BETTER WAYS TO HEAT AND COOL BUILDINGS

Multiphysics simulation helps researchers at the Fraunhofer Institute for Solar Energy Systems develop innovative adsorption-based chillers, heat pumps, and thermal storage units driven by solar, natural gas, and waste heat.

by **GARY DAGASTINE**

FIGURE 1. Example of a commercially available adsorption-based chiller.

The heating and cooling of buildings accounts for nearly 50 percent of energy consumption in Europe, spurring researchers to find alternatives to conventional technologies.

One enticing possibility is to use adsorption-based heating and cooling systems driven not by electricity, but by heat. Because heat could come from solar collectors, from waste heat generated by industrial facilities, or from combined heat and power units, this adsorption technology offers the possibility of significantly reducing electricity consumption and associated CO_2 emissions. The technology can be used not only as a highly efficient heating system that uses gas-fired heat pumps to multiply the heat delivered to a building, but also for the compact storing of energy for a long period of time.

In brief, heating and cooling systems based on this principle use a working fluid in an adsorption/desorption cycle where the fluid's state is altered from liquid to gas and vice versa numerous times (see the sidebar on page 37 for more details). With this technique, special heat exchangers can be built that act as thermal compressors by periodically heating and cooling an adsorbent material at different temperatures and pressures. These systems can replace electrically driven mechanical compressors in heat pumps and chillers with the extra benefit of offering heat storage capacity, which can store up to three times the energy stored using traditional hot water systems.

➔OPTIMIZING THERMAL TRANSFER AND STORAGE

The development of adsorption-based heating systems and chillers is complex. They have discontinuous operating cycles, varying peak energy fluxes, and their dynamic behavior is determined by complex and coupled heat and mass transfer phenomena.

Although some adsorption-based systems are already commercially available (see Figure 1), to realize their full potential on a larger scale the technology must become far more efficient, more compact, and cheaper to produce.

One of the world's leading research organizations in this field is the Fraunhofer Institute for Solar Energy Systems (ISE) in Freiburg, Germany. With a staff of some 1,300 employees, it investigates all aspects of solar energy transformation, storage, and use. It is part of a network of more than 65 Fraunhofer research institutes in Germany that specialize in different aspects of applied science.

Eric Laurenz and Hannes Fugmann, researchers at Fraunhofer ISE, are part of a 20-person group led by Lena Schnabel that is developing higher-efficiency heat exchangers for adsorption systems. Laurenz studies how water vapor and heat flows through porous structures with the goal of optimizing system size and efficiency, while Fugmann conducts design studies involving non-isothermal fluid flows and heat conduction in solids in order to develop better heat

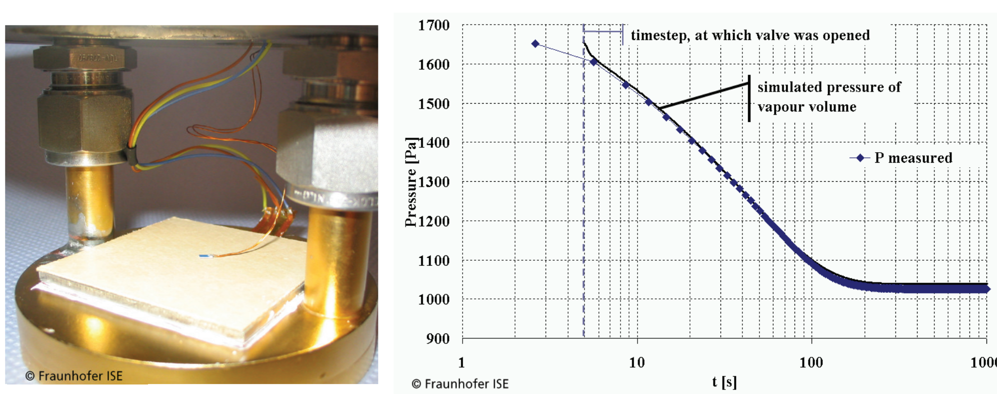


FIGURE 2. Left: Experimental setup used to validate COMSOL® software models of adsorption kinetics, consisting of a thin 50x50 mm² layer of zeolite sorbent on an aluminum carrier, placed on a cold plate in a dosing chamber and monitored with temperature and heat flux sensors. Right: Graph showing excellent agreement between simulated and measured water vapor pressure in a zeolite sorbent test setup at Fraunhofer ISE.

exchanger architectures.

