a number of times. This would result in a 95% reduction of this particular waste group. The PS-waste group might be reduced by 85%. The metal group, which contains mainly film cartridges, could be reduced by as much as 80%.

Focusing on the fractions constituting the hazardous waste, the bleaching- and fixing-overflows should be considered. It is in principle possible to add the concentrate as a solid instead of a liquid. This is already practised on a small scale in smaller photolaboratories as well as in minilabs. For the branch of the photofinishers, however, there is no practical data yet available. This measure could lead to a reduction of the overflows to approximately 10%. It is also possible, by keeping the production conditions as they are, to substantially reuse the overflows. After external treatment, they could be brought back into the production circuit.

Possibilities of waste avoidance in (%)



PS: polystyrene, PE: polyethylene, BL: bleaching both, FX: fixing bath

Figure 6.11: Examples of significant possibilities of waste prevention [%] - Fleischer et al (1992)

Other measures should be taken to reduce the amount of wastewater and the consumption of water. Such measures would include:

- the use of control units to connect the washwater-inflow with the transport mechanisms of the film- and paper-processors
- regulation of the washwater-inflow by measuring the conductivity in the process baths to find out the degree of contamination of the washwater
- recirculation of the washwater
- use of ion-exchange resins to recover wash-water and other valuable components.

6.6.5 Waste minimization and prevention in the leather industry

The tanning industry is known to be a strong source of pollutants, especially through effluents containing high concentrations of organic and inorganic dissolved material and suspended solids. In general, the oxygen demand is high and the effluents contain potentially toxic metal salt residues. Associated with tanning activities are: a disagreeable odour emanating from the decomposition of protein-containing solid waste and the presence of hydrogen sulphide, ammonia and volatile organic compounds.

A change of flow of international trade in raw material and a substantial relocation of leather production from the developed to the developing countries occurred between the 1960s and 1980s. As a result the most highly polluting wet processing activities were moved away from the developed countries at a time when environmental legislation was increasing the cost of effluent treatment installations and operation. In many developing countries regulations were at that time non-existent, or if they did exist, they were not strictly imposed. This undesirable situation in the developing countries is now changing.

In this section cleaner production options are presented, particularly for the tanning industry in the developing countries - Anon (1991).

Curing hides and skins

In developed countries hides and skins are either sprinkled with 30 to 50% salt or they are brine-cured by immersion in an agitated saturated salt solution which is maintained at a specified specific gravity in a raceway. In developing countries salt is often too expensive. Controlled shade drying is the usual method of preservation. Dried hides and skins are often dusted with insecticide. Derivatives of chlorinated aromatic hydrocarbons persist in waste and are toxic to the environment. They are now prohibited in most developed countries. Insecticides based on arsenic and mercury are either banned or severely restricted and listed in the International Register of Potentially Toxic Chemicals (IRPTC).

Where a tannery is close to a large abattoir, green hides can be transferred to the treatment process without the necessity of temporary preservation.

For developing countries reduced quantities of salt should be used. An application of 15% of salt will still provide six weeks of preservation, while 5% salt plus biocide can give two months preservation. For exporting, no long term preservation exists other than drying. Therefore the recommendation is shade drying and sprinkling with a proper insecticide.

The advantages of low waste preservation are the reduction of salt entering wastewaters from 150 to 200 kg/ton down to 30 to 80 kg/ton of hide and the absence of toxic insecticides and biocides. However, these improvements are at the expense of the reduced effectiveness of preservation, the higher cost of innocuous insecticides and biocides and the need for rapid transportation.

Hair-saving methods

In order to prevent degraded keratin from entering the effluent streams, hair saving methods should be used. The commercialization of hair as a by-product offers a potentially economic return. All this has to be balanced against the need for de-hairing machines, screens, the cost of specialty chemicals, capital, maintenance and technical control cost.

Tanning processes

The advantages of process modifications and reuse systems are the increased utilization of chromium and a consequent saving on the cost of chemicals and on effluent treatment cost. The drawbacks are the expenditure on sophisticated chemicals, on special equipment for screening filtering and on monitoring equipment for precise technical control.

Recommendations concerning chromium tanning for the future could be for a replacement of chromium, at least in the first phase of tanning.

Industry initiatives

Tanners in the developing countries can begin by adopting good housekeeping measures which require little or no capital investment, such as water conservation at all stages of wet processing. Savings in chemicals by introducing reuse-recovery-recycle systems can pay for the simple equipment needed to run them.

A reduction of the pollution load by applying low waste technologies will in effect reduce the amount of capital investment that will be required in the treatment of effluent through a reduction in the size of facility needed. By limiting pollutants in the streams, the quantities of effluent treatment chemicals will be commensurately limited. Tanneries should also maximize their returns on residues from sludge and solid waste by investigation of the feasibility of extracting methane, saving hair from conversion into felt, saving protein powders and collagen for sausage casings and medical and surgical films. By commercializing solid wastes, the cost of effluent treatment can, to some extent, be covered.

Conventional tanneries should be expected to tighten-up on the efficiency of their operations to prevent wasting resources, chemicals and water and to avoid these becoming sources of pollution. The introduction of modern production control systems should be encouraged.

Social considerations

Tanning is a traditional industry. In many developing countries it is carried out by a certain sector of the society. Methods of tanning and fabrication of goods are far from being modern. Such segments of society are difficult to bring within the modern framework of production and emission control. Governments often feel inhibited in dealing with such problems, because of the social and even political upheaval that would occur.

The adoption of low waste technology often requires a radical alteration of most tannery processes, while at the same time it must ensure that the ultimate product retains its marketable properties. Therefore, if a tanner is producing a consistent quality of leather which satisfies his customers using a process which may be wasteful in water, energy and utilization of chemicals, he may resist altering his operations to comply with environmental demands.

SAQ 6.7

Give and discuss some examples of waste prevention and minimization in:

(i) the production of caustic soda and chlorine
(ii) the electroplating industry
(iii) the leather industry

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ANSWERS TO SELF ASSESSMENT QUESTIONS

SAQ 6.1

Hazardous waste is generally defined as waste that can be harmful to the health of humans, other organisms or the environment. However several countries seek to expand this definition in order to be more specific about the properties or identity of such wastes. A Canadian definition mentions six properties - see Section 6.1, relative to the main activities of waste management systems, while the EPA of the USA lists specific wastes which are deemed to be hazardous. Yet another aspect of such definitions under the law is the exclusion of certain hazardous wastes which are regulated by separate legislation. Examples are: nuclear and radioactive wastes under the Atomic Energy Act in the USA and toxic waste under a National Law in Belgium.

It should be borne in mind that the discussion on hazardous waste in this module is not exhaustive. Rather it is meant to draw attention to the presence of many such wastes in the stream of municipal solid waste and to introduce the student to the techniques of treating, minimizing and preventing hazardous waste.

SAQ 6.2

Until recently, asbestos, which is a naturally occurring fibrous silicate mineral, was widely used as an industrial material principally because of its unusual and valuable properties of incombustibility, resistance to chemical attack, insulation and low conductivity - see Section 6.2.

Asbestos has been progressively replaced by other materials since it was discovered that it is an agent of cancer and other serious diseases in humans. Section 6.2.1 lists five methods available for the removal of asbestos waste. Of these, it will be noted that two: Big Bag Method and Discharge in Pits, are not recommended.

SAQ 6.3

Inorganic binding materials are the most widely used agents in the treatment of hazardous metal-containing waste, by a solidification / stabilization process. In this technique, soluble metals are converted to compounds of low solubility by binding and other agents to produce a solid substance suitable for disposal at a Class I landfill. Cement, lime and pozzolanas are the most important binding agents. Details of these materials, their properties and interactions with metal-containing waste are given in Section 6.5.4.

SAQ 6.4

Selection of a particular S/S process for hazardous waste treatment depends on economic and social factors as well as on purely technological considerations. The economic factor is important because of the need to minimize overall cost of the selected process, including the cost of disposal in a landfill. Social considerations arise because of the necessity of marrying available technical and managerial skills, infrastructure and level of technological development with the requirements of the treatment process. From the standpoint of technology, the characteristics of the waste and the binder, both physical and chemical, are of greatest importance in ensuring the production of a stable and durable end-product. Finally, due weight should be given to the regulations which apply to the alternatives available for the removal of the solidified product of the process. Each will have its own cost implications which must be factored into the decision-making process.

SAQ 6.5

Minimization of waste at source now constitutes a major thrust in the management of municipal solid waste, largely because of the changing economics of waste recycling and recovery, the high cost of storage, collection, transport and disposal and the difficulty in finding suitable disposal sites. Sympathetic attitudes of workers and managers in an organization play a key role in any waste minimization programme, to the extent that sensitization of the waste producer and the education of personnel under his control should constitute the first level of activities under such a programme. An investment in activities at this level pays rich dividends since it often transpires that quite minor changes in the production process and its equipment, result in a substantial reduction of waste products. The second level of activities entails a finer adjustment of processes, products and equipment. At this level, success depends on the inputs of highly qualified technical personnel - see Section 6.6 and Reference: De Bruycker (1992).

