PhD PROPOSAL
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First Draft

Enhancing the performance of small-scale water supply systems: *solar distillation and fog harvesting units*

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Summary

Arid lands are characterised by inherent water scarcity which is often aggravated by human-induced stress[1] (Alexanda, 1985; Shanyengana, 1997; Whitehead *et al.*, 1992). However, alternative water sources such as sea water, saline groundwater, fog and dew do exist (Cereceda et al., 1996; Nel, 1995; Olivier 1995 and Seely, 1992) and, even though these water sources are currently used, most of the water supply systems used are often inefficient and/or too sophisticated and expensive to be implemented within and by rural communities in arid lands of the southern hemisphere (DWA, 1973; Kalbermatten et al., 1980; Nel, 1995).

Despite some success with expensive desalination techniques (ref), cheap and small-scale water desalination, based on solar distillation has till today proved unsatisfatory owing to low yields (DWA, 1973). Meanwhile, despite numerous fog and fog harvesting studies (see fog bibliography in the appendix) still little is known of the physical, chemical and electrical interactions at molecular levels, between harvesting surfaces and fog water droplets (Schemenauer, 1989).

Thus, there is a need to study these water harvesting systems and better understand the processes involved in order to enhance system performance and efficiency. There is even more urgent need to adapt these systems in order to allow for their implementation by and within the most needy poor rural communities in Arid lands.

***Keywords**: appropriate technology; chemistry; desalination; fog harvesting; saline water*

1 Rationale

Arid lands have severe water shortage. The water shortage varies from a quantity to a quality one, dependent on where and who is affected. For instance, despite the availability of sufficient groundwater reserves in north-central Namibia, the high water salinity often constrains the availability of drinkable water. In oil-rich countries such as in the Middle East, such problems are addressed through expensive desalination schemes, an option that is not available to often much poorer communities in arid lands, particularly in north-central Namibia.

In west coast desert areas mean annual fog precipitation often exceeds mean annual rainfall and presents a more predictable and, reliable, if efficiently harvested, source of freshwater. Even more plentiful is sea water, which, however, needs to be desalinated and is commonly limited to coastal urban settlements due to the high cost associated with desalinated water and the cost of transporting it over often increasing elevation from the coast towards the mainland.

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[1] Water stress: water scarcity resulting mainly from human factors such as overpopulation

Cheap and small-scale water desalination and fog harvesting units are currently used in some desert areas. However, a lot of the designs prove unsatisfactory due to low efficiencies and yields. If properly enhanced, these techniques could improve water availability to arid lands, particularly poorer rural areas in the southern hemisphere. In addition, the above-mentioned water sources hold immense potential in lessening the impacts droughts, which occur so regularly.

2 Introduction

Water is one of the scarcest limiting natural resources in arid lands. These areas are characterised by a water deficit (annual potential evaporation exceeds annual rainfall), often accompanied by human-induced water stress (Shanyengana, 1997; Whitehead *et al.*, 1992). Surface water resources are ephemeral and restrictive, and where available, usable groundwater is confined to ephemeral water courses and it is often connate and exhibits high concentrations of total dissolved solids {DWA, 1990; D.W.A.(GIEO), 1991; DWA (ISWRO), 1991; GCS, 1992; Molebatsi, 1994; Jacobson *et al.*, 1995; Shanyengana, 1997}

However, sea water, fog and dew are plentiful in west coast desert areas such as the Namib, Baja California and the South American deserts (Amiran & Wilson, 1973). Indeed, in all these deserts fog occurs more regularly than rain and, annual fog precipitation exceeds annual rainfall (schemennauer, 1992;.Nel, 1985 and Weather Bureau, 1959). In areas where ephemeral watercourses exist, such as in the semi-arid areas of north-central Namibia, formerly Owambo, groundwater is plentiful, at times less than a metre below the ground surface {DWA (GIEO), 1991; GCS, 1992}. Such groundwater is, however, saline and requires treatment prior to human consumption.

