Sun-soaking device turns water into superheated steam

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Photograph of the outdoor experiment on the MIT roof. Steam generating device is mounted over a basin of water, placed on a small table, and partially surrounded by a simple, transparent solar concentrator. Researchers measured the temperature of the steam produced over the course of the test day, October 21, 2017. Credit: researchers, Thomas Cooper *et al.*

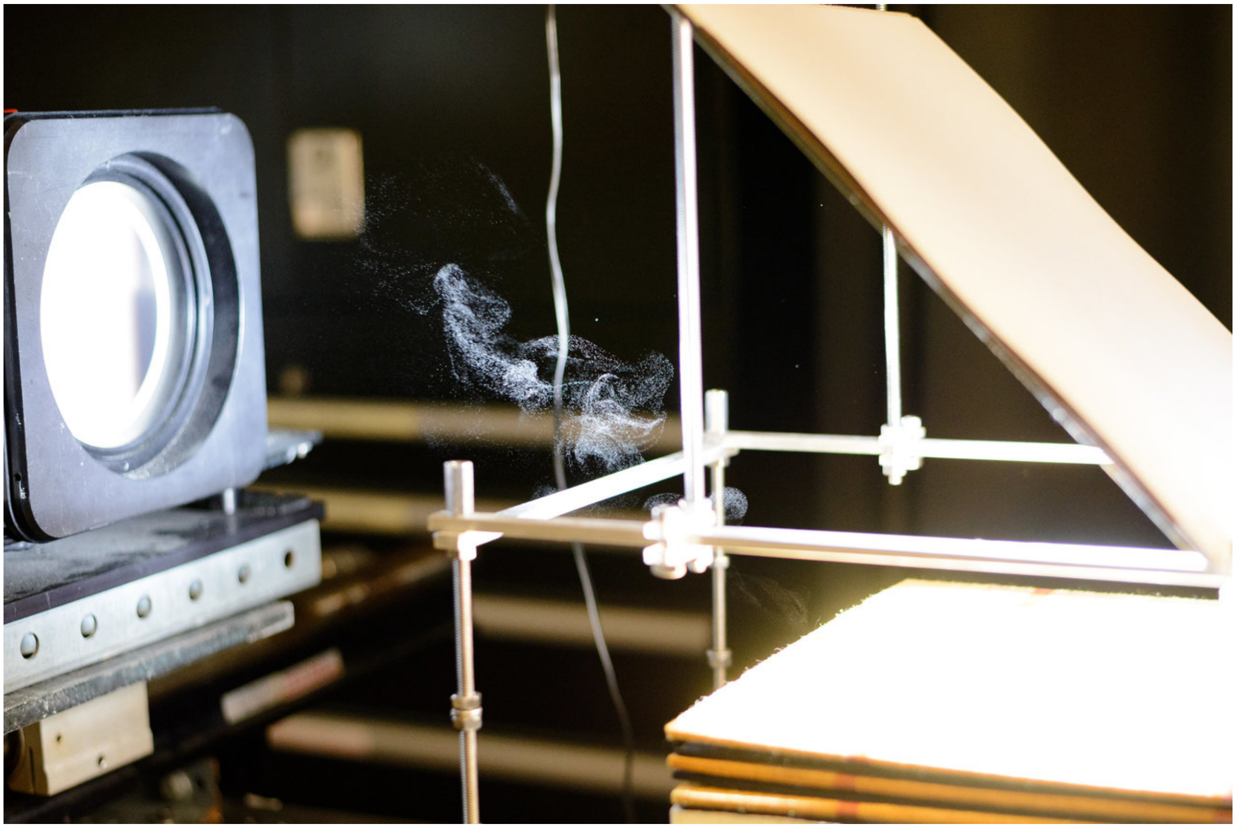
MIT engineers have built a device that soaks up enough heat from the sun to boil water and produce "superheated" steam hotter than 100 degrees Celsius, without any expensive optics.

On a sunny day, the structure can passively pump out steam hot enough to sterilize medical equipment, as well as to use in cooking and cleaning. The steam may also supply heat to industrial processes, or it could be collected and condensed to produce desalinated, distilled drinking water.