"Analytical methods are inadequate for our work because of the strong nonlinear couplings between the heat and mass transfer involved," Laurenz said. "We need to use numerical tools such as COMSOL Multiphysics® to simulate the cyclic loading and unloading of the sorbent and take into account the temperature and mass distribution in both space and time. With these tools, we can make sure that the simulation will correctly capture the dynamics of adsorption and desorption."

As a general approach, the team uses a combination of simulation and well-defined, small-scale experiments to build large-scale models that can accurately predict the complex real-world behavior of the physics being investigated. With the small-scale models, the team can fully model the physical mechanisms in detail, while on the larger scales, complexity can be reduced to save on computational time. This approach can significantly reduce the need to build full-size physical prototypes, saving both time and money.

→VALIDATING THE ADSORPTION PROCESS

One of the key objectives for improving adsorption heat exchangers is to optimize the uptake speed and capacity of the thin sorbent layers used in the system. In one investigation, simulation was used by Lena Schnabel and Gerrit Füldner to build a model that captured the heat and mass transfer interplay dynamics happening in the sorbent layer. With the help of the model, the group was able to fully understand the measurements obtained from the experimental setup shown at left in Figure 2.

"Only by comparing experimental and simulation results using parameter estimation were we able to determine the transport coefficients that could not be measured directly," describes Laurenz. "This data was then used in our more complex simulations of the system."

Schnabel's group first started using COMSOL Multiphysics nearly ten years ago. More recently, however, the group has started to use models with varying levels of detail to estimate transport parameters and to simulate the cyclic behavior of complete systems under dynamically changing operating conditions. The ability to easily simulate coupled physics in complex and dynamic systems has proven indispensable for much of their research at Fraunhofer ISE.

→ENHANCED HEAT EXCHANGER DESIGNS

In his work to optimize heat exchanger architectures, Fugmann performs basic research on heat exchanger designs, including chillers and heat pumps. Some of his geometries are designed to increase heat transfer surface area using wire structures such as those shown in Figure 3, as opposed to the more traditional fin-and-tube heat exchanger designs. In these novel architectures, a wire structure is woven or knitted around a series of tubes, separating the two fluids in the heat exchanger. In an experimental setup for a gas-to-liquid wire heat exchanger, hot water flows within the tubes while cold air flows between the tubes and across the wires.

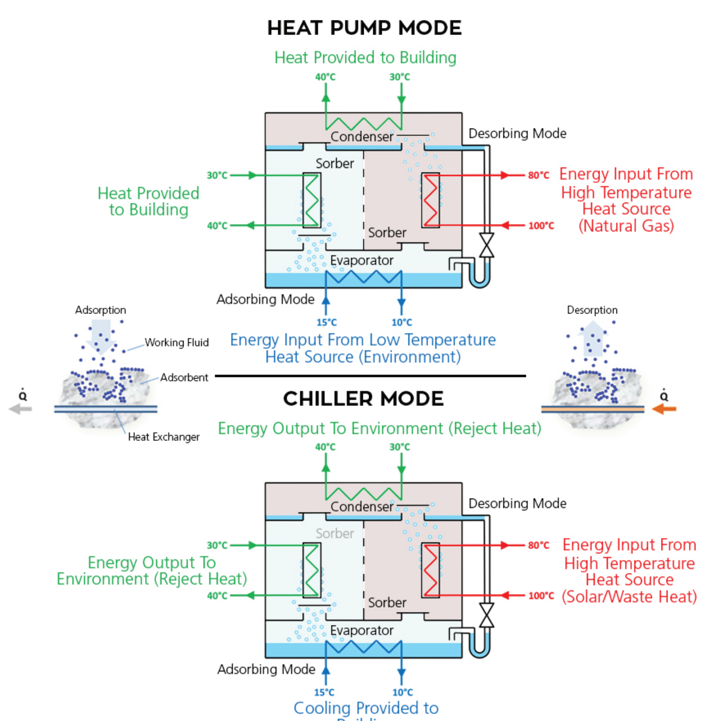
"We found that if we use wire structures, we can achieve a higher heat transfer coefficient with a larger surface, as