SAQ 6.6

The two processes used for the production of titanium oxide (TiO_2) - the sulphate process and the chlorine process - are described in Section 6.6.1, with the schematics of these processes shown in Figs. 6.4 and 6.5 respectively. The sulphate process has the major disadvantage of producing waste products that are environmentally destructive. These are: sulphuric acid, SO_2 emissions and an acid waste stream that contains heavy metals. Sulphuric acid in the waste stream is generated in such quantity as to make treatment through reconcentration a very expensive process. Sulphur dioxide, which is the major contributor to acid rain, is discharged to the atmosphere at unacceptable rates.

The chlorine process , on the other hand, although requiring a slightly higher investment, results in a substantial reduction in objectionable waste products when compared with the sulphate process. The acid waste stream is eliminated and the emission of SO_2 is reduced by 90%. Furthermore, one of the by-products, ferrous chloride, can be used for water treatment. A summary comparison of the two processes from the standpoint of the quality of the wastes is given in Table 6.4.

SAQ 6.7

(i) Caustic soda and chlorine, two valuable industrial products, are produced together by the electrolysis of brine. Unfortunately the traditional methods: mercury electrolysis and diaphragm electrolysis, use two environmentally dangerous substances, mercury and asbestos, as components in the production processes. These pollutants are released with waste effluents. In order to comply with stringent environmental standards, determined efforts have been made, through various methods, to reduce or eliminate them. The introduction of the membrane technique of electrolysis in the 1980's is an excellent example of the prevention/elimination of harmful waste pollutants by technological innovation. Not only have mercury and asbestos been eliminated; but there are additional benefits of lower investment cost and energy consumption - See Section 6.6.2

(ii) The electroplating industry produces waste from the baths in concentrated form and from the rinse water in more dilute form. It contains heavy metals, cyanides and nitrates and is therefore highly toxic. Treatment produces a toxic sludge which traditionally is disposed of at hazardous waste landfills at costs that are rapidly escalating. In this situation, techniques have been developed to reduce the waste effluent and the use of toxic chemicals. Examples are:

- substitution of hexavalent chromium with trivalent chromium
- development of cyanide-free baths
- improving the efficiency of the rinsing process (cascade rinsing), thereby reducing the quantity of rinsing water by a factor of up to 10.
- recycling of rinsing water after removal of pollutants by iron exchange.

Details of these minimizing and prevention techniques are given in Section 6.6.3.

(iii) Waste effluents from the leather industry contain high concentrations of organic and inorganic material as well as suspended solids. The organic components have a high BOD; while the inorganic compounds may be toxic. In the curing process it is possible to reduce waste pollutants by the virtual elimination of salt and to rely instead on shade drying and the use of non-toxic insecticides and biocides. Other techniques of minimization are:

- introduction of low waste technology to the tanning process to replace traditional technology; especially those processes using chromium
- commercialization of waste products such as hair, protein and collagen
- introduction of reuse-recovery-recycle systems

See Section 6.6.5.

CONCLUDING REMARKS

In the preceding chapters we have discussed the technical and technological aspects of the management of municipal solid waste (MSW) and have stressed the concept of appropriate management. This is a recurring theme throughout the six chapters in which each of the functional elements of the management system has been examined in considerable detail. Appropriate management takes account of climate, cultural and social factors, standard of living, level of social and economic development and available skills. Furthermore, since pollution of the land by MSW is closely connected to pollution of water and air, any chosen method of treatment or disposal should avoid the conversion of one form of pollution to another which may be even less acceptable. Successful application of this concept, therefore, requires strict attention to local conditions as well as a co-ordinated approach to the solution of management problems by working closely with other agencies, within the jurisdiction of a common comprehensive legislation.

Management is the art of directing, controlling, administering and regulating a group of activities towards a common goal and defined objectives. Taking the broad view, management of MSW is the application of this art to the manner in which wastes are stored, collected, transferred, recovered, re-used, recycled, minimized, treated and disposed of. On a smaller scale, good management may be seen as the skilful ordering of the day-to-day operations of a solid waste management authority. These concluding remarks focus on the non-technical aspects of such operations.

Legislation

A solid waste management authority cannot discharge its functions efficiently in a legal vacuum or with antiquated laws. Legislation which is in keeping with the contemporary environmental movement is a necessary part of the infrastructure required for operation of the management system. It is, therefore, the responsibility of government - national, state, local - to enact and continually update statute laws, ordinances and regulations which relate to the management of solid wastes. Historically, such legislation developed in a fragmented and unco-ordinated manner, the primary mechanism for the control of pollution being the laws governing public health. Inevitably, this has resulted in gross inefficiencies. Consider this statement taken from a document commissioned by the President of the USA in the late 1960's - EPA (1973).

> *"Fragmentation of government jurisdiction, whether of the administrative, regulatory, operative or investigative level, precludes an effective direct attack on the overall problem ... a fragmentary approach results in solutions by one section that increase the problems which confront another section, for example, a problem in refuse disposal becomes a problem in air pollution or water pollution."*

Realisation of this deficiency has led governments to enact legislation which is both comprehensive and unifying. In the case of the USA, it resulted in the passing of the Resource Recovery Act (1970) and the National Environmental Policy Act (1970), and in the creation of the Environmental Protection Agency.

A good example of comprehensive environmental legislation is the Environmental Protection Act (1990) of the United Kingdom. This sets out broad goals and objectives for environmental quality and establishes the framework for the introduction of a series of regulations which are administered by specified agencies such as the Waste Regulation Authority and waste disposal authorities of local government. Part II of the Act deals specifically with solid waste, containing some forty-eight sections under the headings:

- preliminary
- prohibition of unauthorized depositing, treatment or disposal of waste
- waste management licenses
- collection, disposal or treatment of controlled waste
- special waste and non-controlled waste
- publicity
- supervision and enforcement
- supplemental

In response to increasing pressures exerted by the modern environmental movement which began in the '60's, the developed countries of North America, Europe and Asia have moved quickly to modernise statute laws, ordinances and regulations relating to pollution, public health and the environment. Progress in developing countries, understandably, has been slower but there is encouraging evidence of the acceptance by governments of their responsibility in this regard.

Organizational Structure

Like any other undertaking, a solid waste management authority requires the discipline imposed by an organisational structure to ensure its efficient operation. An organizational structure identifies and formalises the relationships, duties and responsibilities of employees charged with accomplishing the objectives of the authority.

Although there is no unique organizational structure for a solid waste management authority, the underlying principles on which a structure is based are common to all undertakings. The complexity of a structure, however, is clearly a function of its size, as illustrated in Figs 7.1 and 7.2 which contrast the organizational charts for the Department of Sanitation, New York and the Solid Waste Management Company of the small Caribbean islands of Trinidad and Tobago. The basic principles which have proved successful are:

- Top management should be free of routine matters in order to devote full attention to planning, policy making and major management responsibilities.
- The number of sub-ordinates reporting to a supervisor should be no greater than seven.

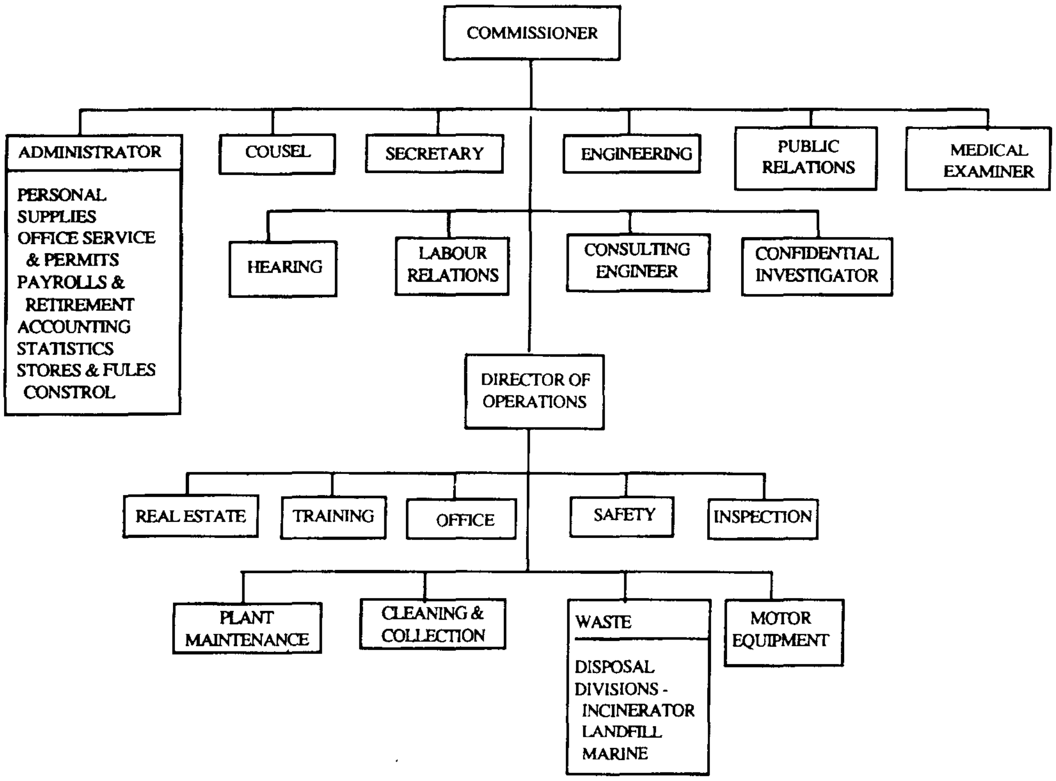

Fig. 7.1: Organisational Chart, Department of Sanitation, City of New York - Source: Municipal Refuse Disposal, Amb. Pub. Wks. Assn