The researchers previously developed a sponge-like structure that floated in a container of water and turned the water it absorbed into steam. But a big concern is that contaminants in the water caused the structure to degrade over time. The new device is designed to be suspended over the water, to avoid any possible contamination.

The suspended device is about the size and thickness of a small digital tablet or e-reader, and is structured like a sandwich: The top layer is made from a material that efficiently absorbs the sun's heat, while the bottom layer efficiently emits that heat to the water below. Once the water reaches the boiling point (100 C), it releases steam that rises back up into the device, where it is funneled through the middle layer—a foam-like material that further heats the steam above the boiling point, before it's pumped out through a single tube.

"It's a completely passive system—you just leave it outside to absorb sunlight," says Thomas Cooper, assistant professor of mechanical engineering at York University, who led the work as a postdoc at MIT. "You could scale this up to something that could be used in remote climates to generate enough drinking water for a family, or sterilize equipment for one operating room."



Photograph of solar-generated vapour droplets rising through a beam of simulated sunlight during a laboratory experiment with the contactless solar evaporation structure. Credit: George W. Ni

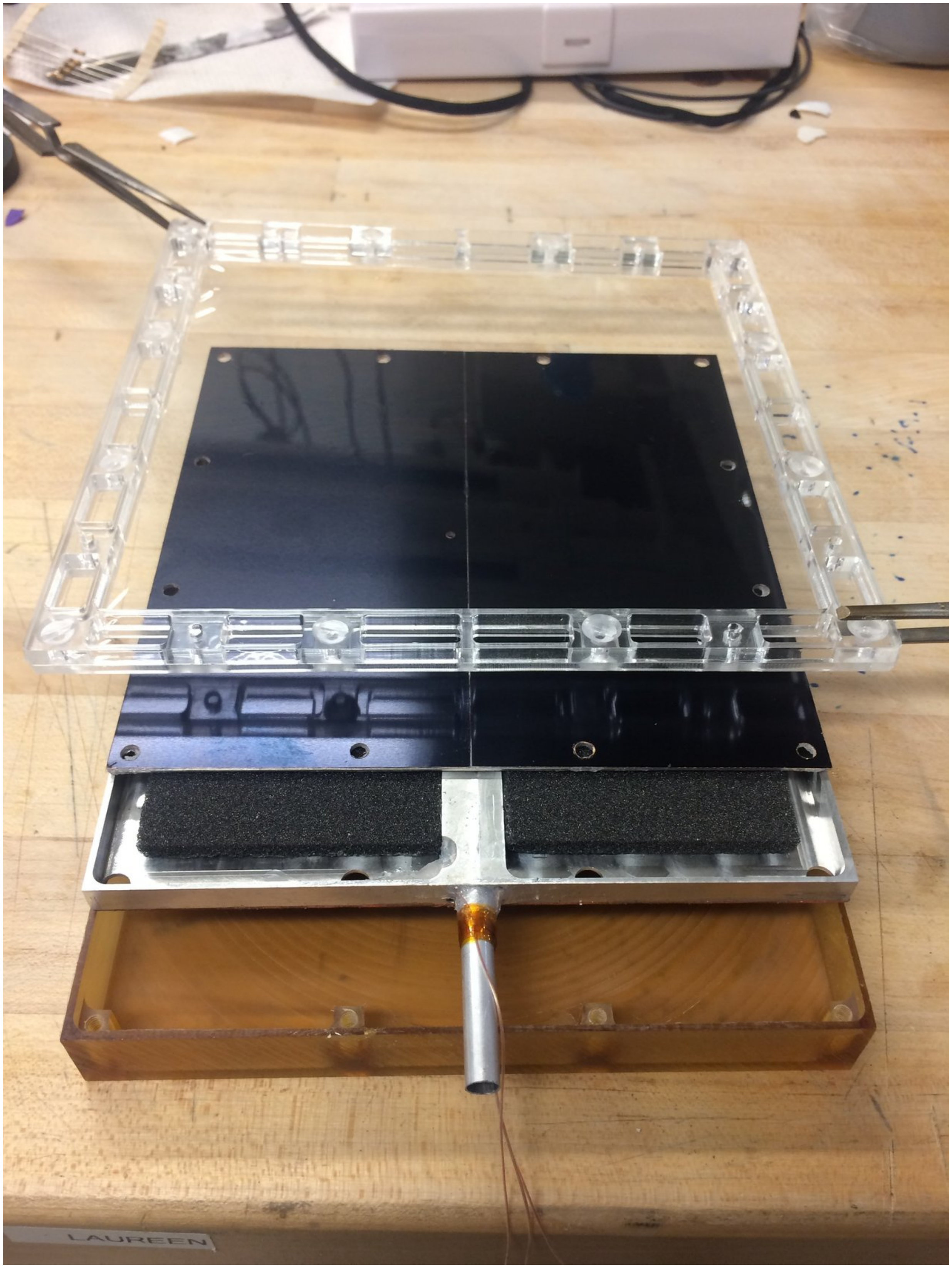
The team's results are detailed in a paper to be published in *Nature Communications*. The study includes researchers from the lab of Gang Chen, the Carl Richard Soderberg Professor of Power Engineering at MIT.

