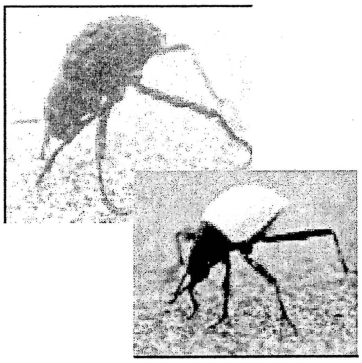
Drinking water from atmospheric moisture:
lessons from nature & prototype collectors in the Namib desert.



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Final results of a PhD study of fog collection in the Namib desert from 1998 to 2001 indicate that adaptations and climatic conditions in arid environments present opportunities that can be used to improve the efficiency of fog collection systems.

The scarcity of freshwater in arid environments makes this resource a primary limiting factor and 'environmental stress' of predominant importance in arid environments. Rainfall in hyper arid west coast deserts such as the Namib and Atacama approaches zero due to the aridifying influence of subtropical high-pressure cells and the adjoining cold ocean currents (1,2). These climatic features are also responsible for the high relative Humidity that predominates in these areas and as result, atmospheric moisture, particularly fog, is generally high along the west coast of continents such that its deposition and frequency generally exceeds that of rainfall (1,3).

It therefore follows that natural selection is expected to favour adaptations that optimise the collection of atmospheric moisture, and/or conservation of body moisture in organisms that inhabit these areas (4). Organisms that inhabit foggy coastal environments therefore engender morphological, behavioural and physiological adaptations to tap this additional water source (4-8).

Atmospheric moisture particularly Fog and dew are also in principle an alternative source of potable water for people living in these environments particularly in less-industrialised locations where it is of good drinking quality due to the low levels of atmospheric pollution (8-11). This study sought to contribute towards bettering the understanding of atmospheric moisture collection, and through this, to improve the efficiency of current collectors (5).

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The study investigates surface properties of two fog-basking beetles, *Onymacris unguicularis* and *Onymacris bicolor* and other non-fog basking relatives of the Namib Desert to see if they have adapted physical properties that can be used to increase fog collection in man-made collectors. These results would also serve to correct some of the earlier findings by Parker & Lawrence who reported fog collection features in a species that is not known for such behaviour (12). The study also used model passive and active atmospheric moisture collectors to investigate the feasibility of enhancing the efficiency of current fog collectors.

Fog collection was also done with 1 m^2 fog collectors made from a double layer of 35% Raschel mesh as used in fog collection schemes throughout the world, and with single strands of the same material that were grated to varying degrees in order to mimic the surface conditions that were found on the cuticles of fog basking beetles. The contact angles were determined with the Cahn Instruments' DCA-322. The passive collectors were constructed from a cooling system and an extractor, Figures 1 and 2 (**Supplemental data**). The cooling system is made from an ordinary refrigeration compressor and is able to cool the surface of the collector to about –2 °C. Measurements were conducted at varying relative humidity, and internal and external temperatures in order to determine the effect of these parameters on the rate of fog collection. The extractor-fan collector was designed to induce a maximum speed of about 10 ms^{-1} over the surface of the fog collector that is fixed at its terminus. This collector was aimed at mimicking fog collection in high elevations where fog collection is reported to be higher due to the high wind speed experienced in this type of areas.

The results indicate that it is possible to enhance the efficiency of the current fog collectors. The results of contact angle analyses in the fog basking beetles indicate that their un-wetted surfaces (advancing angle) are hydrophobic (≥90°) and as a result, they enhance the formation and runoff of large water droplets as opposed to film formation which occurs in the case of hydrophilic surface conditions (≤90°) as found in the non fog harvesting species, Figure 3 and **supplemental data**.

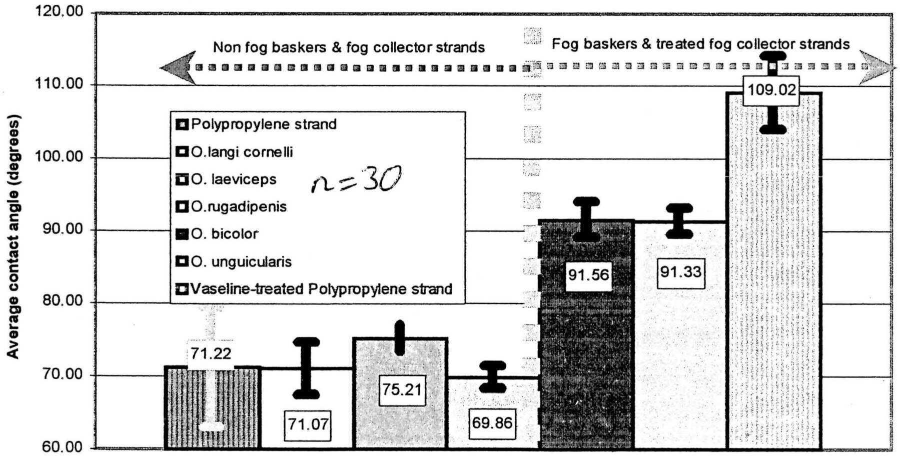

Figure 3. A graph showing the contact angles of cuticles of fog basking beetles and non fog basking relatives in the Namib desert as well as those of Vaseline-treated and un-treated polypropylene strands.

