Can Mimicking Nature Quench Our Thirst?

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Patterned polymer surfaces based on the African Stenocara beetle could be applied to our roofs to collect drinking water from the atmosphere.

Maintaining a stable supply of drinking water in Australia is a continual challenge. In 2006 the drought that gripped most of the Australian mainland was termed “the worst drought in 1000 years”, with the once-ferocious Murray River receiving only 5% of its average inflow.

Australia’s major cities have not been spared, with a recent report showing that Melbourne overdrew from its dam infrastructure by close to 400 billion litres during the past decade. Severe water restrictions have been placed on residents elsewhere along the eastern seaboard, including Brisbane and Sydney, with the very real fear that dams may run dry.

Unfortunately, there is very little infrastructure for water collection outside of the pre-existing dams that provide water for Australia’s major cities. Recently, much attention has been turned towards desalination of seawater, with the opening of the Kurnell desalination plant in southern Sydney in January this year. The plant, with construction costs at an estimated $1.9 billion, uses reverse osmosis to remove salt from seawater and can potentially provide 15% of Sydney’s drinking water.

Sydney Water is also in the process of building wastewater recycling plants for non-drinking purposes, with the goal of recycling 70 gigalitres of water per year by 2015.

However, these methods are energy-intensive, and critics of desalination cite...
the potential for increased environmental impact. There is also the significant issue of water wastage through evaporation from pre-existing bodies of water, meaning that valuable drinking water is simply lost to the atmosphere.

According to the 2001 national census, more than 85% of the Australian population lives within 50 km of the coastline. Weather conditions close to the coastline are typically characterised by higher relative humidities than those of inland cities, and cooling sea breezes.

These conditions provide a unique opportunity. The atmosphere near the coast contains a significant volume of water in the form of fog, ocean spray and high humidity, and this water is locally accessible to a large fraction of the Australian population.

While it sounds like the stuff of science fiction, could it be possible to collect drinking water from the atmosphere? The potential to harness the water that is all around us, as well as minimise water loss from our dams due to evaporation, would be a huge boon for industry and provide a cost-effective and localised method of water capture.

Amazingly, some of the secrets to capturing water from the atmosphere have been revealed to us in nature. One of the most stunning examples of turning atmospheric water into a source of drinking water is performed by *Stenocara*, which is also known as the Namib desert beetle. *Stenocara* is a native of the Namib Desert in southern Africa, which is home to one of the most arid climates on the planet.

With a dearth of groundwater, one of the few sources of moisture that exists in the Namib Desert is a prevailing fog that comes off the Atlantic Ocean each morning when temperatures are low. *Stenocara* has a unique mechanism to convert this atmospheric water – which exists in a fog of droplets 1–50 µm in size – into a viable drinking source. Its secret is an exoskeleton that promotes atmospheric condensation.

In a 2001 paper published in *Nature*, Andrew Parker and Chris Lawrence of The University of Oxford demonstrated that the *Stenocara* exoskeleton consists of a near-random array of bumps approximately 0.5–1.5 mm apart and 0.5 mm in diameter on top of a smooth and waxy background. The bumps were hydrophilic (water-loving) while the waxy background was particularly water-repellent.

When the beetle flies into the morning fog, moisture rapidly condenses on the bumps. Re-evaporation is minimal due the reduced surface area of bumps, so each droplet of water grows with continued condensation of water until it completely covers each hydrophilic bump. The water droplet then rolls down *Stenocara*’s exoskeleton and into its mouth, providing a continual source of drinking water. The success of this process is solely governed by the clever combination of surface chemistry and patterning.

The success of *Stenocara*’s ability to capture water from the atmosphere has led to a number of attempts from research groups to create synthetic surfaces that mimic this behaviour. These biomimetic surfaces require the development of sub-micron patterns where one part of the pattern is hydrophilic and the other component is water-repellent.