A clever combination

In 2014, Chen's group reported the first demonstration of a simple, solar-driven steam generator, in the form of a graphite-covered carbon foam that floats on water. This structure absorbs and localizes the sun's heat to the water's surface (the heat would otherwise penetrate down through the water). Since then, his group and others have looked to improve the efficiency of the design with materials of varying solar-absorbing properties. But almost every device has been designed to float directly on water, and they have all run into the problem of contamination, as their surfaces come into contact with salt and other impurities in water.

The team decided to design a device that instead is suspended above water. The device is structured to absorb short-wavelength solar energy, which in turn heats up the device, causing it to reradiate this heat, in the form of longer-wavelength infrared radiation, to the water below. Interestingly, the researchers note that infrared wavelengths are more readily absorbed by water, versus solar wavelengths, which would simply pass right through.

For the device's top layer, they chose a metal ceramic composite that is a highly efficient solar absorber. They coated the structure's bottom layer with a material that easily and efficiently emits infared heat. Between these two materials, they sandwiched a layer of reticulated carbon foam—essentially, a sponge-like material studded with winding tunnels and pores, which retains the sun's incoming heat and can further heat up the steam rising back up through the foam. The researchers also attached a small outlet tube to one end of the foam, through which all the steam can exit and be easily collected.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Photograph of the disassembled layered contactless solar evaporation structure showing (from bottom to top): water basin; superheater shell and reticulated vitreous carbon foam; selective surface; and transparent polymer glazing. Credit: Thomas A. Cooper

