Project

Materials for adsorption heat pumps

A new material uses waste heat more efficiently

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At present, a lot of energy is lost in the form of heat, for example waste heat from factories or computer centres. This energy could be siphoned off and used with the help of so-called adsorption heat pumps. Until now, however, such systems have been inefficient and expensive. Researchers from the Swiss Federal Laboratories for Materials Testing and Research (Empa) have now developed a new material that makes adsorption heat pumps much more efficient.

For experiments in the laboratory: the thermohydraulic system simulates the functioning of an adsorption heat pump.
Source: HEIG-VD

At a glance

- The energy for the heating and cooling of buildings and industrial processes is still not used efficiently enough today: a large part of this energy is lost in the form of waste heat. This thermal energy could be used in future with adsorption heat pumps.
- In order to make such systems more efficient and cheaper, researchers at the Swiss Federal Laboratories for Materials Testing and Research (Empa) in Dübendorf have further developed carbon-based sorption materials – the sorption material is the heart of an adsorption heat pump.
- The new materials are two to three times more efficient than the substances that have been available until now.

Half of the energy consumed in Switzerland is used to produce heat. We use this to warm buildings, heat water for households or drive industrial processes. If we exclusively look at electricity consumption, some 40 % of this is used for heating and cooling.

Many heating processes now in turn release heat into the environment or generate new heat energy that can be made use of. At present, however, this resource still escapes into the air in many places. “We should make more systematic use of waste heat in future”, says Matthias Koebel, a materials researcher at Empa in Dübendorf. One possibility is to use so-called adsorption heat pumps. With such systems, waste heat from factories, computer centres or thermal solar plants, for example, could be collected and reused. However, the systems to date have still been relatively inefficient and expensive. Koebel and his team have now further developed the heart of such heat pumps – the sorption material – and made it more efficient. The work was performed as part of a sub-project of the joint project “Heat utilisation through sorption technology”, which aimed to make adsorption heat pumps marketable.

No electricity required

Like common heat pumps already used today, adsorption heat pumps can also extract heat from their surroundings and increase it. In contrast to conventional heat pumps, they require almost no electricity for this and instead use heat as a drive source. The process works from a temperature of 35 to 60 degrees Celsius. The heat is firstly used to evaporate a refrigerant – this is often water in adsorption heat pumps. The resulting water vapour is absorbed by a sorption material with a structure that resembles a nanoporous sponge. In the material, the steam is compressed and thereby heated further. If the absorption capacity of the material is exhausted, it has to be regenerated again – as part of this process, the now hotter, adsorbed water is expelled once more by adding some waste heat. The heat gained can be fed into a heating circuit.

Like conventional compression heat pumps, adsorption heat pumps can also be used for cooling. In cooling mode, the machine is then based on the cooling of the evaporating refrigerant. A typical system functions in such a way that the evaporator unit and the elements with the sorption material – the adsorber packages – are duplicated. During operation, one of the adsorber packages actively generates cold or heat, while the other one regenerates. After a few cycles, they are switched.

The efficiency of an adsorption heat pump is mainly determined by the sorption material used. Such materials are already offered by commercial manufacturers, for example as drying agents. A simple version of this are silica gel bags, which are often found in newly purchased bags or in the packaging of electronic appliances. Most sorption materials consist of such silica gel, i.e. they comprise amorphous silicon dioxide or activated carbon – porous, fine-grained carbon. There are also sorption materials made from organometallic compounds. However, these are much more expensive.

Comparison of sorption materials

In order to establish a benchmark for subsequent improvements, the researchers initially investigated a whole range of such commercially available substances. They analysed them in laboratory tests using four different scenarios for the future use of the heat pumps. Research colleagues had previously designed these application scenarios as part of another sub-project:

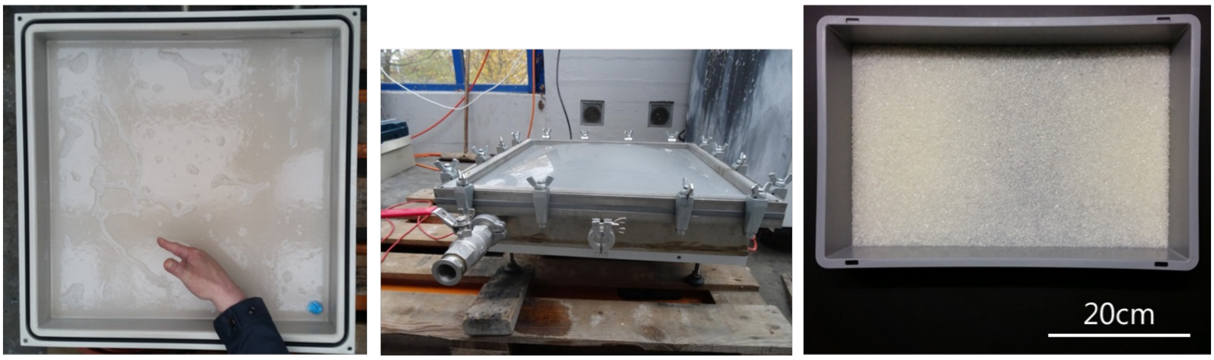
- 1: Use of waste heat from industry for heating via district heating pipelines.
- 2: Transformation and distribution of heat for more energy-efficient heating via district heating pipelines.
- 3: Strengthening of wood pellet heating systems.
- 4: Cooling of a computer centre. Just like conventional heat pumps, adsorption heat pumps can also work in the opposite direction for cooling.