The high contact angle formed between the cuticle and the fog droplet increases the water repellence of the surface and thus, enables the droplet to roll freely to the beetle's mouthparts. Such a surface is not beneficial to the beetle during high wind speeds because most of the fog that is collected on the surface will be blown away, however, it is suitable in low altitudes such as the Namib desert where fog deposition generally occurs at low wind speed (2,3,13,14). Indeed, fog-basking beetles have previously been noted to cease fog-basking activities and burrow into the sand as soon as the wind speed increases (15).

These physical properties have direct applications to atmospheric collectors such as the Raschel mesh fog collectors. Analyses of the contact angles of polypropylene strands used in fog collectors indicate that these are less hydrophobic, Figure 3 and **supplemental data**. These fibres could be made more hydrophobic by polishing them with commercially available hydrophobic coats. Such alterations have been modelled to enable a three folds increase in fog collection, Figure 4.

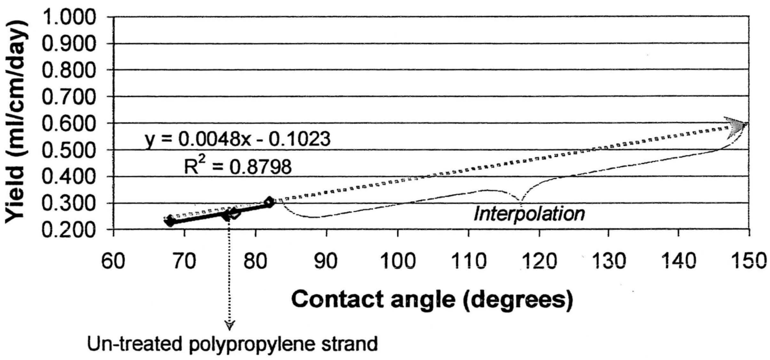

Figure 4. Results of fog collection with single strands of polypropylene with altered contact angles and the interpolation for fog collection at higher contact angles.

Experiments with the extractor-fan based collector also indicate that it is possible to increase fog collection in a Raschel mesh up to three fold. The relation of the amount of water collected and the wind speed can be summarised as follows; $Y = 115X + 266$ where Y is the amount of water collected (ml/m^2) and X is the wind speed (m/s). The increase in fog collection would depend on the speed induced by the extractor fan and therefore implies that an even higher increase in fog collection is possible. However, increasing the wind speed would also affect how much fog is forced through the collector and it might be beneficial to also increase the percent shade coefficient of the collector. That is, a higher percent shade coefficient (smaller openings) would accompany an increased wind speed.

The cooling system yields the same amount of water as the Raschel mesh of equal surface area during fog events (ca. 100% relative humidity), however, it still maintains up to 70% of this fog collection even when there is no fog, up to a relative Humidity of about 40%, Figures 5 & 6 (**Supplemental data**). Fog collection in this collector was noted to increase with relative humidity and the outdoors temperature, $Y(ml/m^2) = 1.24X + 14012$ and $Y = 17.15 + 1015.1$ respectively.

This is can be attributed to the cooled collector surface inducing a more pronounced thermal gradient than the non-cooled controls and other fog collectors that would then enhance condensation and collection of atmospheric moisture during warmer periods of fog deposition. These characteristics would make this collector more appropriate for hot-humid locations such as the Southern coasts of the Red Sea and the Persian Gulf.

In conclusion, the results indicate compelling evidence that it is possible to enhance collection of fog and general atmospheric moisture in water supply schemes as exist today in arid regions. For instance, that fog collection in the current Raschel mesh collectors can be increased by mimicking the surface properties of fog basking beetles- *making the collector surfaces more hydrophobic*. A combination of the extractor fan- and cooling system-based collector would also increase fog collection, enabling water production even during periods when there is no fog deposition. Larger collectors such as the 48 m^2 ones used in most fog collection schemes would require large and more expensive extractor fans and/or cooling units and could thus be uneconomical depending on how much fog they collect; and for what end-uses. However, much cheaper alternatives could also be considered, such as attaching a wind vane behind the collector or designing the collector to act as a wind tunnel. These types of systems could improve fog collection particularly in low altitudes where fog deposition and thus, its collection is often minimal. Indeed, further research into these systems stands to benefit many people in arid regions by improving their access to water and therefore, their quality of life.

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