USING ADSORPTION FOR HEATING AND COOLING SYSTEMS

A schematic of the two-step cycle used to design adsorption-based chillers and heat pumps is shown in the figure below. To explain, let's look at what takes place during the heat pump mode. The cycle is composed of one adsorption and one desorption step. During the adsorption step, the working fluid is evaporated at a low temperature. At the same time, the working fluid is adsorbed by an adsorbent at a medium temperature, where the heat released can be used to heat a building.

Once the sorbent is saturated, the process is inverted and the desorption step starts. The sorbent is heated to a high temperature, thereby desorbing the working fluid. Next, the working fluid is condensed at a medium temperature, and the released heat of condensation can be used to heat a building.

In summary, for heating applications (heat pumps) the building is heated while energy is removed from the environment. Conversely, in cooling applications (chillers), the building is cooled down while heat is released to the environment. When the cycle is interrupted, the potential heat of adsorption can be stored loss free. Depending on the desired application, adsorption can be used to heat or chill a building, while the environment acts as either a heat source or sink.



The sorber continuously switches between the adsorbing and desorbing modes during operation

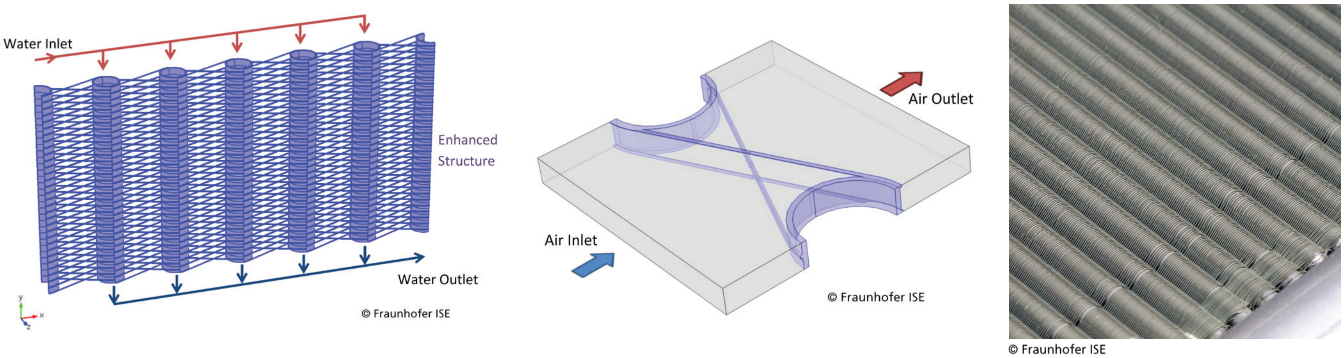


FIGURE 3. Left: Device geometry showing warm water entering the tubes. Cold air is passed across the tubes, cooling the water as it flows through the tubes. Middle: Simulated geometry showing the cold air entry and warm air exit. The wire structure and the tubes are shown in purple. Right: Device geometry used in experimental testing.

well as significantly reduce material usage," said Fugmann. "We are able to do this without noticeably increasing the pressure drop, and the flexibility of the wire structures also gives us the ability to easily adapt the geometry depending on the operating parameters of the design."