This technical challenge has meant that many attempts to create water-capturing surfaces involve complicated syntheses and specialised materials that do not lend themselves to large-scale manufacturing. As we are interested in ultimately creating large-scale surfaces that could, for example, be placed on roofs or walls to capture moisture from humid air, we have been investigating a procedure to create micro-patterned surfaces that are easy to create from cheap and readily available starting materials without compromising the efficiency of water collection.

To create materials that satisfy these requirements, we have tried creating micro-patterned surfaces using the dewetting of polymer films. Polymers are macromolecules that are typically inert and stable for long periods of time, and common polymers such as polystyrene are very cheap to manufacture. They can also be readily cast into polymer films from solution, allowing the preparation of polymer coatings on a variety of different surfaces. These coatings can be up to 10,000 times thinner than the width of a human hair. Polymer coatings can be applied by a variety of techniques such as spin coating, dip coating or even spraying, allowing for large-scale manufacturing and preparation.

To create micro-patterned surfaces that replicate *Stenocara*’s exoskeleton, we have exploited both the instability and immiscibility of polymer coatings. Unlike a mixture of different small molecules, polymers are so large that two different types (e.g. a
polystyrene and a polyester) will not stay mixed together but will instead separate into two different phases. This phenomenon allows two separate coatings to be applied on top of each other without them mixing together. This is known as a bilayer.

In our work we have prepared a variety of bilayers made from different polymers where the bottom layer is water-repellent while the top layer is significantly more hydrophilic.

When a polymer bilayer is heated to temperatures in excess of 150°C, the top layer spontaneously breaks apart into a series of isolated droplets. This behaviour is known as dewetting. This break-up of the top layer occurs in order to minimise the amount of surface points where the two polymers are in contact. Put simply, the two polymers do not like each other. At room temperature these patterns become “locked in” and provide a pattern that is similar to the surface of Stenocara, with hydrophilic spots on a water-repellent background.

The phenomenon of polymer film instability and the process of thin film dewetting are well-documented and understood at a fundamental level, but these concepts have never been previously exploited for an application such as capturing water.

An added advantage of this technique is the fine level of control that is possible by changing the starting conditions (e.g. the types of polymers used, their molecular weights and the thicknesses of the layers) and the experimental conditions (e.g. heating temperature and heating time). For example, the size and height of the dewetted droplets is related to the original thickness of the top layer, so in theory dewetted “bumps” can be made to any desirable shape and size.

For this technology to provide any advantage with respect to atmospheric water capture, it has to successfully capture more water from the air than what would be possible using currently available substrates. Many surfaces can condense water from humid air, especially when the surface is chilled – which explains the formation of dew in the early morning and condensation on the surface of a bottle taken from a refrigerator – but can we create surfaces that promote condensation, minimise evaporation and potentially do both under conditions that are less humid?

Our micropatterned surfaces, which are made from a modified polystyrene, provide a significant advantage because the size of the hydrophilic bumps where atmospheric moisture can condense are typically very small (~5 µm). The composite nature of our surfaces also helps condensed water droplets to detach from the surface, just like Stenocara.

Water droplets detach from our composite surface at half the volume required (~10 µL) for a smooth polymer coating made of only one polymer. These results can also be achieved at much lower humidities than the average humidity in major Australian coastal cities such as Sydney (where the average humidity ranges from 60–70% throughout the year).

To date we have prepared our surfaces on well-characterised substrates such as polished silicon, which is used in the electronics industry. The next step is to move from these conditions to those that will find use in the real world, and to create scalable surfaces to capture moisture from the atmosphere.

We envisage preparing our coatings on large sheets of plastic to make them lightweight and portable, enabling them to be set up on suburban roofs along the Australian coastline. If successful this technology could provide an alternative renewable source of drinking water that would require only the initial outlay of installing the coating instead of the time- and power-intensive methods currently being used.

If, sometime in the future, your next glass of water comes courtesy of the air around you, there is a little beetle in Africa that needs a great deal of thanks.

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