Arid lands present environmental opportunities, such as high solar radiation and wind, that can be used to harvest and tap the above-mentioned water resources. To date, systems based on these opportunities, for instance solar-based desalination and fog harvesting screens have received little, if any, attention owing to their low efficiencies (DWA, 1973; Nel, 1995). It is thus imperative that such systems are enhanced, and most importantly made affordable and manageable by the mostly "poor" and rural communities in arid lands of the southern hemisphere.

If properly understood, tapped and harvested, the above-mentioned water sources could help provide water to arid lands, in particular, settlements within the Namib desert and north-central Namibia.

3 Background

3.1 Study areas

The study areas are the Namib desert and north-central Namibia. Field data collection and experimentation within the Namib desert will be conducted at Gobabeb and Swakopmund, while in north-central Namibia it will be conducted at the Okashana Rossing Training Centre, in the Oshikoto region (Political region). Since fog does not occur in north-central Namibia, only solar-based desalination related studies will be conducted at the proposed site.

Gobabeb is an arid lands research station located close to several rural communities living within the Namib Desert. The site in north-central Namibia is a conference and training facility and is equally located close to rural communities in the area. North-central Namibia makes-up more than half of Namibia's total population and, more than 70% of the areas poppulation leads a rural subsistence lifestyle.

3.2 Location

The Namib Desert is a foggy, west coast desert. It extends for about 2000 Km from the Olifants river in the Cape province, South Africa, to approximately the Carunjamba river in Southern Angola, bounded by the South Atlantic Ocean to the west and the Great Escarpment in the east at about 140 Km inland (Seely and Ward, 1988). Both study sites are within the central Namib. Swakopmund is located on the coast while Gobabeb is approximately 60 Km inland, just at the edge of the fog belt.

North-central Namibia, formerly Owambo, is the north-central-most part of Namibia, bordering Angola. The area constitutes four political regions namely: Oshikoto, Ohanguena, Oshana and Omusati. The study area falls within the Oshikoto region.

3.3 Relevant Climatology

3.3.1 Central Namib

The central Namib is a hyper-arid zone. Fog is a characteristic feature, more common than rain, occurring mostly in winter at the coast and during the later half of the year further inland. Annual fog precipitation exceeds the annual rainfall by about 7 times (i.e., 130 / 18 mm) at the coast, at Swakopmund, and by about 2 times (i.e., 37 / 21 mm) about 60 km inland, at Gobabeb (Lancaster et al., 1984 and Weather Bureau, 1959). Rainfall is low, seasonal and highly variable in time and space, with an overall average standard deviation from the long term mean of about 80% for the central Namib and, about 123% at Gobabeb (Henschel, pers. Comm., 1997). Below, table 1 provides a summary of several climatic parameters recorded at Gobabeb from 1962 to 1996.

PARAMETER	AVERAGE	RANGE	SUMMER	WINTER
Annual Rainfall	20.8 mm	2.0 - 115.1 mm	77%	23%
Annual Fog Precipitation	36.8 mm	11.1 - 77.0 mm	41%	59%

Fog Days/Year	37	-	47%	53%
Temperature	21.1 °C	1.0 - 42.8 °C	23.1 °C	19.2 °C
Daily Temperature Range	17.0 °C	4.0 - 30.0 °C	16.4 °C	17.1 °C
Daily Sunshine Hours	10.4 h	-	11.2 h	9.5 h
Daily Solar Radiation	19.2 $MJ.m^{-2}$	-	23.6 $MJ.m^{-2}$	13.8 $MJ.m^{-2}$
Humidity	50%	1 - 100%	55%	44%
Annual Evaporation (pan-evaporimeter)	4631 mm	-	49.6%	50.4%
Avg. Hourly Wind Speed	2.9 m/s	0 - 17 m/s	3.0 m/s	2.8 m/s
Daily Occurrence of Wind Speed > 4 m/s	5.9 h/day	0 - 24 h/day	6.3 h/day	5.5 h/day
Major Wind Direction			SW	NE

Table 1: Summary of climatic parameters measured at Gobabeb, 1962 - 1996.

