Project

Materials for adsorber heat exchangers

From the 3D printer: more efficient materials for adsorption heat pumps

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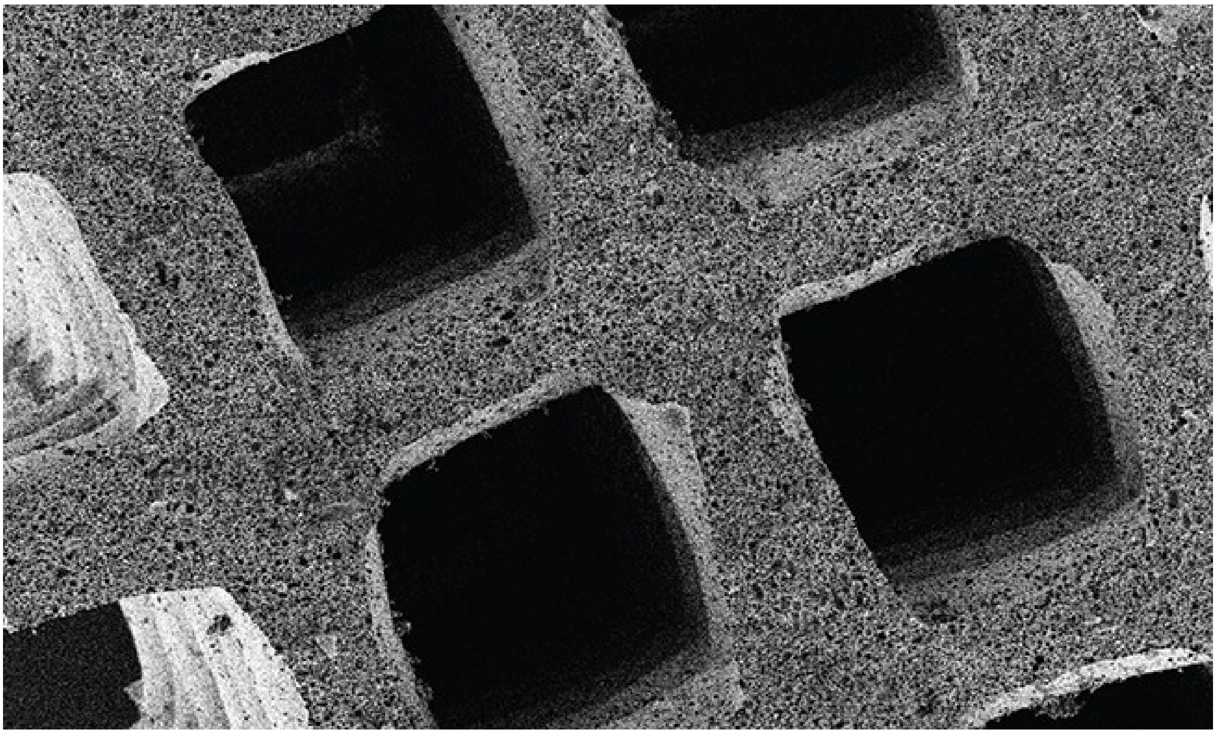
In future, waste heat from so-called adsorption heat pumps could be used much more systematically than before. Researchers from ETH Zurich, the Swiss Federal Laboratories for Materials Testing and Research (Empa) and IBM Research have now developed new material structures using a 3D printing process in order to use the core material of such systems much more efficiently.



Under the electron microscope, the fine structure of the sorption material, which was produced using 3D printing, becomes visible: the pores of different sizes make the material much more efficient. *Source:* ETH Zürich/Carla Minas

At a glance

- Until now, adsorption heat pumps have been inefficient and expensive. For this reason, researchers from ETH Zurich, the Swiss Federal Laboratories for Materials Testing and Research (Empa) and IBM Research have developed a new way of structuring the sorption material – the heart of such systems – more intelligently, thus making it more efficient.
- Among other things, the researchers use a specially developed experimental setup and a 3D printing process. This is because 3D printing allows microstructures to be introduced into the sorption material in a targeted manner. These microstructures influence how efficient the sorption material is.
- In this way, the research team created a structure that triples the efficiency of the sorption material.

Generating heat requires a great deal of energy: in Switzerland, we use half of our total energy consumption to warm our homes and offices, to heat our shower water and dishwater and to power industrial processes. The energy for this still primarily comes from fossil sources such as crude oil and natural gas. If we exclusively look at electricity consumption, 40 % of this is used for heating rooms or materials. This will have to change in future because Energy Strategy 2050 demands that CO_2 emissions be significantly reduced and that nuclear energy disappear as a source of electricity.

Ways of using heat more efficiently are therefore being sought. For example, by collecting and reusing waste heat more systematically than before. So-called adsorption heat pumps can help here. Similar to the compression heat pumps commonly used today, they can draw heat from the environment and enhance it. To this end, adsorption heat pumps require driving heat at temperatures of at least 35 to 60 degrees Celsius. Unlike conventional heat pumps, however, they consume almost no electricity. Such systems could, for example, use waste heat from factories, computer centres or heat energy from renewable sources such as thermal solar plants.