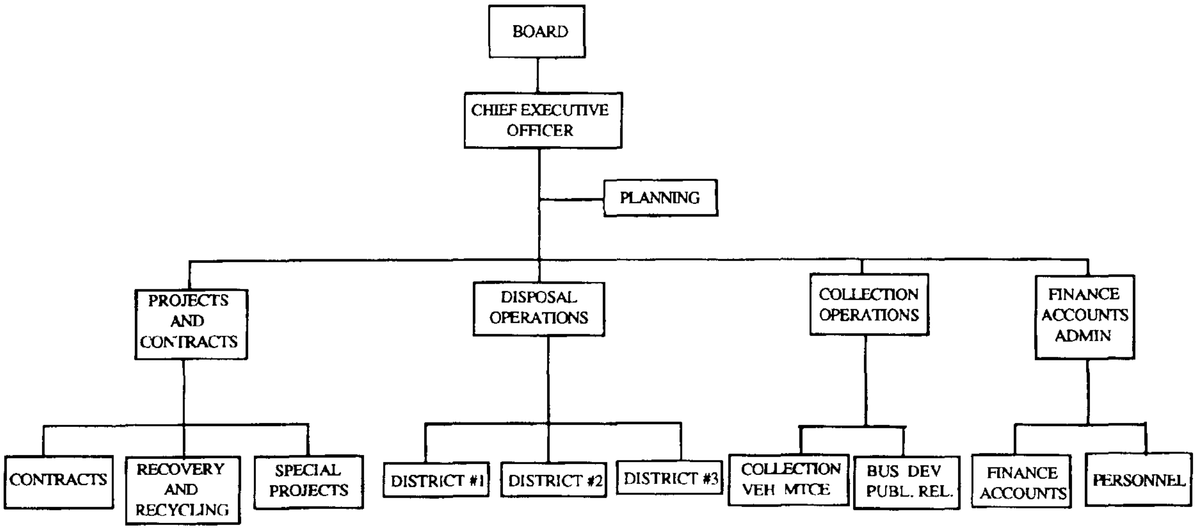

Fig. 7.2 : Organisation Chart for the Solid Waste Management Co. Trinidad and Tobago

- There should be easy flow of ideas and information up and down the organizational structure.
- Similar functions, both primary and supporting, should be grouped together.
- Responsibility and authority should be delegated at the proper level; a responsibility should not be assigned to more than one person.
- Line relations in the organization should be reserved for operations and staff relations for assistance, planning and advisory functions.
- Adequate attention should be paid to all important functions, each of which should be assigned to an individual or unit.
- Co-ordination and teamwork should be encouraged and simplified.
- Special local conditions that affect work output should be identified and catered for.
- Costs of management and administration should be minimized.

Education

The principal role of education in the management of MSW is to influence the behaviour and attitudes of individuals and communities in such a way that they understand the importance of the system in preserving and improving public health and the quality of the environment. With such understanding, attitudes to the activities of the authority become more sympathetic and the task of implementing sound management practices, with the active co-operation of the community, becomes immeasurably less difficult.

Over the decades of the 70's and 80's our understanding of the environment and development has changed from one of categorizing problems in a narrow context by sectors - air, water, land and energy - to one in which we view such problems in a holistic context. Education which relates to environmentally sound management of solid waste should not, therefore, be considered in isolation, but rather as part of a general programme embracing all aspects of the environment.

Behavioural attitudes and concepts of ethics and morality are developed at an early age, so that it is entirely proper that environmental education should begin at the primary level, proceeding through secondary school to the tertiary level at technical colleges, polytechnics and universities. An additional objective of tertiary level education is to train skilled manpower required for operating the management system.

A manifestation of the importance attached to Environmental Education was the launching in 1975 of the UN International Environmental Education Programme for the promotion and development of environmental education for all types and levels of education. The goal of environmental education, now fully endorsed by the international community, were formulated at the UN Intergovernmental Conference on Environmental Education (1977) held in Tbilisi. They are:

- to foster awareness of and concern about economic, social political and ecological interdependence in urban and rural areas.
- to provide every person with opportunities to acquire the knowledge, values, attitudes, commitment and skills needed to protect and improve the environment;
- to create new patterns of behaviour of individuals, groups and society as a whole towards the environment.

At the time of preparation of this text, environmental education was an integral part of UNESCO's Third Medium-Term Plan (1990-1995) which gives it high priority as part of basic education, at the levels of primary, secondary, technical, vocational and higher education - Ghaznawi (1989).

Public Information

In Chapter 3 we drew attention to the fact that individuals and communities are primarily concerned with the collection of waste. The prevailing attitude to disposal, especially in developing countries, is one of indifference, that is, until proposals are made to locate a disposal facility close to the community. Indifference then quickly turns to concerted opposition. This syndrome, which has come to be known by the acronym (NIMBY) (Not In My Back Yard), is one of the major impediments to the national planning of disposal and other solid waste facilities - refer to Section 4.2.2. It has developed and is sustained in the minds of the public because disposal sites are associated with squator, noise, odour, dust, smoke and vermin. As long as such conditions remain a feature of solid waste facilities, co-operation of the public cannot be expected. Rehabilitation of sites, to the extent that they are transformed to aesthetically pleasant areas, should be a first priority in laying the foundation for an effective public information programme - refer to Section 4.2.3.

The collection system is itself undergoing change as the imperatives of recycling, re-use and resource recovery become more urgent. Householders, institutions, commercial organisations and manufacturers are being prevailed upon to separate, at source, wastes such as paper, glass and plastics, for individual collection. Changes like this also provoke stubborn resistance.

In time, as environmental education becomes an integral part of the curricula of schools, colleges and universities, an enlightened public will become more receptive to proposals for developing the solid waste management system. There will, nevertheless, always be a need for communication between the management authority and the community to ensure their participation in the decision-making process. Activities directed towards this end are what constitute a public information programme. Leadership should be provided by the authority.

A public information programme has two main objectives:

- to inform and instruct the public abut the solid waste management system and about specific proposals for change.
- to allow the public to communicate their own needs and concerns.

There are numerous ways in which the two-way flow of information and ideas may take place, but experience has shown that the following simple, direct techniques are the most effective:

- articles in newspapers;
- printed pamphlets with simple statements about the management system or about new proposals, animated by graphics;
- public hearings;
- consultations with professional organisations - medical, legal, engineering;
- consultations with pressure groups, particularly the environmentalists.

Adequate funding for a public information programme is an absolute necessity if success is to be assured.

Other important aspects of management of the day-to-day operations of an authority, in particular, personnel administration and fiscal management, lie outside the scope of this text and the student is referred to standard texts for relevant information and discussion - American Public Works Association (1970).

The United Nations Agenda 21

We end with a final word about the international dimensions of solid waste management. In Section 1, paragraph 12(9) of UN General Assembly resolution 44/228 (Dec. 1989), the Assembly affirmed that environmentally sound management of waste was among the environmental issues of major concern in maintaining the quality of the Earth's environment and especially in achieving environmentally sound and sustainable development in all countries. These sentiments led the UN Conference on the Environment and Development (Earth Summit '92), held in Rio de Janeiro, to draw up a programme of activities which was recommended to the international community as a guideline for national action on environmental issues. This programme is set out in a document known as Agenda 21 - Earth Summit '92.

A separate Chapter - Chapter 21 - entitled:
Environmentally Sound Management of Solid Waste and Sewerage-related Issues focuses on four programme areas which are interrelated and mutually supportive. The document cautions that the mix and emphasis given to each of the four programme areas will vary according to the local socio-economic and physical conditions, rates of waste generation and waste composition, and urges that all sectors of society should participate.

The programme areas identified are:

- Minimizing waste;
- Maximizing environmentally sound waste reuse and recycling;
- Promoting environmentally sound waste disposal and treatment;
- Extending waste service coverage.

Each programme area is discussed under the headings:

- Basis for Action;
- Objectives;

- Management Activities;
- Financial and Cost Evaluation

and time frames recommended for the achievement of objectives. In addressing the problems of the 1990s, Agenda 21 aims at:

> '. . . *preparing the world for the challenges of the next century. It reflects a global consensus and political commitment at the highest level on development and environmental cooperation. Its successful implementation is first and foremost the responsibility of Governments*'.

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7. ADDITIONAL SELF ASSESSMENT QUESTIONS

SELF ASSESSMENT QUESTIONS

Topic 1 : Introduction

SAQ1.1 List the various differences in the solid waste management systems in developing and developed countries.

SAQ1.2 Discuss the role of wastepickers vis a vis the recycling of constituents of municipal solid waste.