3.3.2 North-central Namibia

North-central Namibia is mainly semi-arid. A warm steppe region, Bshgw[2], according to the Köppen classification (MWPO, 1990). Mean annual rainfall ranges from 300 mm in the west to about 550 mm in the north-east. However, the rainfall is erratic and exhibits high spatial and temporal variability with deviation from the annual mean of between 30 to 50% (DWA, 1990). Mean annual potential evaporation is about 2,600 mm and, the yearly water balance indicates a water deficit in eleven out of twelve months. Mean annual temperature amounts to 23 °C, ranging between 5 °C in winter to 35 °C during summer (DWA, 1991). Strong winds are rare. However, reasonably windy conditions are registered before and during thunderstorms, and around August to September.

3.4 Water resources

In the Central Namib, usable water resources are limited to highly ephemeral surface water sources, westward-flowing ephemeral rivers, and alluvial aquifers within the river channels. Surface water is short-lived and, groundwater is minimal and, often, very saline.

In North-central Namibia, surface water is equally ephemeral found mainly in ephemeral shallow river channels locally known as oshana (s). Surface dams exist, however, they are often limited to depths of not more than 5 metres below the ground surface due to the presence of saline groundwaters beyond. Groundwater is often plentiful. It is however, very saline and exhibits increased salinity further into the dry period.

3.2 Appropriate technology and the DRFN

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[2] B = Dry region with rainfall deficiency; s = Steppe or semi-desert; h = Annual mean temperature above 18°; g = Month with maximum temperature in early summer; w = Summer rainfall

The DRFN is a privately-funded research, training and environmental education institution. The DRFN commits itself to *creating and furthering awareness and understanding of natural resources and arid environments....and developing the capacity, skills and knowledge to manage them appropriately".* The DRFN and the Ministry of Environment and Tourism (MET) have shared an arid lands' research centre in the Namib desert, Gobabeb, for more than 30 years.

Both parties are currently working towards remodeling the center into a training and research centre which will mainly serve training and research activities pertaining to the environment within Namibia and the SADC region.

The centre is further envisaged to be a model for the sustainable use of natural resources, conducting research, demonstrations and promoting appropriate technologies suitable for arid lands. Appropriate technology for arid lands is here defined as: *technology that is essential, affordable, of low maintenance, and furthers the sustainable use and management of resources and opportunities in arid lands with due consideration of the local environmental, social, economic and political settings- conditions and values* (Shanyengana, in press).

Otherwise, tools that are requisite, unsophisticated, affordable and of low maintenance, not necessarily cheap, small scale and less efficient. Such tools should make use of local manpower and skills and, combine indigenous knowledge, science and the local environmental opportunities through effective, efficient and sustainable use of locally available resources. The DRFN's programme on appropriate technologies is coordinated by Mr. Shanyengana, the PhD candidate.

4 The Study

4.1 Theoretical background

4.1.1 Fog harvesting

4.1.1.2 plants and animals

Fog, particularly in west coast deserts where it occurs, serves as an important sources of moisture for a number of life forms { Marloth, 1910; Rundel, 1976 & 1978; Seely, 1977, 78, 79 (1 & 2) and 81; Louw & Seely 1980; Mooney *et al.*, 1980; Anon, 1981; Lange *et al.*, 1994; Gioda *et al.*, 1995; and others (see selected literature)}. In the Namib desert fog contributes twice as much moisture as rainfall with a third of the variability (Pietruszka & Seely, 1985; Robinson & Seely, 1980). This has lead to the evolution of endemic life forms which use fog as a source of moisture {Hamilton & Seely 1976 (1 & 2)}.

