Quenching the world's water and energy crises, one tiny droplet at a time

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A beetle in the Namib Desert of Africa uses its textured back to gather drinking water from the fog-filled morning wind. If researchers can perform some beetle biomimicry, that would mean a new source for water in dry areas. Credit: James Anderson (CC BY-NC-SA 2.0)

In the Namib Desert of Africa, the fog-filled morning wind carries the drinking water for a beetle called the Stenocara.

Tiny droplets collect on the beetle's bumpy back. The areas between the bumps are covered in a waxy substance that makes them water-repellant, or hydrophobic (water-fearing). Water accumulates on the water-loving, or hydrophilic, bumps, forming droplets that eventually grow too big to stay put, then roll down the waxy surface.

The beetle slakes its thirst by tilting its back end up and sipping from the accumulated droplets that fall into its mouth. Incredibly, the beetle gathers enough water through this method to drink 12 percent of its body weight each day.

More than a decade ago, news of this creature's efficient water collection system inspired engineers to try and reproduce these surfaces in the lab.

Small-scale advances in fluid physics, materials engineering and nanoscience since that time have brought them close to succeeding.

These tiny developments, however, have the prospect to lead to macro-scale changes. Understanding how liquids interact with different materials can lead to more efficient, inexpensive processes and products, and might even lead to airplane wings impervious to ice and self-cleaning windows.

Beetle bumps in the lab

Using various methods to create intricately patterned surfaces, engineers can make materials that closely mimic the beetle's back.

"Ten years ago no one had the ability to pattern surfaces like this at the nanoscale," says Sumanta Acharya, a National Science Foundation (NSF) program director. "We observed naturally hydrophobic surfaces like the lotus leaf for decades. But even if we understood it, what could we do about it?"

What researchers have done is create surfaces that so excel at repelling or attracting water they've added a "super" at the front of their description: superhydrophobic or superhydrophilic.

Many superhydrophobic surfaces created by chemical coatings are already in the marketplace (water-repellant shoes! shirts! iPhones!).

However, many researchers focus on materials with physical elements that make them superhydrophobic.

These materials have micro or nano-sized pillars, poles or other structures that alter the angles at which water droplets contact their surface. These contact angles determine whether a water droplet beads up like a teeny crystal ball or relaxes a bit and rests on the surface like a spilled milkshake.

By varying the layout of these surfaces, researchers can now trap, direct and repulse small amounts of water for a variety of new purposes.

"We can now do things with fluids we only imagined before," says mechanical engineer Constantine Megaridis at the University of Illinois at Chicago. Megaridis and his team have two NSF grants from the Engineering Directorate's Division of Chemical, Bioengineering, Environmental and Transport Systems.

"The developments have enabled us to create devices—devices with the potential to help humanity—that do things much better than have ever been done before," he says.

Megaridis has used his beetle-inspired designs to put precise, textured patterns on inexpensive materials, making microfluidic circuits.

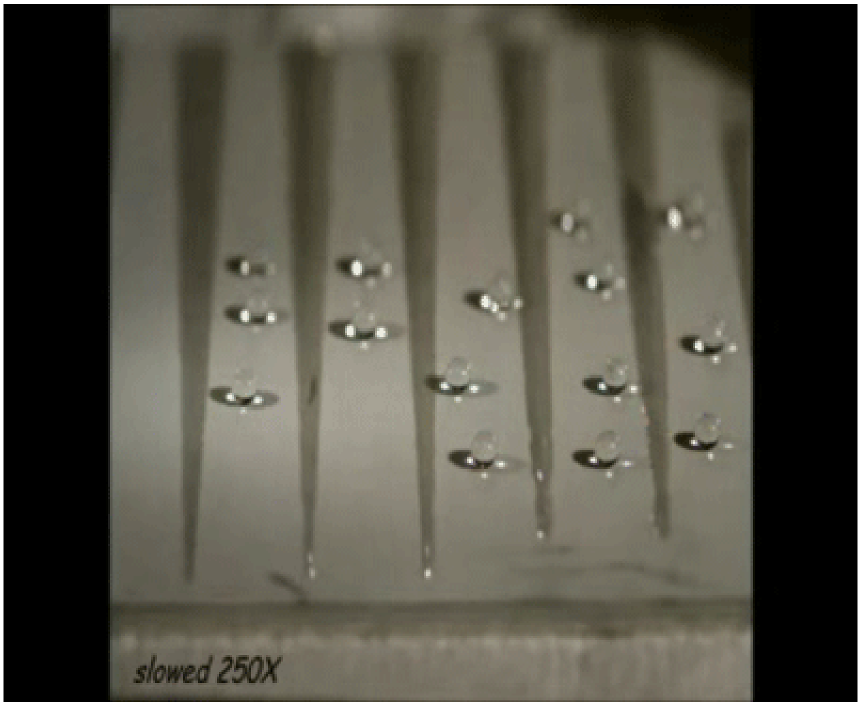
Plastic strips with superhydrophilic centers and superhydrophobic surroundings that combine or separate fluids have the potential to serve as platforms for diagnostic tests (watch "The ride of the water droplets").