Topic 2 : Composition, Characteristics, Quantities and Environmental Effect

SAQ2.1 Explain the need for routine collection and analysis of solid waste and describe the various decisions that can be taken on the basis of this information.
SAQ2.2 Estimate the reduction in quantity of waste by recycling and indicate the saving in transport cost and disposal volume.
SAQ2.3 Using the knowledge of past trend of change in waste characteristics indicate the expected waste characteristics in 2001.
SAQ2.4 Estimate the calorific value of a sample having 40% moisture content and loss on ignition at 60%.
SAQ2.5 Describe the factors affecting short and long term changes in characteristics of municipal solid waste.
SAQ2.6 Describe the method of collection of representative samples.
SAQ2.7 Discuss the various factors affecting the per capita quantity of solid waste and its variation in future.

Topic 3 : Waste Storage, Collection and Transportation

SAQ3.1 Explain the reasons as to why house to house collection is not commonly used in Indian cities.
SAQ3.2 Compare the advantages and disadvantages of Community bin, House to House and Bell Ringing system of collection.
SAQ3.3. Explain as to how would you like to involve NGO's in obtaining efficient collection of solid waste.
SAQ3.4 For a city having a population of 100,000, spread over an area of 15 sq.km, refuse generation rate of 0.5 kg/capita/day & density of 500 kg/m^3, plan the following :

i) Manpower for sweeping and collection including supervisory staff
ii) Brooms, baskets, handcarts for sweeping staff

iii) Types of community bins/containers and volume (capacity) of each
iv) Intermediate distance between bins

SAQ3.5 Suggest the points to be considered in the design and location of community bins.

SAQ3.6 Give the basic requirements to be considered while selecting a transport vehicle.

SAQ3.7 Discuss the various measures to be taken in the maintenance of refuse vehicles. Identify the approximate garage area required for a town of 100,000 population

SAQ3.8 Discuss the benefits of use of transfer station and draw a rough sketch of a simple split level transfer station. (Make your own assumptions and state them)

SAQ3.9 Briefly bring out the need for optimisation of refuse transportation routes. Also indicate the various constraints that will have to be kept in view while carrying out such an exercise.

SAQ3.10 Identify the welfare schemes and the facilities that you would recommend for the collection staff and bring out the advantages of providing them.

SAQ3.11 Discuss the need for unitary control and management information system for increased collection efficiency.

Topic 4 : Waste Disposal

SAQ4.1 Briefly describe the various factors that need to be considered during selection of a new landfill site.

SAQ4.2 Describe the mechanism of generation of leachate.

SAQ4.3 Discuss the pollution potential of leachate and indicate the various precautions to be taken during construction of sanitary landfills to reduce the leachates.

SAQ4.4 Discuss the `water balance approach' for estimation of quantity of leachate from a landfill.

SAQ4.6 Describe the method of operation of a sanitary landfill when the available quantity of cover material is limited.

SAQ4.7 Explain the need to monitor the air and water during and after completion of the landfill.

SAQ4.8 Describe the method of closure of a completed site and list out the various uses to which it can be put.

SAQ4.9 Describe the steps for conversion of a dump to sanitary landfill.

SAQ4.10 Describe the mechanism of settlement in a landfill.

Topic 5 : Waste Treatment & Resource Recovery

SAQ5.1 Give the sale prices of the following reclaimed material in your city :

SAQ5.2 Discuss the advantages and disadvantages of air separation and manual separation of waste material.

SAQ5.3 Discuss briefly the reasons due to which incineration is not commonly used in developing countries.

SAQ5.4 Describe in details the reasons for non functioning of the mechanical composting plants that were constructed during 1975-80. How would you avoid the pitfalls and under what conditions would you recommend their adoption.

SAQ5.5 Find out the amount of biogas that will be generated per tonne of MSW having following composition :

SAQ5.6 What is the difference between Incineration and Pyrolysis ?

SAQ5.7 Describe the benefits of using compost over chemical fertilizers.

SAQ5.8 Describe as to how you will adjust the C/N ratio while composting waste with low C/N ratio.

SAQ5.9 Describe the possible approaches for integrated waste processing.

SAQ5.10 Describe the process of anaerobic decomposition leading to generation of biogas.

SAQ5.11 Describe the conditions under which conversion of MSW to refuse derived fuel can be considered.

Topic 6 : Hazardous Waste Treatment and Management

SAQ6.1 Discuss the laws and acts controlling activities of hazardous waste management in India.

SAQ6.2 What are the standard norms and guidelines for transportation of hazardous wastes followed in India ? Which agencies enforce these guidelines ?

SAQ6.3 A typical waste has been received which is not included in the standard list of hazardous wastes and chemicals. How would you ascertain whether the waste is hazardous or not ?

SAQ6.4 Name various types of incinerators used for destruction of hazardous wastes. What precautionary measures should we adopt during operation of such an incinerator ?

SAQ6.5 What are the major features of environmental auditing ? Why is it so important now a days ?

SAQ6.6 What are the major factors to be considered during selection of disposal site for hazardous wastes ?

SAQ6.7 What are the major factors to be considered for co-disposal of hazardous waste with municipal solid waste? What are the limitations of this process

SAQ6.8 Identify hazardous wastes from the following list of wastes.

i) Brine sludge from mercury cell from chlorine production unit.
ii) Bamboo dust from paper mills.
iii) Cyanide wastes from heat treatment process.
iv) Wastes from fish canning plant.

v) Chromium sludges from tanneries.
vi) Debris from construction works.
vii) Coconut pith from coconut processing industries.
viii) Spent solvent from paint industries.
ix) Caustic sludge from oil refinery.
x) Rice husk
xi) Spent catalyst from petrochemical industries.
xii) Unused pesticides from farms.
xiii) Lead sludge from battery production unit.
xiv) Wheat straw
xv) Nickel waste from electroplating unit.
xvi) Acid batteries from vehicle maintenance shop.

SAQ6.9 Name eight heavy metals to be considered in EP toxicity determination.

SAQ6.10 What is solidification ? Name some common binding agents used in solidification process.

SAQ6.11 Draw a labelled diagram and indicate salient features of a chemically secured landfill site.

SAQ6.12 How would you convert hexavalent chromium present in a waste to trivalent chromium?

SAQ6.13 Give examples of the following types of wastes/chemical

a) Explosives
b) Flammable liquids
c) Flammable solids
d) Flammable gases
e) Oxidiser
f) Organic peroxides
g) Poisonous waste
h) Infectious substance
i) Corrosive substances
j) Toxic substance

ANSWERS TO SELF ASSESSMENT QUESTIONS

SAQ 1.1

Due to higher per capita income, higher degree of social developments (like education, literacy rate, health care and care for aged), higher degree of industrialisation, difference in climatic conditions and availability of well defined bye laws and acts there are differences in solid waste management in developed and developing countries which are listed below :

SWM Component	Developed Countries	Developing Countries
Quality	- Lower density of municipal solid waste (100-170kgm3) - Lower Moisture content (10-20%) - Lower Putricible organic content (20-40%) - Higher paper content (20-40%) - Higher metal content (2-10%) - Higher plastic content (2-10%) - Large particle size >50 mm (10-85%)	- Higher density of municipal solid waste (250-600kg/m3) - Higher Moisture content (10-20%) - Lower Putricible organic content (40-85%) - Lower paper content (1-10%) - Higher metal content (1-2%) - Lower plastic content (1-5%) - Smaller particle size >50 mm (5-35%)
Quantity	- Higher per captia quantity (0.7-2.3 kg/cd)	- Lower per captia quantity (0.3-0.6 kg/cd)
Household storage	- In disposable plastic bags, in specially designed container	- Assorted type of containers or no containers at all
Street Cleansing	- By mechanical means - No supervision needed	- Manually on 'beat' basis - Supervision needed which is often poor

SWM Component	Developed Countries	Developing Countries
Collection	- House to house collection system - Direct collection in compactor vehicles - Regular frequency of collection - Highly mechanised collection system, hence lesser number of staff involved	- Community bin system of collection - Manual collection by use of handcarts - No regular frequency of collection - Manual operation requiring manpower
Transportation	- MSW is transported via transfer station through specially designed large sized refuse transportation vehicles having mechanical loading/unloading facilities - Only vehicles specially designed for MSW are used - Well equipped garages & workshops	- MSW is directly transported from collection points to disposal site in open body trucks involving manual loading and unloading - Assorted type of vehicles used for transportation - Inadequate garage and workshop facilities
Resource Recovery	- Planned resource recovery system	- Unplanned resource recovery system - Extent of recycling is difficult to predict though maximum resource recovery takes place
Energy Recovery	- Energy is recovered by incineration - Biogas is recovered from landfills	- No energy is recovered through incineration - Large scale biogas recovery is not adopted
Disposal	- Sanitary landfills used	- Mainly crude dumping takes place
Legislation	- Acts and bylaws regarding waste disposal are strictly followed	- Old and inadequate bylaws which are not followed strictly

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SAQ 1.2

Wastepickers play an important role in the recycling of the constituents in municipal solid waste. The wastepickers recover various constituents like paper, plastics, metals and other items which have a ready market in the developing countries.The wastepickers recover the constituents mainly from collection points and disposal sites. They are often exploited by the solid waste management authorities and also by antisocial elements who extract some money from them. The wastepickers reduce the volume of waste to be transported and disposed of. Also the recovered constituents can be recycled which saves the natural resources and also saves the energy. However, due to the picking activities of the wastepickers at collection points the waste is often spread around which is a nuisance to the surroundings.