The researchers now carried out laboratory tests to determine how well systems with commercial sorption materials could fulfil these tasks. They tested a total of 14 different purchased products and determined, among other things, how well they store water and nitrogen, how porous they are and how dense they are.

It turned out that some materials were better suited for scenarios 1 and 3, while others are more appropriate for scenarios 2 and 4. “This is because the scenario pairs each require similar sorption properties”, explains materials researcher Koebel. For scenarios 1 and 3, a material made from crystalline silicon-aluminium phosphate gave the best results. For scenarios 2 and 4, some carbon and silica gel products were found to be equivalent. Especially in scenario 4, however, an organometallic compound called aluminium fumarate demonstrated the best sorption capacity. However: “Aluminium fumarate is by far the most expensive material”, says Koebel. “It is often not even available in the large quantities that would be required for adsorption heat pumps”. For economic reasons, the team focussed on improving materials made from silicon dioxide and carbon.

Better than commercial counterparts

The researchers initially optimised the synthesis of silica sorption materials. They mixed an aqueous suspension comprising silicic acid and silicon dioxide with an ammonia solution. The mixture was subsequently gelled and dried at 65 degrees Celsius. In various experiments, the researchers now varied the concentration of the substances used and recognised that they could thus control the size of the particles produced and the pore size in their surface – both characteristics that determine a material's the sorption properties. In this way, the materials researchers created a material that performs better than its commercial counterparts, especially in scenario 4.



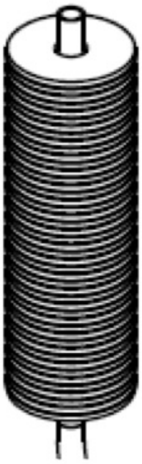
The production of the improved silica gel: from the suspension (left) through to the drying process and the product itself, the silica beads. Empa

However, the team achieved even better results with carbon materials. They also improved production here step by step. In the original synthesis, melamine, a nitrogen compound, and the organic molecule resorcinol are mixed with water as well as gradually with sodium hydroxide solution and hydrochloric acid. This results in a gel that is then pre-dried and carbonised in an oven at 900 degrees Celsius. The final step is the activation: here, part of the carbon is converted into gaseous carbon oxides, creating additional pores in the process. This increases the surface area of the substance and enhances its sorption capacity.

This activation was the first thing Empa researchers improved in their experiments. They achieved the best results with carbonisation at 800 degrees Celsius under a constant carbon dioxide stream. Next, in the synthesis, they varied the chemical structure of their material and finally the microstructure: the size and shape of the pores in the material.

The process of creating a sorption material made from activated carbon: the gel is mixed together from different molecules before being shaped, dried and carbonised at 800 degrees Celsius. The resulting discs are suitable for use as a stable and efficient sorption material. Empa

They finally succeeded in producing carbon discs on a large scale that were both stable and efficient: they adsorb and desorb steam two to three times as well as commercial materials. And they demonstrate significantly better sorption properties, especially for scenarios 2 and 4.



In the heat pump, the carbon discs are then glued between heat-conducting copper plates and stacked around the coolant pipe. The design of such heat exchanger elements is as important for the operation of the heat pump as the performance of the material. IBM/HSR

Fewer greenhouse gases in the atmosphere

Finally, the researchers combined these findings with the results of the other sub-projects of the joint project. These had looked at the heat transfer in the adsorption heat pumps as well as the environmental influences and economic viability of the systems. Conclusion: if adsorption heat pumps were introduced across Switzerland in just the considered scenarios by 2050, emissions of greenhouse gases would fall by up to 5 %.

Produkte aus diesem Projekt

- Monolithic nitrogen-doped carbon as a water sorbent for high-performance adsorption cooling
  Date of publication: 01.01.18
- Water sorption behavior of physically and chemically activated monolithic nitrogen doped car-bon for adsorption cooling
  Date of publication: 01.01.18
- The effect of activation time on water sorption behavior of nitrogen-doped, physically activated, monolithic carbon for adsorption cooling
  Date of publication: 01.01.18
- Facile synthesis of resorcinol-melamine-formaldehyde based carbon xerogel
  Date of publication: 01.01.18
- Kälte aus der Sonne - Nachhaltig Heizen und Kühlen
  Date of publication: 01.01.18
- Resin based carbon Aerogels and Xerogelsfor energy: Synthesis, processing and applications
  Date of publication: 01.01.18
- Monolithic Carbon XerogelSorbents
  Date of publication: 01.01.18
- Adsorbent materials for sustainable water sorption heat pumps
  Date of publication: 01.01.18

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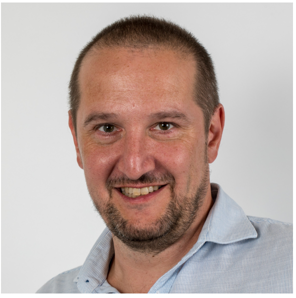

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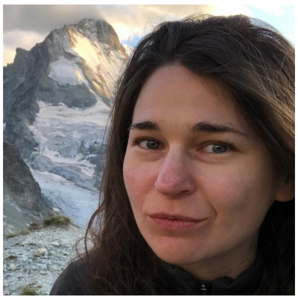

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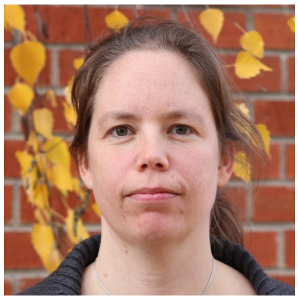

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All information provided on these pages corresponds to the status of knowledge as of 06.06.2019.