Some of the best known animal adaptations to harnessing fog water are found in the tenebrionid beetles of the Namib desert dunes (Seely, 1992). The 'head standing' and 'fog basking' beetle *Onymacris unguicularis*, and others such as *Onymacris bicolor* collect fog on their backs and allow it to run down to their mouths. These beetles are observed to take-up an amount of fog water equivalent to at least 40% of their original body weight, within a single morning fog incidence (Seely & Hamilton, 1976; Seely, 1992). Beetles of the genus *Lepidochora* construct narrow trenches, fog traps, on the sand surface in a direction perpendicular to the fog-bearing wind. Other species such as the *Palmatogecko rangei* and the side-winding snake, *Bitis peringueyi*, collect fog water on their bodies and use their tongues to drink it off.

Plants are also known to intercept fog and absorb moisture from the atmosphere (Stone, 1957; Baladon, 1980; Gioda *et al.*, 1995; Price *et al.*, undated)In the Namib desert, plant species such as *Trianthema hereroensis, Arthraerua leubnitzia, Welwistchia mirabilis* absorb fog water through their leaves, *Stipagrostis sabulicola,* absorb it through the roots and, others through their stems (Bornman *et al.*, 1972; Seely 1992;). Some lichens, particularly *Caloplaca* which occur as upright subfoliose morphotypes are also known to intercept fog (Rundel, 1978) and, others absorb water vapour from unsaturated air.

Several studies, particularly in the Namib desert, have investigated the use of fog by plants and animals. Often, such studies looked at identifying the different fog-using species and estimating amounts harnessed. To date, there has been little, if any attempts to study the physical and chemical properties of fog and dew collection surfaces in fog-using plants and animals and, their interactions with fog and dew droplets.

4.1.1.3 Fog collectors

Generally, varying fog collectors, for fog precipitation estimations or water supply, have been used since the turn of the century. For instance in South Africa reed bundles on top of a normal rain gauge have been used to estimate fog precipitation (Schemenauer and Cereceda, 1994). Similarly, wire and plastic meshes have and still are used in fog harvesting instruments: for fog precipitation measurements and water supply infrastructure (see selected literature).

However, of interest to this study are fog harvesting meshes. These fog collectors, ones used in the Atacama at the village of Chungungo, consist of a double flat rectangular net 12 m wide and 4 m high, suspended vertically 1 to 2 m above ground. The net is a triangular weave of flat fiber about 1 mm wide and 0.1 mm thick. The fiber is woven into a mesh with a pore size of about 1 cm (Schemenauer and Joe, 1989; Nel, 1995). Below, a fog-harvesting catchment with 50 screens provides on average 7200 litres of water per day to a village, Chungungo- Chile, of about 330 inhabitants (Schemenauer & Cereceda, 1992).

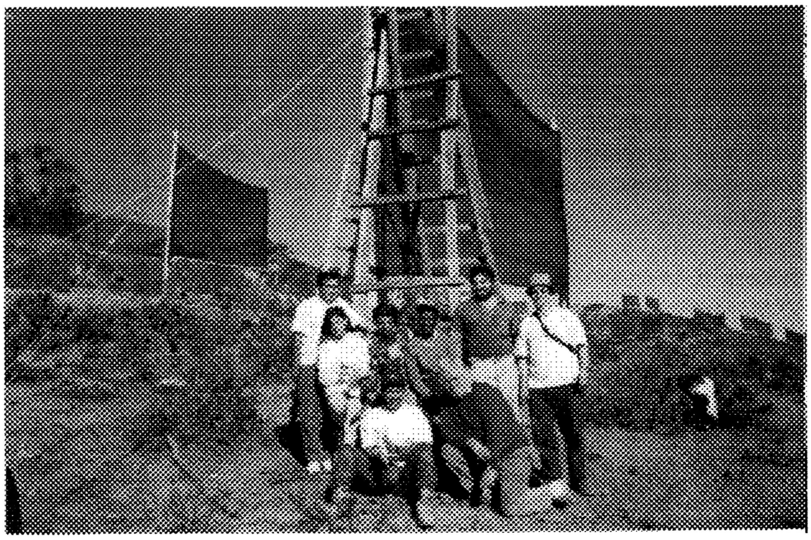

Figure 1: Fog collecting screens in Chile.