SAQ 2.1

Routine collection of solid waste samples and analysis indicates the physical and chemical composition of the waste. Based on these characteristics, the collection and transportation frequency and mode of disposal can be decided. It also indicates the changes in characteristics with time and type of generating area. It provides information regarding amount of compostable matter, heating value and quantity of biogas that can be obtained. Hazardous waste component, can also be identified based on waste characteristics. It also helps in taking appropriate decision on collection system (design and capacity of dustbins), designing of vehicles, arriving at the transportation capacity of vehicles, manpower deployment and future planning.

SAQ 2.2

The manpower requirement and expenditureon collection, transportation and disposal of solid waste increases with the increase of quantity of waste. Paper, plastics, glass and metals are commonly recycled. The volume of waste is reduced as paper and plastics have large volume. Plastics do not degrade and create problems during disposal. Its recycling reduces the quantity needing collection and disposal. This results in saving in transport and disposal cost. Recycling is a source of livelihood for socially weaker section of society.

SAQ 2.3

The characteristics of waste depend on a number of factors such as social status of people, habits of people, standard of living, climatic conditions, and industrial activity. The past trends indicate that biodegradable and fine ash and earth which form the major components of Indian refuse are decreasing. Non-biodegradable packaging material and plastic films are found to increase in solid waste. As Gross National Product (GNP) increases, the quantity of waste per capita is also expected to increase. The past trend indicates this to increase at 1 to 1.33% per year.

SAQ 2.4

Calorific value

$$= VS\,(100-w) \times 0.444 - 6\,W \text{ in k.cal/kg}$$

Where VS = Percentage volatile substance
W = Percentage moisture content

Therefore calorific value

$$= 60\,(100-40)\,0.444 - 6 \times 40$$
$$= 1358.4 \text{ k.cal/kg}$$

SAQ 2.5

Factors affecting long term changes
- Industrial and Urban Development
- Environmental awareness
- Availability of packaged consumer products
- Government policy and laws for solid waste management
- Increase in income or standard of living

Factors affecting short term changes
- Seasonal changes
- Festivals and social gathering
- Fairs and exhibitions
- Climatic changes
- Natural disasters such as floods and earthquake

SAQ 2.6

While collecting a samples of municipal solid waste (MSW), major collection points (dustbins) are identified which represent a larger population area. Based on the type of area such as residential, commercial, industrial, market and slum etc., sampling points are distributed uniformly all over the study area. The sampling points are further classified based on the economic status of population (high, middle and low income).

In small places where the quantity of solid waste in various dustbins is not large, one sample of 10 kg from each selected sampling point (dustbin) is collected after thoroughly mixing the waste at that point.
In larger cities where the quantity is large (few truck loads), about 10 kg of MSW is collected from 10 different points from outside and inside of the waste mass at the collection point. The total quantity of waste so collected is thoroughly mixed and then reduced by method of quartering till a sample size is obtained which can be handled in the laboratory (normally 12.5 kg). This sample is subjected to physical analysis, moisture determination and preparation of sample for further chemical analysis.

SAQ 2.7

The per capita MSW is known to increase proportional to the per capita income. Variation in food habits of the population and introduction of various consumer articles in the markets are found to affect per capita quantity of solid wastes. Use of plastic bags and packaging of various grossery and consumer items (milk, tea, beverages) in plastic and plastic reinforced paper bags has added large quantity of plastics and paper to solid waste stream. The use of packed food items might further decrease garbage component in MSW. The factors affecting future per capita quantity of solid waste are

- Rapid industrialization which contributes to industrial solid waste
- Rapid urbanization adding debris and construction wastes
- Changes in climatic conditions
- Reuse and recycling of useful components

SAQ 3.1

In house to house collection the waste has to be stored in individual premises in containers of a specific design. The houses in the developing countries are often quite small and as the containers have to be stored inside the houses it poses a number of aesthetic and sociological problems. Further the low purchasing power of the residents may pose problems in purchase of standardised containers. It will be difficult and costly for the municipal agency to provide and maintain such a large inventory of containers.

The lesser per capita quantity and the higher density of municipal solid waste will result in lesser volumetric capacity per household. Thus the vehicle will have to collect the waste from larger number of premises before it is filled. This will result in increase in cost of collection/tonne. Hence for the above mentioned reasons house to house collection is not commonly used in Indian cities.

SAQ 3.2

A. Community Bin System

Advantages	Disadvantages
- Fewer stoppages of transport vehicle, enabling more trips/day can be performed provided it is properly monitored	- Improper community bins, their locations and frequency of collection affects:-
	. Some bins are under-utilised and some overflow
	. stray animals and ragpickers spread the solid waste at community bin
	. Rain water enters the community bin and increases the weight of SW
	Unhygeinic conditions develope if scheduled collection frequency is not followed

B. House to house collection system

- city roads remain clean as no SW is found on road/lanes	- system can not be adopted in all localities due to use of non-standardised containers and vehicles for transport
	- House owners are reluctant to keep the container outside the house due to chances of theft and nuisance due to pedestrians, animals etc.
	- Involves higher cost on equipment, larger manpower etc.
	- Market, commercial areas require larger containers.

C. Bell ringing system

- It gives better performance if the work is properly monitored by supervisory staff	- Vehicle arrival time may not suit all the houseowners
	- Requires large manpower, inadequate monitoring by supervisory staff poses problems in areas having large population density.

SAQ 3.3

Presently the ragpickers reclaim the various recyclables from the community bins and disposal sites. If these workers are allowed to collect the waste from the residence, they can recover the recyclables more conveniently and they would also be able to earn more because of the cleaner material received by them. In some Indian cities these waste pickers have been grouped together by NGOs who give them the identity. They also pursuade the houseowner to pay certain monthly fee to these waste pickers. Thus as the waste is now collected from the individual premises by the waste pickers who reclaim the recyclables and deposit the remaining in the community bin a better collection occurs.

SAQ 3.4

City having 100,000 population spread over 15 sq.km. area. Refuse generation rate of 0.5kg/c/day. (density $0.5 T/m^3$)

i) Manpower - Assume 2 persons/1000 population

$$\text{So sweeping staff required} = \frac{100000 \times 2}{1000} = 200\text{Nos}$$

Add 15% for leave reserve

Total staff = 230 Nos.

Mukadams - 1 No./20 sweepers

Nos. of Mukadam, including 15% standby $= \frac{200 \times 1.5}{20} = 14$Nos

Sanitary Inspectors - 1No/7-8 Nos. Mukadams

Number of Sanitary Inspectors including 10% standby = 3 Nos.

ii) Brooms, Baskets and handcarts

Assume Brooms are issued to every sweeper, having life of 4 months

Number of brooms/yr = 230 x 3 = 690 Nos./yr

Number of baskets (plastic)having life of 6 months = 230 x 2 = 460 Nos/yr.

Handcarts - Assuming one handcart issued to a pair of sweepers

Total including 15% standby $= \frac{230}{2} \times 1.15 = 133$No

iii)Types of community bins/containers and volume of each

Total quantity of solid waste generated/day $= \frac{0.5 \times 100000}{1000} = 50$ Tones

Total volume = 100 m^3
(density $0.5T/m^3$)

Assuming collection frequency of once in 3 days and 33% extra capacity considering failure of visit of transport vehicles due to unforeseen reasons

Total required volume= 100 x 4 = 400 m^3

Number of community bins (Assuming 2.25% area having narrow lanes is served by pushcarts/tricycles) $= \frac{14.775 \times 106}{31{,}400} = 471$

$$\text{Volume of bin} = \frac{360}{471} = 0.76$$

$$= 0.8\ m^3$$

Hence 1m dia x 1m high RCC bin will be suitably placed at a radial distance of 100 metre.

SAQ 3.5

During the design of community bins, the following criteria should be used

The capacity =contributing population x per capita
x frequency of removal in days

The above volume will be multiplied by a factor of 1.33 or 1.5 depending on whether the frequency of collection is once in three days or once in two days. The community bin should be located where it can be easily approached by the vehicles and the residents. The distance between two successive bins should not exceed 200 metres.

SAQ 3.6

Loading and unloading should be easy and loading height <1.5m for manual loaders and unloading by hydraulic tipping gears.

- Turning radius conforming to normal city road width (max. 6 metres)
- The vehicle should conform to prevailing motor vehicle rules
- Driver should be protected from heat, rains and provided with a proper cushion and spring loaded seat
- Vehicle should rugged in construction and should be painted with atleast 2 coats of anticorrosive paint of specific colours and should have tyres suitable for easy movement at landfills
- It should be properly covered by tarpauline/cloth while transporting the SW to disposal site

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SAQ 3.7

The vehicles should be parked in suitable garages to protect them from rain and sun. A garage should have the following necessary facilities.