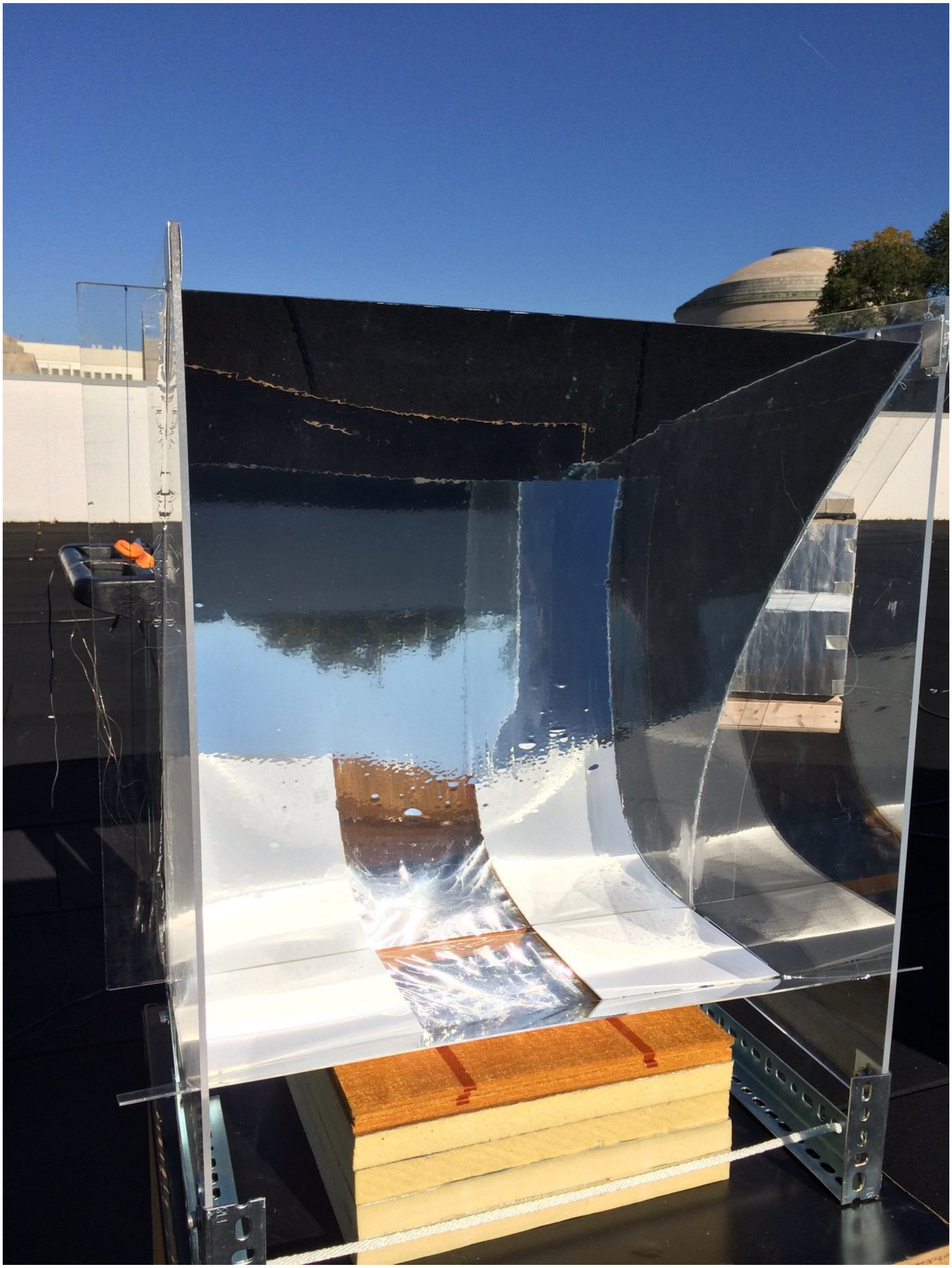
Finally, they placed the device over a basin of water and surrounded the entire setup with a polymer enclosure to prevent heat from escaping.

"It's this clever engineering of different materials and how they're arranged that allows us to achieve reasonably high efficiencies with this noncontact arrangement," Cooper says.

Full steam ahead

The researchers first tested the structure by running experiments in the lab, using a solar simulator that mimics the characteristics of natural sunlight at varying, controlled intensities. They found that the structure was able to heat a small basin of water to the boiling point and produce superheated steam, at 122 C, under conditions that simulated the sunlight produced on a clear, sunny day. When the researchers increased this solar intensity by 1.7 times, they found the device produced even hotter steam, at 144 C.

On Oct. 21, 2017, they tested the device on the roof of MIT's Building 1, under ambient conditions. The day was clear and bright, and to increase the sun's intensity further, the researchers constructed a simple solar concentrator—a curved mirror that helps to collect and redirect more sunlight onto the device, thus raising the incoming solar flux, similar to the way a magnifying glass can be used to concentrate a sun's beam to heat up a patch of pavement.



Photograph of the contactless solar evaporation structure operating on the roof of MIT in October 2017. A non-tracking solar concentrator allows steam temperatures as high as 146 °C to be achieved even in autumn months.

With this added shielding, the structure produced steam in excess of 146 C over the course of 3.5 hours. In subsequent experiments, the team was able to produce steam from sea water, without contaminating the surface of the device with salt crystals. In another set of experiments, they were also able to collect and condense the steam in a flask to produce pure, distilled water.

Chen says that, in addition to overcoming the challenges of contamination, the device's design enables steam to be collected at a single point, in a concentrated stream, whereas previous designs produced more dilute spray.

"This design really solves the fouling problem and the steam collection problem," Chen says. "Now we're looking to make this more efficient and improve the system. There are different opportunities, and we're looking at what are the best options to pursue."

More information: Thomas A. Cooper et al. Contactless steam generation and superheating under one sun illumination, *Nature Communications* (2018). DOI: 10.1038/s41467-018-07494-2

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