A simple and inexpensive Standard Fog Collector (SFC) was proposed by Schemenauer & Cereceda (1994) and is currently used for preliminary evaluation of fog harvesting potential, chemical deposition and other purposes in high elevation areas. As a standard tool, the SFC has added advantages of enabling data comparison in areas throughout the world, where it is in use. Generally, an SFC consists of a frame that measures 1.0 x 1.0 m inside, a double layer of coresa 35% shade coefficient polypropylene Raschel mesh and a specified collection trough. The frame itself is made of a 1 cm diameter metal (for rigidity) suspended 2 m above the ground. This study will use SFCs. All tests and experiments will be performed relative to the SFC design specifications in order to enable interpolation of findings to other areas.

Several studies have looked into some of the aspects that could influence the yield of fog collectors, for instance, terrain features such as elevation and physical features, wind speed, mesh and ribbon sizes and, fog water droplet size (e.g., Schemenauer *et al.*, 1987; Schemenauer & Joe, 1989; Schemenauer & Iwra, 1994; Schemenauer *et al.*, 1995 and others in selected literature). However, there is no evidence of studies that have investigated and/or attempted to use surface physical and chemical properties of fog harvesting plants and animals on man-made fog collectors.

4.1.1 Water desalination systems

Water desalination refers to the removal of salts and other solutes from saline waters such as brackish water and sea water, thus converting saline water to freshwater (Stanger, 1994). Several desalination techniques, mainly small-scale, have been used since the turn of the twentieth century, particularly in sea-going vessels. Currently, the most used technique is reverse osmosis. This technique involves forcing water through a semi-permeable membrane, against an osmotic gradient, leaving the solutes behind and delivering freshwater. The technique is, however, limited by the high power required to force water through a membrane against the osmotic gradient and is thus mainly practiced by oil-rich countries of the Middle East.

Water desalination by distillation, particularly sea water desalination is a common occurrence in nature's hydrological cycle. Using the sun's energy, open water bodies such as oceans, lakes, reservoirs and rivers lose water to the atmosphere through evaporation. The evaporating water leaves most salts and other solutes behind, resulting in desalination.

There are several distillation-based desalination techniques. Solar distillation is thought to have started in Chile's Atacama Desert in 1872 (NAS, 1982) though, some evidence suggests its origin to be much earlier, particularly in the far East. Typical solar-based desalination is carried out in solar stills, generally referred to as double tilted-roof solar distillation units.