However, the systems have until now still been relatively inefficient and expensive. In particular, the sorption material used – the heart of an adsorption heat pump – determines how efficient the systems are. For this reason, a research team headed up by André R. Studart, a professor at the Materials Research Centre at ETH Zurich, has now developed a new way of producing such sorption materials – using a 3D printing process. “3D printing gives us far greater control over the microstructure of the material than is the case with conventional synthesis”, explains Studart. And it is precisely this microstructure that influences how efficient the sorption material is.

3D printing provides control

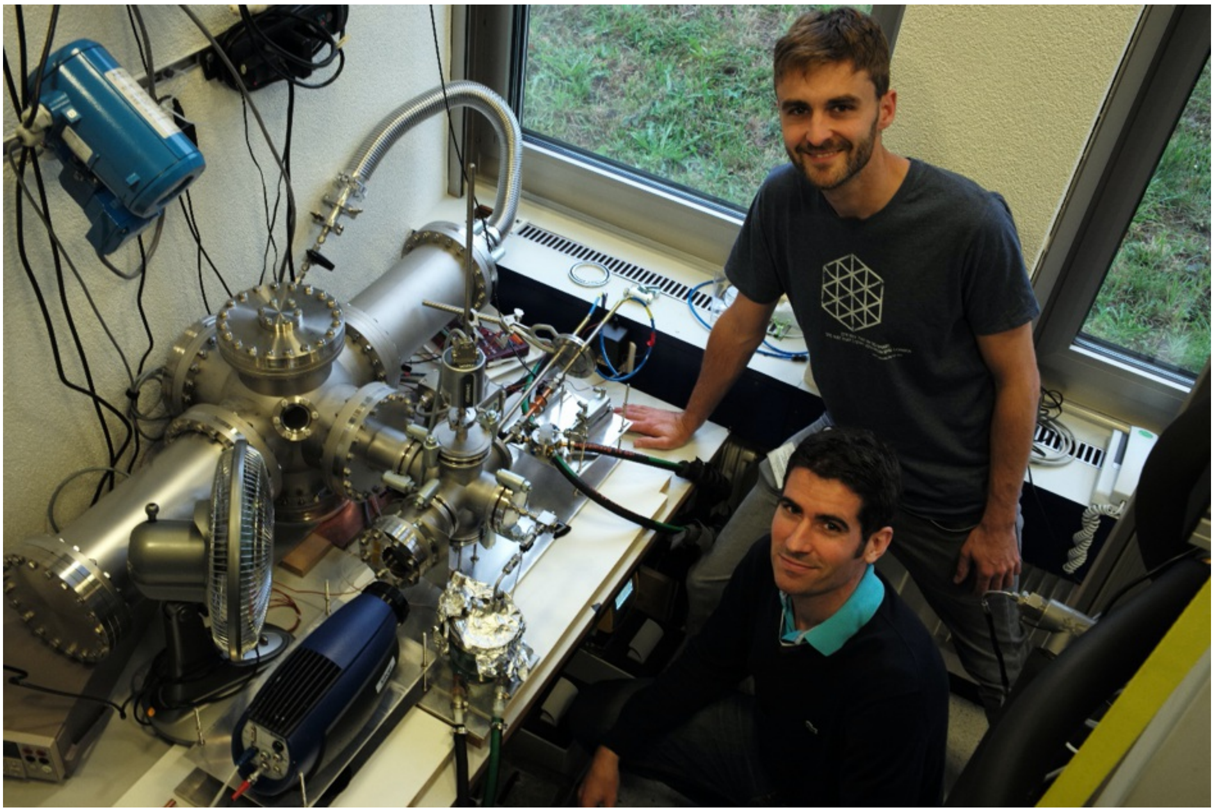
It works inside the adsorption heat pump as follows: the input heat is initially used to evaporate water. The steam is then fed into an adsorption heat exchanger where it is adsorbed and compressed by a sorption material. This process further heats the steam – the temperature increases. The system now needs some driving heat to release the hotter water vapour once more. In technical jargon, this is referred to as desorbing. Finally, the steam is condensed back into water and the heat gained from the adsorption and condensation processes can be fed into a heating circuit.

How quickly the sorption material works depends on the material's structure. This contains a multitude of pores which influence how quickly the material can absorb a certain amount of water vapour. The number, distribution and size of the pores are the decisive factors.

The right experimental setup

As the basis for their work, the ETH Zurich researchers chose a sorption material made of silicon aluminium phosphate called SAPO-34. This and other similar silicon-based materials are commercially available and are used, for example, as drying agents. A widespread version of this are silica gel bags, which are often found in the packaging of electronic appliances.