- Fuel pump, washing platform, servicing facility
- Minor repairs

A workshop for major repairs should be provided with the following facilities :
Major overhauling of engine, gear box, body repairs, brakes, suspension, upholestery work etc. The spare part inventory should be maintained for minimum 4-6 months period. The proper tools and equipments for carrying out repairs needs to be provided at workshop. An assembled unit sections be maintained which helps faster replacement of units and reduces downtime.

For the per capita of 0.5kg/c/day

Quantity generated/day = 50 tonnes/day = $100m^3$

It is assumed that, conventional Dumper of 6m3 cap. is used and performs 2 trips/day

Number of vehicles required

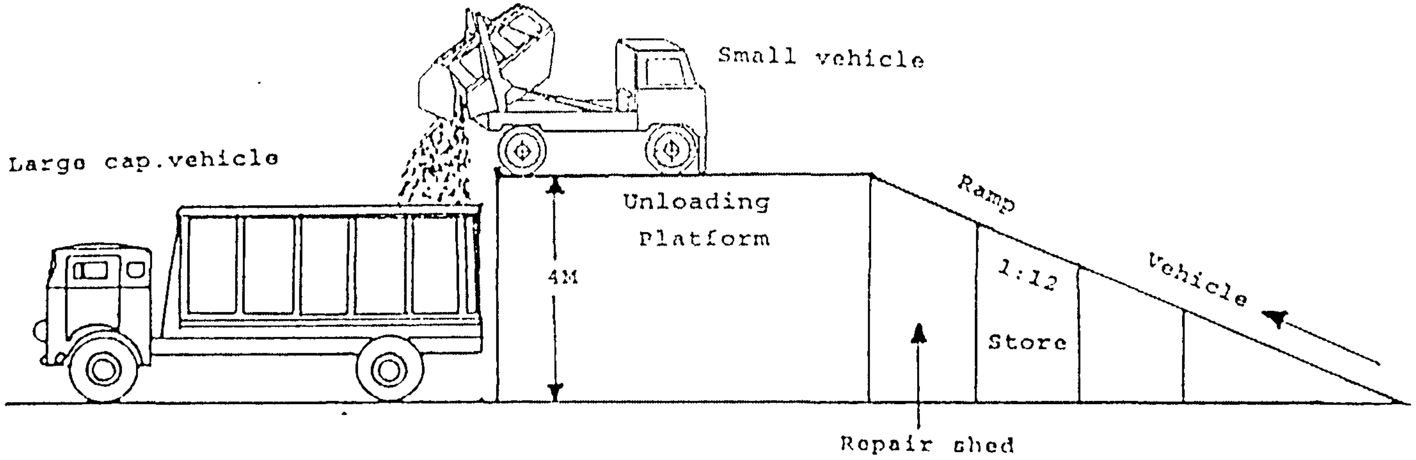
$$\text{including 15\% stand by} = \frac{100 \times 1.15}{6 \times 2} = 10$$

It is assumed that one vehicle requires 100 sq.m. area

Total area required for 10 vehicles = 1000 sq.m.

SAQ 3.8

A transfer station is used to transfer waste from smaller transportation vehicle to larger transportation vehicle. A larger transportation vehicle normally gives lesser unit transportation cost and is normally adopted when the transportation distance to the processing or disposal site is large. The decision regarding the provision of a transfer station is taken after comparative cost analysis of direct transportation to the processing or disposal site is compared to the cost of provision of transfer station and the transportation cost by the use of larger transportation vehicles. A schematic diagram of split level transfer station is enclosed.



Split level transfer station

SAQ 3.9

The transportation system requires vehicle fleet and operating manpower. The vehicle fleet requires large amount of capital expenditure thereby necessitating their optimal utilization. Presently the routes, through which these vehicles operate, are based on the convenience and experience of operating personnel (mostly the drivers). These routes are not necessarily optimum and do not utilise the resources (vehicles and manpower) optimally. Therefore the optimization of routes is desirable.

The route optimization can be achieved through use of mathematical techniques for which there is a need of appropriate mathematical models along with the solutions preferably in computer based user friendly form, a reliable and accurate input data on the demands of solid waste transportation at various collection points and the associated costs and above all the will and interest of the management to apply and implement the solution obtained through such exercises.

The optimisation of transport routes is normally carried out by using mathematical techniques by making various simplified assumptions. The traffic and road conditions and restrictions as well as the specific problems of loading and unloading of waste, type of vehicle may however affect the final values.

SAQ 3.10

The collection staff plays a very important role and unless the collection is carried out promptly and efficiently, the transportation and disposal will be adversely affected. The collection staff unfortunately is not provided with properfacilities.

They are often required to assemble at some road side points for their attendence. They are not provided with any recreational facility. It is hence desirable that specific offices be created where this staff reports for duty, where they can store and collect their implements, and where bathroom and toilet facilities are provided. It will boost up their morale if a physician visits this site and gives them necessary treatment for minor ailments. They should also be promptly rewarded whenever better performance is observed.

SAQ 3 .11

In majority of the Indian cities the collection and disposal staff works under one authority while the transportation work is managed by another. Due to lack of coordination between these two agencies often the waste collected at the community bin is not taken away for disposal, even though the vehicles are available for its transportation. When the whole operation is controlled by the same authority such problems will not arise.

A Management Information System should promptly feed information to the control unit about all parameters responsible for various aspects of the system. When such information is readily available, the management is able to take prompt remedial action to take care of any problems inthe collection system.

SAQ 4.1

During selection of a new landfill site thefollowing points have to be considered

i) The selected site should not be far off from the area to be served so as to keep the transport cost to a minimum. It should have proper access.
ii) The selected site should be adequate for the design period
iii) The landfilling operation at the site should not result in air or water pollution
iv) The site should be such that it does not disturb the ecology. The hydrogeological conditions should be such as will avoid environmental pollution.
v) The site should be such that it is not within the prohibited zone of the airport
vi) The use of site as a landfill should conform to the land use regulations
vii) Adequate cover material should be available at or near the site.

SAQ 4.2

Out of the rainfall over a landfill site a part escapes as surface runoff, part gets evaporated due to the surface evaporation and transpiration losses from the vegetation and the remaining infiltrates in the landfill. The water is retained in the landfill till its field capacity is reached. Any water in excess of the field capacity tends to escape as leachate.

SAQ 4.3

The leachate comes in intimate contact with the deposited waste when the soluble constituents get dissolved in it. Thus the pollution potential of the leachate depends upon the composition of the deposited waste and varies with time as the deposited material gets stabilised.

To prevent the pollution of surface and ground water by leachate system of leachate collection and treatment followed by discharge of the treated leachate has to be provided. The quantity of leachate can be kept to a minimum by providing proper surface slopes, covering of the exposed waste layer and by proper site selection to ensure that the site is not located in the path of a surface water source.

SAQ 4.4

The water balance approach calculates the quantity of leachate by subtracting from the quantity of the incident rainfall, the losses due to evaporation and transpiration and the surface runoff.

To calculate the design quantity of the leachate the maxiumum rainfall intensity observed in the preceeding number of years equal to the design period is considered.

SAQ 4.5

The most economical method of treatment of leachate involves. its recycling and recovery of biogas. It can also be anaerobically digested for a seven days detention period when a 99% of removal of COD is observed.

In general, when the BOD/COD ratio is in the range of 0.4 to 0.8, biological treatment is preferred. Treatment in aerated lagoons with a detention period of 10 days is also able to give high efficiency. Initial COD upto 16000 mg/l has been treated in such lagoons.

SAQ 4.6

In the normal method of operation various cells are created to the same level in a given area one after another and after the whole area has been provided with this arrangement, the second lift is given over the earlier laid material. However, this method of landfilling requires considerable amount of cover material. In such cases, where the available cover material is less, the cells are provided one above another till the required height is reached. This method is known as "multiple lift method" and requires lesser quantity of cover material.

SAQ 4.7

During the operation of landfilling site movement of heavy earth moving machinery results in a large amount of dust and fine particles getting airborne leading to air pollution. Further, the anaerobic decomposition generates CH_4, H_2S and such other gases which also adds to the air pollution. In some locations the deposited waste is burnt to reduce its volume and as it is uncontrolled burning air pollution is caused. It is hence necessary to continuously monitor the air both during and after completion of the landfilling.

During the construction, the rainwater falling over the exposed working face generates leachate. Similar leachate generation can also occur if proper leachate collection system has not been provided.It is hence desirable to continuously monitor the quality of surface as well as ground water at the landfill.

SAQ 4.8

After the filling of the landfill site is complete the final earth cover of at least 60 cm has to be given. In case the site has to be used as a park or a green area, suitable soils have to be used and planting by appropriate plant species should be carried out.

Though completed landfill sites have sometimes been used for construction of structures it is commonly used for recreation purposes by planting suitable trees.

SAQ 4.9

For conversion of an existing dump to a sanitary landfill, the first step involves collection of the deposited waste in an orderly fashion. It is then immediately provided with at least 30 cm soil cover excepting the area which is to serve as the working face. The landfilling is then carried out by following standard procedure.