"Imagine you want to bring drops of blood or water or any liquid to a certain location," Megaridis explains. "Just like a highway, the road is the strip for the liquid to travel down, and it ends up collecting in a fluid storage tank on the surface." The storage tank could hold a reactive agent. Medical personnel could use the disposable strips to field-test water samples for E. coli, for example.

Devices such as these—created in engineering labs—are now working their way to the marketplace.

Water, water in the air

NBD Nanotechnologies, a Boston-based company funded by NSF's Small Business Technology Transfer program, aims to scale up the durability and functionality of surface coatings for industrial use.



Superhydrophobic materials have micro or nano-sized pillars, poles or other structures that alter the angles at which water droplets contact their surface. These contact angles determine whether a water droplet beads up like a teeny crystal ball or relaxes a bit and rests on the surface like a spilled milkshake. By varying the layout of these surfaces, researchers can trap, direct and repulse small amounts of water for a variety of new purposes. Credit: Constantine M. Megaridis, Aritra Ghosh, Ranjan Ganguly, Mechanical and Industrial Engineering, University of Illinois at Chicago

One of the most impactful applications for superhydrophobic or hydrophobic research is improved condensation efficiency. When water vapor condenses to a liquid, it typically forms a film. That film is a barrier between the vapor and the surface, making it more difficult for other droplets to form. If that film can be prevented by whisking away droplets immediately after they condense—say, with a superhydrophobic surface—the rate of condensation increases.

Condensers are everywhere. They're in your refrigerator, car and air conditioner. More efficient condensation would let all this equipment function with less energy. Better efficiency is especially important in places where large-scale cooling is paramount, such as power plants.

"NBD makes more durable coatings that span large surface areas," says NBD Nanotechnologies senior scientist Sara Beaini. "Durability is an important factor, because when you're working on the micro level you depend on having a pristine surface structure. Any mechanical or chemical abrasion that distorts the surface structures can significantly reduce or eliminate the advantageous surface properties quickly."

NBD, which you might have guessed stands for Namib Beetle Design, has partnered with Megaridis and others to improve durability, the main challenge in commercializing superhydrophobic research. Power plant condensers with durable hydrophobic or superhydrophobic coatings could be more efficient. And with water and energy shortages looming, partnerships such as theirs that help to transfer this breakthrough from the lab to the outside world are increasingly valuable.

Other groups have applied hydrophobic patterning methods in clever ways.

Engineers look to nature to learn how to reduce the time it takes for a water droplet to bounce away from a surface. Lotus leaves, once considered the gold standard of superhydrophobic materials, are naturally water-repellant due to the tiny bumps on their surface. Photo taken at Meadowlark Botanical Gardens, Vienna, Va. Credit: Paloma E. Gonzalez

Kripa Varanasi, mechanical engineer at MIT and NSF CAREER awardee, has applied superhydrophobic coatings to metal, ceramics and glass, including the insides of ketchup bottles. Julie Crockett and Daniel Maynes at Brigham Young University developed extreme waterproofing by etching microscopic ridges or posts onto CD-sized wafers.

With all these cross-country efforts, many are optimistic for a future where people in dry areas can harvest fresh water from a morning wind, and lower their energy needs dramatically.

"If someone comes up with a really cheap solution, then applications are waiting," said Rajesh Mehta, NSF Small Business Innovation Research/Small Business Technology Transfer program director.

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