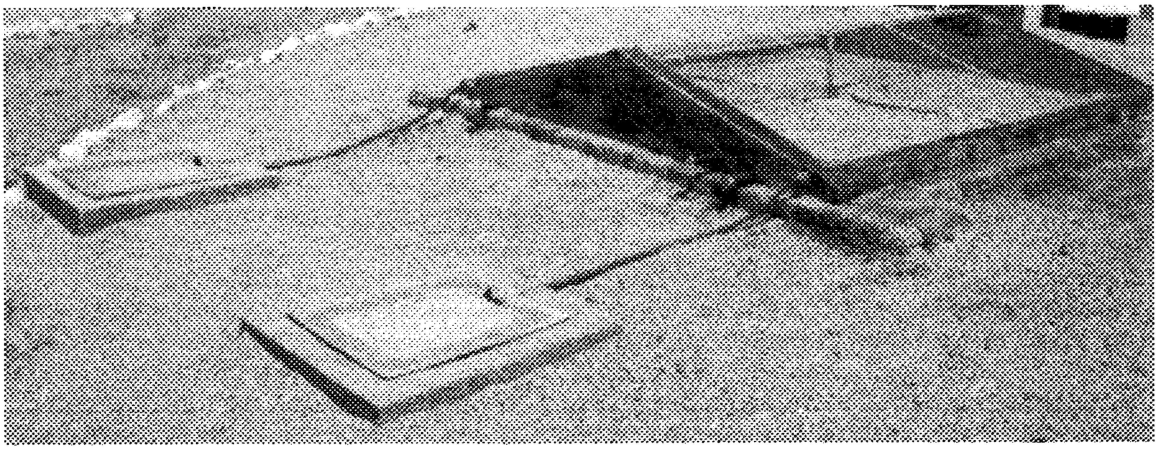

Figure 22: A simple double tilted-roof solar distillation unit

Generally, a solar distillation still consists of a shallow basin covered with a tilted glass roof. The saline water contained in the basin is evaporated by the solar radiation that passes through the glass cover; the vapour collects on the overlying glass cover and is collected and stored for use. The distilled water is free of salts and needs to be mixed with a fraction of saline water at a pre-determined ratio, prior to human consumption. Test experiments conducted in Namibia, (with an evaporation area of 4,95 m2; depth 25 mm; volume of brackish water in the basin 125 litres) indicated the following results:

Location	Maximum Litres / day	Minimum Litres / day
Windhoek	27	6
Aroab	27 +	6
Owambo	27 +	12 +
Möwe Bay (coast)	18 +	4
Rössing	27 +	7

Table 5: Results of solar distillation experiment in Namibia (source: DWA, 1973).

NB: The total construction cost of a single distillation unit was N$ 79,00., in 1973.

On the shores of the Red Sea near the Eritrean port of Massawa experiments to enhance the performance and yield of the simple solar still have been carried out (Economist, 1995). The enhanced solar-powered desalination plant yields enough freshwater to supply a small village. In essence, it is a shallow pool covered by a greenhouse, with a pipe leading to a solar-powered condenser. Polycarbonate plastic, rather than glass, is used for roofing the greenhouse. This transmits the light more effectively, and also insulates the greenhouse better than glass. Cotton cloths hung from washing lines across the pool dipping into the pool, in order to reduce reflection from the water surface, and also to soak up the water and increase the surface area available for evaporation. The inventor believes that a 14 x 14 metre structure would produce between 5,000 - 6,000 litres of distilled water a week.

4.2 The Proposed study

Fog and dew harvesting plants and animals display special physical adaptations to enhancing condensation and runoff on their collection surfaces, mainly leaves, stems and cuticles. Given the limiting nature of moisture availability in arid lands, such surfaces would have evolved towards perfecting moisture collection in the forms of fog, dew and other sources of atmospheric moisture. Indeed, millions of years, if not more, of adaptive evolution. Some such general surface physical properties are for instance: *spines*: that are known to condense and collect water in cacti; *striations* and/or *ridges*: on plant leaves, stems and back of some tenebrionids such as *O. unguicularis*. Adaptive evolution of other surface properties for instance, material physical (e.g., thermal) and chemical properties (e.g., hydrophobism and hydroplilism), roughness and/or smoothness and related angles are also suspect.

Indeed, both fog harvesting and solar distillation are underpinned by two major thermal processes namely; heat gain and heat loss or alternatively, evaporation and condensation. Fog harvesting requires an intercepting and preferably cold surface. In fog collectors, the which are almost always in the open, the collection surface should be able to avoid gaining heat and/or loss it rapidly and efficiently. Similarly such surfaces are required within a solar distillation still in order to collect the evaporated water within the solar still atmosphere. In contrast material that allows for rapid heat gain and storage is also required in the solar still basin in order to provide the energy required for evaporation.

This study is based on chemical and environmental engineering. The study will look into investigating major physical and chemical surface adaptations, features and properties, for water moisture harnessing in desert plants and animals. Such results will help to understand evolutionary adaptations to enhanced condensation and will be used to compare and, where appropriate, adjust current knowledge on thermodynamically 'ideal' condensation surfaces, features and properties such as proposed by Beysen et al., 199X.

The results will further provide ideal design considerations for enhancing the performance of man-made fog harvesting surfaces and solar distillation-based desalination.