SAQ 4.10

The settlement in landfill consists of the following stages:

i) Primary consolidation
ii) Secondary Compression and Creep
iii) Decomposition

In the primary consolidation a large proportion of total settlement occurs in a short duration and is also known as short term shear deformation. The secondary compression proceeds slowly and the factors affecting it are the same as in first stage. In the last stage, the organic matter decomposes and is converted into stable end products. The resultant increase in density is reflected by further settlement. Out of the three stages, the second and third stages are slow and cannot be mechanically hastened.

Primary consolidation depends on weight, decomposition and arrangement of particles, depth of fill and moisture penetration. Out of these factors, for a given case, only unit weight of fill material can be increased. This increase can be acheived by using heavy equipment which due to large static compactive force and dynamic forces results in better arrangement of particles and voids to give a higher density.

SAQ 5.1

The sale prices of the following reclaimed materials in Nagpur are

Paper	Rs. 2 - 5 per kg
Plastics	Rs. 4 - 6 per kg
Ferrous Metal	Rs. 5 - 8 per kg
Glass	Rs. 0.50 - 0.75 per kg

SAQ 5.2

Air separation : This method uses the difference in density of the waste constituents. The waste is suspended in a stream of air and the different constituents are allowed to settle out depending on their densities. This method gives high efficiency of separation when the various constituents are in a comparatively cleaner state. However, the cost of air separation is quite high and a number of problems are faced in maintenance of machinery involved. The method also poses problems when the moisture content of the waste is high.

Manual separation : Manual separation is quite efficient and can be used even when the different constituents are completely intermixed. However, it requires a large manpower with attendant management problems.

SAQ 5.3

In developing countries the ash and earth content is comparatively high due to the common habit of mixing of street sweeping in the waste. In these countries the fresh vegetables are commonly used and in certain seasons heavy rainfall occurs. This results in high moisture content.

The paper, plastic and such other constituents which mainly contribute to the calorific value are present in very small concentration and the calorific value is hence on the lower side.

Thus the low calorific value, high moisture and ash & earth content results in situation where a self sustained combustion cannot be achieved and auxillary fuel will have to be added thus increasing the cost. Hence due to very high capital and operating cost, incineration is not commonly used in the developing countries.

SAQ 5.4

The mechanical composting plants that were set up during 1975-80 in India are not functioning mainly due to over- mechanisation, provision of number of redundtant units and absence of adequate market. The plants did not consider the social cost and hence from purely commercial angle they did not yield any profit.

Hence if mechanical composting plants are constructed with minimum degree of mechanisation and when proper market is developed within a short distance it would work successfully and can be recommended.

SAQ 5.5

The municipal solid waste has the following composition

Fats - 0.5 %
Proteins - 5.0%
Carbohydrates - 67.0%

Hence municipal solid waste will contain

Fats - 5.0 kg/tonne
Proteins - 50.0 kg/tonne
Carbohydrates - 670.0 kg/tonne

Assuming 50% biodegradability of these constituents, their respective quantities that will get converted to biogas will be

Fats - 2.5 kg/tonne
Proteins - 25.0 kg/tonne
Carbohydrates - 335 kg/tonne

Biogas yield per kilogramme of fats, proteins and carbohydrates are 1430 litres, 517.4 litres and 373 litres respectively

Hence biogas produced will be

2.5 kg fats per tonne = 1430 x 2.5 = 3575 litres
25 kg protein per tonne = 517.4 x 25 = 12935 litres
375 kg carbohydrate per = 373 x 335 = 214955 litres tonne

Total 141465 liters/ tonne of waste

SAQ 5.6

Incineration involves complete combustion of the material in the presence of large amount of excess air. The air after incineration takes along products of incomplete combustion leading to air pollution. The residue remaining after incineration can be disposed of.

Pyrolysis involves destruction of the materials at high temperature in the absence of oxygen. The products hence consist of an inert residue, volatile liquids and mixture of gases, each of which can be used as a source of energy. However, pyrolysis can not be used for all types of wastes and is normally used for wastes having high organic content.

SAQ 5.7

Chemical fertilizers are mostly of inorganic origin whereas manure is of biomass origin. Nutrients in the chemical fertilizers are easily water soluble whereas nutrients from manure are slowly released. Manure in addition to nutrients contains essential trace elements such as boron, copper, magnesium, manganese, iron etc. Chemical fertilizers do not add to the fertility of the soil. Addition of manure improves the physical properties of soil such as decrease in density, increase in water retention capacity & cation exchange capacity, formation of water stable aggregates etc.

SAQ 5.8

During decomposition of organic matter microbes utilizes 30 part of carbon for every part of nitrogen. Nitrogen is recycled whereas carbon gets reduced during microbial decomposition.

Normally, biomass with Carbon/Nitrogen ratio in the range of 25 - 40 can be properly composted. Higher the C/N ratio, more time is required for composting. Composting of the solid waste with low C/N ratio, results in loss of nitrogen due to ammonia volatalization. Increased ammonia volatalization occurs with increase in temperature and alkaline pH.

For composting of waste with low Carbon/Nitrogen ratio mixing of additional carbonaceous waste such as paper, cardboard, hay and straw etc., helps increase C/N ratio for proper composting.

The quantity of carbonaceous material to be added can be calculated by estimating Carbon & Nitrogen content in the waste to be composted and in the carbonaceous material to be amended.

SAQ 5.9

Among the various biotreatment approaches adapted for management of municipal solid waste none of the process utilizes carbon, nitrogen, phosphorous & potassium potential of the organic fraction to the fullest extent.

Anaerobic digestion converts carbon to methane and carbon dioxide whereas during aerobic processes carbon dioxide is formed and escapes unutilised. Thus carbon, nitrogen, phosphorous and potassium are recycled during anaerobic decomposition (some nitrogen is changed to ammonia and oxides of nitrogen). Under aerobic decomposition nitrogen gets lost due to ammonia volatalization which increases with increase in temperature and pH. In landfills part of the carbon, nitrogen, phosphorous and potassium gets leached.

Integration of aerobic and anaerobic process and some alternatives for nitrogen and phosphorous recovery, if adopted will result in maximum utilization of C, N, P & K. The end product is safe for disposal. Among the total quantum of C,N,P,K in the biomass, part is available during initial period of decomposition and in the later period they are slowly mineralised. In view of this, the integrated approach is outlined below. The approach utilizes municipal solid waste without separation of constituents.

i) **Bioenergy :** Anaerobic digestion of high total solid concentration with phase separation approach is used for biogas generation. After conversion to biogas the residue is processed for nutrient recovery.

ii) **Nutrients :** In the first step only available carbon gets converted to biogas whereas nitrogen, phosphorous and potassium remains quantitatively the same. The nutrients released under submerged condition are utilized for biomass development. Aquatic macrophytes such as lemna sp. which has tremendous growth potential utilizes nitrogen, phosphorous and potassium. The harvested biomass can be either composted, vermicomposted, processed for biogas generation or used as poultry and livestock feed.

iii) **Humus :** The residue of second step is stabilized and can be composted, vermicomposted or landfilled which has least pollution potential.

SAQ 5.10

The biological conversion of biomass into methane is a complex process which involves three trophic groups of anaerobic bacteria. The process of anaerobic decomposition leading to biogas generation is described below :

i) **Hydrolysis and fermentation :** Polymers such as carbohydrates, fats and proteins etc., are hydrolysed into soluble sugars, amino acids, long chain carboxylic acids etc.,by hydrolytic and fermentative bacteria.

ii) **Acetogenesis :** The soluble products of first step are converted by second group of bacteria into products that can easily be utilized by methane formers.

Acetogens consist of two groups of microbes

- Homoacetogens : Homoacetogens ferment hexoses, $H_2 + CO_2$ to acetate.
- Hydrogen producing acetogens:This group of bacteria converts butyrates, propionates, ethanol etc., to acetate and CO_2
- The acetogen ensures that the full range of nutrient material available to anaerobic microbial ecosystem can ultimately be converted to acetate and hydrogen. The transformation to acetate is possibleonly in the presence of hydrogen oxidizing bacteria i.e. methanogens and sulphate reducing bacteria.

iii) **Methanogenesis :** Methanogens can utilize only limited number of substrates ie. formate, methanol, hydrogen + carbon dioxide and acetate to methane.

SAQ 5.11

Municipal solid waste can be converted to refuse derived fuel by removing the inerts and noncombustibles. This is commonly achieved through single or multiple stage air separation. The moisture content of the material is reduced either by sun-drying or by using exhaust gases from some other processes. The remaining material is then mixed with a binder and then converted to suitable briquettes and used as refuse derived fuel.

The feasibility of preparation of refuse derived fuel depends upon proportion of combustible fraction, availability of suitable cheap binders, availability of land suitable for sun drying or exhaust gas for drying purposes. The system can be economically used when adequate market exists.