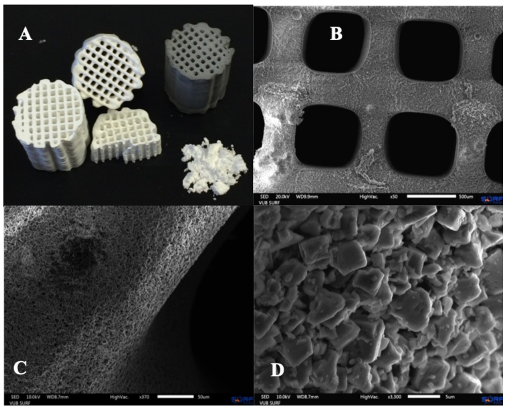
In order to investigate the base material SAPO-34 and later the further developed materials, the research team first designed a new experimental setup. The aim was to precisely analyse the absorption and release of the water vapour in order to determine which factors in the material influence the efficiency of the process. Adsorption and desorption are determined by two different physical processes: On the one hand, by mass transport. On the other, by heat transport. Mass transport refers to the diffusion of water molecules into the sorption material. Heat transport, in contrast, describes thermal conductivity, i.e. how quickly the material can supply and dissipate the heat converted during the sorption processes. With their new experimental setup, the researchers were now able to distinguish for the first time between mass transport and heat transport in the sorption material and determine which of the two phenomena limits the speed of the processes.



The researchers Jens Ammann and Patrick Ruch with the experimental setup with which they characterised the heat and mass transport in the sorption heat exchangers. IBM Research - Zürich

They use an infrared camera to measure the temperatures in the sorption material and on the surface of the heat exchanger. At the same time, they analysed the absorption and release of water vapour by recording the change in pressure. In this way, the researchers initially examined the basic material SAPO-34. The evaluation of the measurement results now showed that the heat transfer in the material is very efficient. However, this was not the case for the mass transfer: this slows down the entire adsorption-desorption process.

The right ink for printing



The 3D-printed sorption material: the electron microscope (images B to D) reveals the different microstructures. The larger pores (B) have a diameter of 650 micrometres, which is about two-thirds of a millimetre. In the largest magnification (D), the individual material crystals become visible. Couck et al. 2017

The researchers therefore focussed on improving mass transport. They did so by incorporating a specific pore structure into the material. Using 3D printing, they produced model structures of the material in order to investigate the influence of geometry on the adsorption rate.

The team tested various emulsions, including those containing a synthetic polymer and methyl cellulose – a chemical substance that is also used as wallpaper paste and makes the emulsions gel-like. Printed in 3D, the emulsions produced different porous materials which the researchers then investigated experimentally. Supported by computer simulations, the researchers finally found the optimal source material in this way: a kind of foam structure with directed channels that should quickly bring the water vapour quickly into the material. This was the idea anyway and it was confirmed by the measurement results: in the new sorption material, both mass transport and heat transport are significantly improved.

Practical application

The researchers then developed a process to incorporate these directed channel structures into the sorption material while applying it as a coating to a heat exchanger. This is an important step towards in future being able to use the material in adsorption heat pumps. Result: the coating material structured in this way demonstrated a power density three times higher than that of the previous unstructured variant. In other words, you need three times less material and heat exchanger surface in an adsorption heat pump to generate the same output, making the systems both more efficient and cheaper.

“This significant improvement in efficiency is likely to also make adsorption heat pumps much more financially attractive in future”, says Studart. He hopes that the systems will quickly spread throughout the country. This would have a major impact on CO_2 emissions, as a study by the joint project showed: even with the application in four specific tested scenarios, electricity consumption could be reduced by up to 9 % and CO_2 emissions by up to 5 %.

Produkte aus diesem Projekt

- 3D Printing of Emulsions and Foams into Hierarchical Porous Ceramics
  Date of publication: 16.09.16
- Quantification of heat and mass transport limitations in adsorption heat exchangers: Application to the silica gel/water working pair
  Date of publication: 20.12.19
- 3D-printed SAPO-34 monoliths for gas separation
  Date of publication: 01.01.18
- Insights from modeling dynamics of water sorption in spherical particles for adsorption heat pumps
  Date of publication: 20.12.19
- Characterization of transport limitations in SAPO-34 adsorbent coatings for adsorption heat pumps
  Date of publication: 20.12.19
- High-Power Adsorption Heat Pumps Using Magnetically Aligned Zeolite Structures
  Date of publication: 18.06.19
- Sorption rate enhancement in SAPO-34 zeolite by directed mass transfer channels
  Date of publication: 20.12.19

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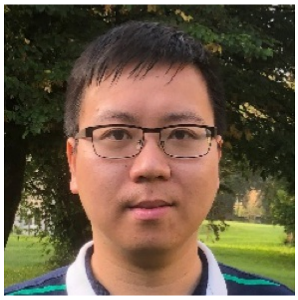

Xiaohai Zhou

All information provided on these pages corresponds to the status of knowledge as of 17.12.2018.