4.3 Aims and objectives

The study aims to:

- identify and understand general physical and chemical surface adaptations, features and properties, for water moisture harnessing in desert plants and animals with a view of understanding evolutionary adaptations to enhanced condensation;
- to compare and, where appropriate, refine our current understanding of thermodynamically 'ideal' condensation surfaces;
- understand the physical and chemical processes and interactions between condensation surfaces and water droplets in order to enhance the performance of fog collectors and condensation within solar-distillation-based desalination systems;

4.4 Key questions

- What physical and chemical properties, features, and ~~properties~~ components + processes, of surfaces and water droplets influence condensation on the surfaces of desert plants and animals;
- What chemical and physical properties of fog droplets and man-made collectors influence fog interception. What molecular surface processes and reactions at the collectors and droplets influence fog capture, and how can they be capitalised upon.
- Based on the above findings, what is an ideal, theoretical and conceptual, condensation surface and how does its yield; compared to thermodynamically 'ideal' condensation surfaces as proposed in literature today; and current man-made fog collection surfaces such as meshes;
- Within an enhanced solar distillation-based desalination unit, as the one proposed for Massawa, how and to what extent do the new adjustments enhance the performance and yield; what additional small-scale adjustable variables such as chemical and physical properties would result in significant enhancement of yields e.g., ideal condensers, concentration manipulations; boiling point depressants; colouration etc..

3.4 Methods

3.4.1 General

Select representative plants that collect fog and other forms of atmospheric moisture on their leaves and stems and, use field and laboratory experiments such as applying tritiated water to ascertain the moisture uptake through the suspect organs;
Select representative animals that collect fog and other forms of atmospheric moisture on their surfaces and perform field and laboratory experiments to ascertain up-take;
Identify visible and microscopic surface features of the animal and plant collection surfaces;
using electron micrography and chemical tests, identify physical and chemical properties of animal and plant collection surfaces, such as:

striations and ridges per unit area; degree of smoothness/roughness; angle of striations; material chemistry- hydrophobic/hydrophilic; charge;
use electron micrography to study water droplet interactions with the surfaces of the chosen plants, animals, and models of the plants and animals with their main adaptations removed from the surfaces, as well as typical non-fog collecting species; fog meshes and the 'ideal' grass-like condensers proposed in literature;

3.4.2 Solar-based desalination

Influential chemical and physical parameters, of fog droplets and screens, will be determined, and thermodynamic calculations performed in order to derive mathematical (thermodynamic) and conceptual models of an ideal solar still and "solar-based desalination plant".

An attempt will be made to test the effect of several adjustments, proposed from the study and general literature, to a normal double tilted-roof solar distillation still. Some such adjustments will involve:

- incorporation of "villi" of cold grass-like condensation surfaces and proposed ideal condensation surfaces, from the study;
- isolation of the distillation basin from the ground by insulation;
- increased heat transmission, absorption and retention in the basin by black lining, increased water density gradient and colouration;
- enhanced evaporation through boiling point depression and increased internal surface area for evaporation;