SAQ 6.1

The various laws controlling activities of hazardous waste management in India are i) Hazardous Wastes (management and handling) Rules, 1989 (ii) Motor Vehicle Act 1988 and (iii) Atomic Energy Act, 1962. As per Hazardous Wastes (management and handling) Rules, owners of the industries generating hazardous wastes are required to identify likely hazards and their danger potentials and are expected to take adequate steps to prevent such occurrences. The generation of the hazardous wastes is regulated by this law. The generator should take all practical steps to ensure that such wastes are properly handled and disposed of without any adverse effect on the human health and environment. The rules also describe a permit system administered by State Pollution Control Boards for handling and disposal of hazardous wastes. It has been directed to follow the rules as per Motor Vehicles Act, 1988 for packaging, labelling and transport of hazardous wastes. Significantly, the import of hazardous wastes into India for dumping and disposal is prohibited under the laws. Handling and disposal of radioactive wastes are regulated by Atomic Energy Act.

SAQ 6.2

The transporter who transports hazardous wastes from the source of generation to the offsite facility should check proper labelling and marking on the container and the condition of the container before loading on to vehicle. He should also provide necessary equipments like fire extinguishers, gas masks, safety goggles, first aid kit etc., to the driver and also proper training to handle the equipments and tackle the emergency situation. A transport emergency card (TREM card) carrying instructions to be followed in case of spillage or accident should be provided to the driver.

A 'manifest system' should be adopted in order to keep track of the movement of the hazardous wastes from the source of generation to the disposal site and also to entrust responsibilities to the concerned persons. It includes detailed information about the wastes to be transported like nature, quantity, composition, special precautionary measures, mode of transportation etc. The manifest should be duly signed by generator, transporter and the owner of the disposal site. Off hand emergency plan should be prepared by the generator for tackling emergency situation like spillage, accident etc.

State Polution Control Board and Department of transport enforce the guideline.

SAQ 6.3

The waste which is not included in the list may still be hazardous by virtue of possessing any one of the four characteristics-ignitability, corrosivity, reactivity and toxicity. These parameters can be studied for identifying unknown hazardous wastes.

Ignitability : If the flash point of the waste is less than 600C, it is treated as ignitable.

Corrosivity : If pH is less than 2 and greater than or equal to 12.5 it is treated as corrosive.

Reactivity : A reactive waste has a tendency to become chemically unstable under normal condition or react violently when exposed to air or mixed with water, or can generate toxic gases. The reactive characteristics is a narrative definition without a mandatory testing protocol or specified decision levels.

Toxicity : The fourth characteristics is EP toxicity. The solid waste is mixed with an acidified leaching medium for a period of 24 hrs. The liquid extract from this leaching procedure is then analysed for the presence of any of the specifed contaminants. EPA recently introduced a new leaching procedure called the Toxicity Characteristics . Leaching Procedure (TCLP). It involves extraction followed by analysis for 38 constituents. It includes eight metals i.e. Arsenic, Barium, Cadmium, Chromium, Lead, Mercury, Selenium, Silver etc.

SAQ 6.4

The incinerators used in Hazardous Waste Management are

a) Fluidized-bed incinerators
b) Rotary kiln incinerator
c) Open hearth furnace

Precautionary measures

i) Excess air should be supplied to ensure complete combustion
ii) The gases should be monitored for various pollutants like carbon monoxide, sulphur dioxide, dioxin, hydrochloric acid, hydrogen sulphide etc. The necessary Pollution Control Equipment like electrostatic precipitator, scrubber etc., should be provided with the incinerator.
iii) The ashes should be monitored to check the presence of heavy metals.

SAQ 6.5

Environmental Auditing is a management tool comprising a systematic, documented, periodic and objective evaluation of how well the environmental organisation, management and equipment are performing with the aim of helping to safeguard the environment by

i) facilitating management control of environmental practices
ii) Assessing compliance with company policies, which would include meeting regulatory requirements.

During the audit a team of individuals complete a field assignment which involves gathering basic facts, analysing the facts, drawing conclusions concerning the status of programmes audited with respect to specific criteria and reporting the conclusions to appropriate management. These activities are conducted within a formal structure in a sequence that is reported in each location audited to provide a level of uniformity of coverage and reliability of findings that is maintained from audit to audit.

Rapid industrialisation and unplanned development are causing serious damage to the environment. It is necessary to review the performance of the existing system of environmental status before going in for the further development. Environmental auditing helps us in achieving the goal of sustainable development. Major benefits from environmental auditing are

a) facilitating comparison and interchange of information between operation and plant
b) increasing employee awareness of environmental policies and responsibilities
c) identifing potential cost savings including those resulting from waste minimization
d) providing an information base for use in emergencies and evaluating the effectiveness of emergency response arrangements
e) assuring an adequate, upto date environmental data base for internal management awareness and decision making in relation to plant modifications, new plant etc.

SAQ 6.6

If a waste cannot be processed for recovery or as a source of energy and cannot be treated for discharge to the surface water or air, it must be disposed of on land. The landfill site should be designed properly in order to reduce environmental and health risks.

The major aspects that must be considered are as follows:

- Type and volume of hazardous and non-hazardous wastes to be landfilled.
- Life expectancy of landfill during its active operating period.
- Topography & soil characteristics at the life and in its vicinity
- Climatic conditions throughout the year
- Surface water and ground water in the vicinity
- Collection and treatment of surface run off.
- Soil cover requirements for individual containment cells
- Anticipated quality and volume of leachate
- Selection of leachate collection and treatment systems
- Monitoring of ground water and surface water during operation
- Selection of venting systems for gaseous products
- Selection of membrane liners and other impermeable liners
- Closure and post closure plans
- Effect on human health & the environment.

Secure landfill has been established as a viable and highly professional weapon in hazardous waste management. A chemical waste landfill, if it is to be designated as a secure landfill, should choose and condition the wastes properly so that their properties will either not change or will improve with time.

SAQ 6.7

Co-disposal in a landfill is the controlled induction of hazardous waste into municipal solid waste landfill. The danger of hazardous waste is reduced by diluting it with municipal solid waste and taking advantages of attenuation mechanisms. Waste compatability is the major factor to be considered for co-disposal. Detailed studies should be carried out to ensure that any undesirable product is not formed due to interaction between municipal solid waste and hazardous wastes. It is also necessary to fix an optimum municipal solid wastes and hazardous waste ratio which is allowable in codisposal process and does not cause any adverse effect on the environment.

Major limitation of the process are

i) The biodegradation of municipal solid waste is affected due to presence of toxic compounds in hazardous waste.

ii) The presence of toxic substance in the leachate to a higher degree than that observed during disposal of municipal solid waste alone

iii) A lot of pre-studies are needed before implementation

SAQ 6.8

i) Brine sludge from mercury cell from chlorine production unit.
ii) Bamboo dust from paper mills.
iii) Cyanide wastes from heat treatment process.
iv) Wastes from fish canning plant.
v) Chromium sludges from tanneries.
vi) Debris from construction works.
vii) Coconut pith from coconut processing industries.
viii) Spent solvent from paint industries
ix) Caustic sludge from oil refinery.
x) Rice husk
xi) Spent catalyst from petrochemical industries.
xii) Unused pesticides from farms.
xiii) Lead sludge from battery production unit.
xiv) Wheat straw
xv) Nickel waste from electroplating unit.
xvi) Acid batteries from vehicle maintenance shop.

SAQ 6.9

Arsenic, Barium, Cadmium, Chromium, Lead, Mercury, Selenium, silver.

SAQ 6.10

The term solidification/stabilisation is normally used to designate a technology that makes hazardous waste non-hazardous or acceptable for land disposal by mixing the waste with stabilizer. The waste may be treated to bind the toxic elements into a stable, insoluable form or to entrap the waste in solid crystalline matrix. The common stablizers used are fly ash, lime, cement.

SAQ 6.11

A typical secure landfill system consists of a series of adjacent cells. Each cell is constructed to provide permanent containment using a triple liner system which includes a reinforced polymer membrane between two layers of highly impermeable clay. Internal monitoring and collection wells are installed to collect rainfall and leachates. Completed cells are capped off with additional clay or clay and membrane combination, then top soil and grass. A gas venting system under the cap ties with the collection system. The leachate collected is monitored, removed and treated.

The types of membrane liners used in landfills are Butyl rubber, chlorinated polyethelene, chlorosulphonated polyethelene, Neoprene, Polyvinyl chloride, polyethelene etc.

SAQ 6.12

The method is based on the reduction of very hazardous Cr+6 to Cr+3, that can be precipitated as an almost insoluble hydroxide. The reaction can be accomplished by using sulphate or sulphite or hydroxide of iron. Cr+3 can be precipitated with calcium hydroxide as $Cr(OH)_3$ at pH = 8.5

SAQ 6.13

Explosives : Trinitrotoluene, fireworks
Flammable liquids : Ethyl Alcohol, gasolene
Flammable solids : Phosphorous, nitrocellulose
Flammable gases : Hydrogen, LPG
Oxidiser : Potassium bromate, Hydrogen peroxide
Organic peroxide : Benzoyl peroxide
Poisonous waste : Potassium cyanide, phenols
Infectious substance : Hospital wastes
Corrosive substances : Sulphuric acid, hydrochloric acid
Toxic substance : Pesticides, wastes containing heavy metals