Hybrid device captures and stores solar thermal energy with high efficiency

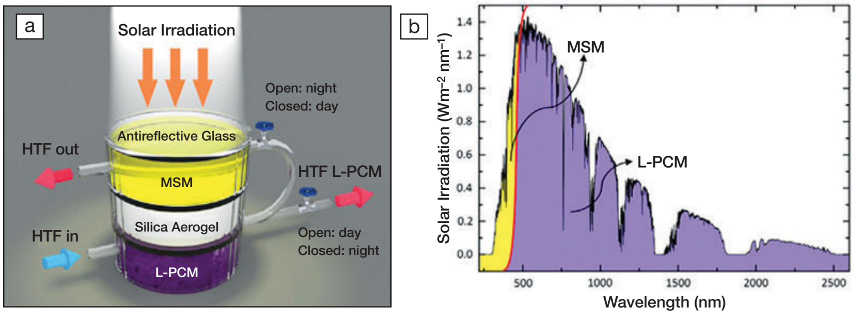
A new device harvests the sun's heat and stores it for use with far higher efficiency than any other known solar thermal energy technology. The device, reported in the journal *Joule* (doi:10.1016/j.joule.2019.11.001), combines a phase-change material (PCM), which absorbs and releases heat as it melts and freezes, with a novel molecular storage material (MSM) that changes its structure and stores energy within its molecular bonds.

While photovoltaics convert sunlight into electricity, solar thermal technologies tap the copious heat energy from the sun that falls on Earth. Solar thermal plants typically use large, costly mirror arrays to focus the solar heat onto molten salts that then store the heat; this can later be used to produce steam to spin generator turbines.

All solar thermal systems today have separate parts for harvesting and storing energy, says Hadi Ghasemi, a professor of mechanical engineering at the University of Houston. In addition, because the energy is stored as heat, he says, some of that heat is lost over time "so you lose some storage capacity." But the new system can harvest over the entire ultraviolet, visible, and infrared spectrum of sunlight and store it all in one device. "Also the stored energy is mostly in molecular form so there's no temporal loss," Ghasemi says.

Using their new device, the researchers can recover 80% of the solar energy that the device captures and stores. For other solar thermal systems, this efficiency typically reaches only between 20% and 30%.

The device contains three layers. At the bottom is the PCM, which is a compound of potassium nitrate, sodium nitrate, and lithium nitrate. Above that is a transparent silica aerogel layer, topped with a layer of the MSM norbornadiene-quadricyclane.



(a) This hybrid solar-energy capture-and-store device consists of a molecular storage material (MSM) and a phase-change material (L-PCM), separated by a silica aerogel. HTF is heat-transfer fluid. (b) Wavelengths of the solar spectrum captured by the MSM and L-PCM are shown. Credit: University of Houston.

The researchers infuse the PCM with carbonized rayon, a highly efficient heat absorber that creates local hot spots. During the day, the PCM layer absorbs sunlight and undergoes a solid-to-liquid phase transition, storing heat in the process. The MSM, meanwhile, absorbs UV radiation, which triggers the molecule's isomerization, a process that stores energy. "It causes a chemical transformation by which the molecule gets converted to a more highly strained molecule," says T. Randall Lee, a professor of chemistry and co-author of the article. "When it converts back to its original form you get energy out."

A heat-transfer fluid can funnel heat away from the PCM for use during the daytime. During night, the fluid transfers heat to the MSM, which helps it revert back to its low-strain form, releasing energy. In this way, the device can produce energy continuously. And because heat is harvested at night from both materials, the device efficiency is higher at night (80%) than during the day (73%), when the fluid only harvests heat from the PCM. By using different combinations of PCMs and MSMs, the efficiency could increase further, Ghasemi says.

The hybrid device is about 5 cm × 5 cm in size now but should be easy to scale up to any size, Ghasemi adds. And it could find uses other than power generation. It provides heat constantly above 100°C, which is important for water distillation, says Tengfei Luo, professor of aerospace and mechanical engineering at the University of Notre Dame, who was not involved in this study. "The materials cost and durability could be potential concerns," he says.

This is the first time that MSM has been combined with more traditional PCM-based storage, says Kasper Moth-Poulsen, professor of chemistry and chemical engineering at Chalmers University of Technology, who was not involved in this study. The MSM offers long-term storage with minimal losses and it does not need any insulation. The material could even be shipped elsewhere for use. However, MSM is still in early-stage development, Moth-Poulsen says, and "we still need to learn more about the cost and large-scale production."

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