Using COMSOL® software, Fugmann performed parametric sweeps to investigate specific pressure drops, heat transfer coefficients, material usage, and other analyses of the design's geometry. Figure 4 shows the temperature distribution and the velocity magnitude of an optimized geometry of the wire structure and the tubes.

Fugmann describes the device: "From the measurements, we found that the bonded connections between wires and tubes yield a high and dominating heat resistance. By understanding the limitations of heat transfer in the wire structures, we can further optimize the design."

Due to their higher heat exchange surface per volume, the wire structures are also analyzed experimentally and numerically at Fraunhofer ISE for use as sorptive-coated structures and as surface enlargement for heat exchangers in thermal storages.

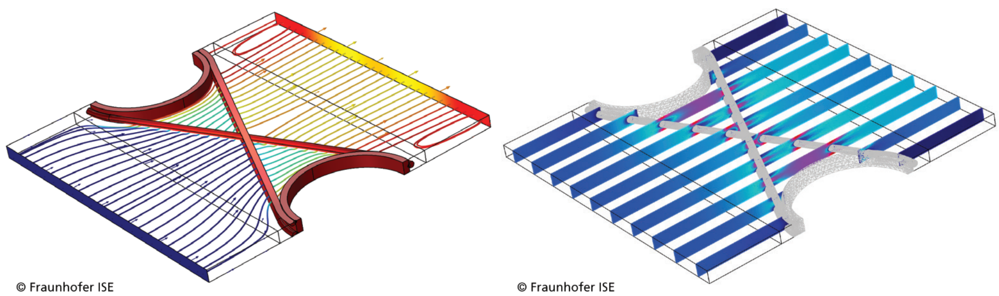
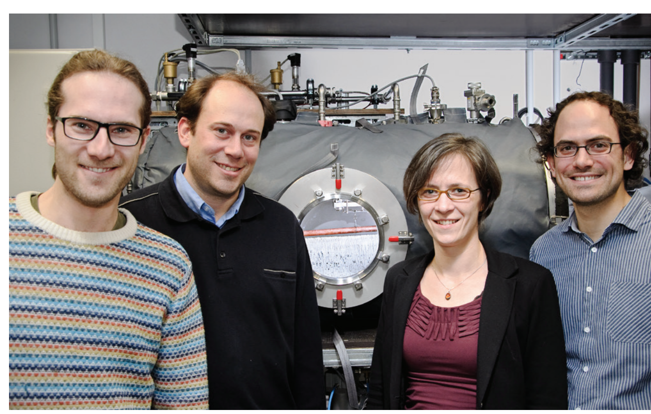


FIGURE 4. Left: Simulations showing velocity streamlines and the temperature distribution in air, in the tube wall, and in the wire connecting the two tubes (red: warm; blue: cold). Right: Simulations showing the velocity magnitude in air (red: high; blue: low).

➔LOOKING AHEAD

"Our immediate goal is to increase knowledge and competence in these areas so that we can help both our customers and others at Fraunhofer ISE who are developing different aspects of adsorptive climate control systems," said Laurenz. "Longer-term, we look forward to the day when such technologies are in widespread use in society, helping to reduce the load on the electrical grid and conserve the earth's resources." ❖



The Fraunhofer ISE team includes (from left) Hannes Fugmann, Gerrit Füldner, Lena Schnabel, and Eric Laurenz. They are standing in front of an experimental setup for the dynamic characterization of adsorption heat exchangers. The setup is used to generate experimental data for simulation-based parameter estimation.

REFERENCES

[1]Füldner, G. & Schnabel, L., 2008. Non-Isothermal Kinetics of Water Adsorption in Compact Adsorbent Layers on a Metal Support. In Proceedings of the COMSOL Conference 2008 Hannover. COMSOL Conference. Hannover.