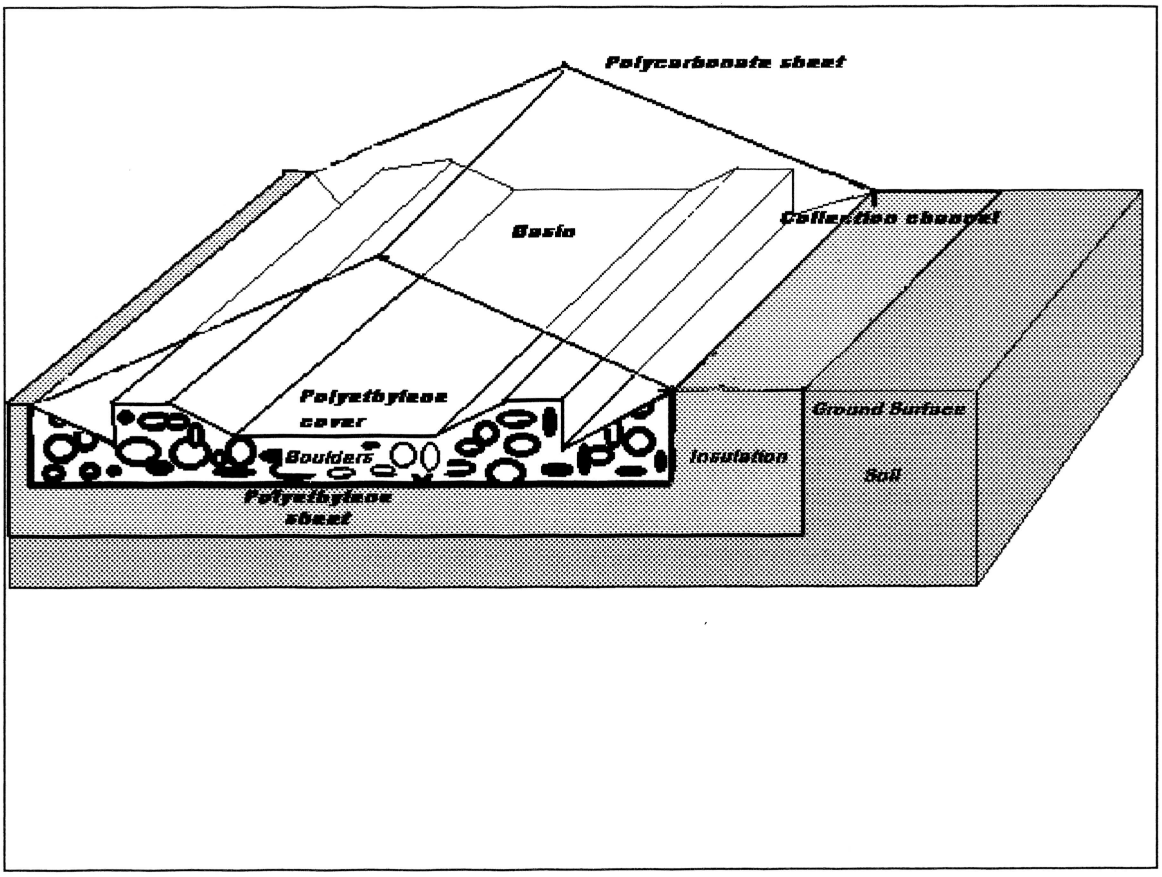

Figure 2: An explanatory design of the enhanced solar distillation unit

3.4.2 Fog harvesting

Predominant chemical and physical parameters relating to droplet formation, aggregation/nucleation and capture will be established, and collector designs and thermodynamic calculations performed in order to derive mathematical (thermodynamic) and conceptual models of an ideal fog collecting surface.

3.6 Relevance of study to development

The study will help to improve understanding of aspects related to solar-based desalination and fog collecting systems. This will in turn help to improve the performance and efficiency of the studied water systems. In general, such improved performance and efficiency will contribute towards water provision in arid lands. Where appropriate, increased use of fog water could also relieve pressure off groundwater resources, for instance in the Kuiseb river, Namib desert, and allow for ecosystems to function and provide essential ecological goods and services unimpeded. In short, the benefits of the study to development are *more water for arid lands* and reduced effects of drought, water sanitation-related sicknesses, increased support for development activities and many others.

The study will also fund and assist two counterpart students towards their **technical diploma** in water harvesting systems and **MSc** in **Chemistry** or related field. As such, the study would contribute to human capacity building in appropriate water technologies for Arid Lands.

4 Proposed budget

Some funding has been secured through the National Endowment Fund of Namibia in the president's office. Additional funding is still to be acquired to cater for the requirements of one technical diploma and B.Sc. Hons/MSc counterparts.

A more detailed budget proposal will be presented after consultations with the relevant institutions, supervisors and advisers.

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