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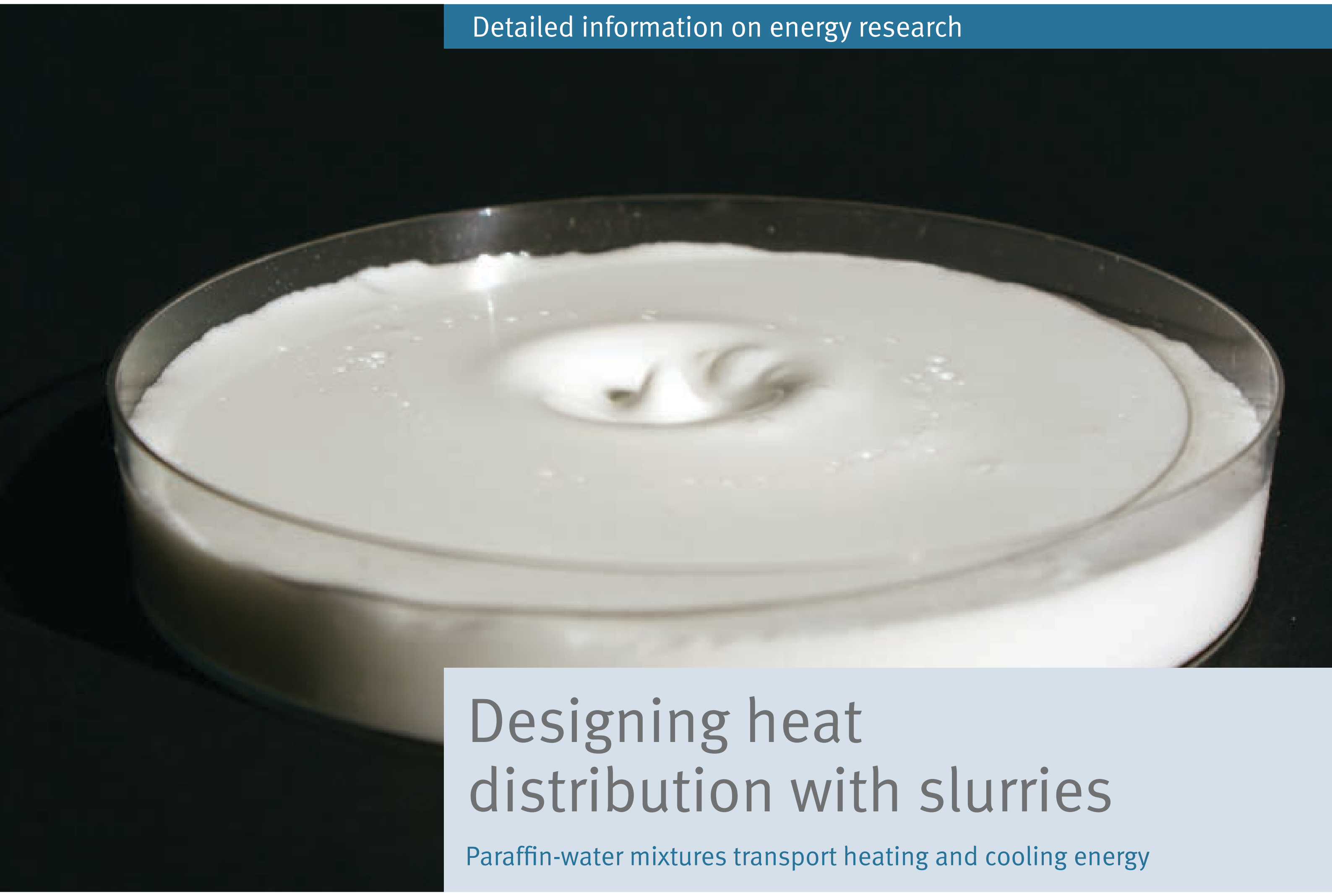
Detailed information on energy research



Designing heat distribution with slurries

Paraffin-water mixtures transport heating and cooling energy

BINE Information Service

In heating and cooling systems, water is mostly used for transporting heat. For special applications, dispersions of paraffin and water could carry out this task more efficiently. These so-called slurries achieve high heat capacities within a narrow temperature range. Scientists at RWTH Aachen are simulating the complex behaviour of the fluids in hydraulic networks. With new simulation models they are investigating possible uses – ranging from underfloor heating in family homes to district heating networks.

When paraffin is heated above its melting point, it absorbs heat for the liquefaction and releases it again when it solidifies. This latent heat storage is used by dispersions consisting of finely dispersed paraffin in water. In a narrow temperature range around the melting point, these slurries exceed the heat capacity of water by more than double. Depending on their chemical composition, paraffins are theoretically suitable for freezer temperatures ranging from minus 20 to around 110 °C. However, until now the fluids have hardly been used for transporting heat. This means that only a few long-term stable products have been available until now and the experience and calculation methods for their practical use have been largely lacking. In experimental and theoretical research work, researchers at RWTH Aachen and the Fraunhofer Institute for Environmental, Safety and Energy Technology (UMSICHT) have significantly improved the bases for their practical use. New experimental equipment and methods now enable the dispersions to be better characterised. The scientists have also made progress in the production of temperature-stable fluids. The simulations presented here from the Aachen-based researchers reveal which specific energy systems would make an application worthwhile. Cooling applications and, in particular, district heating systems proved to be promising candidates.

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Federal Ministry for Economic Affairs and Energy (BMWi)

Heating networks

The use of paraffin-water dispersions in district heating networks proved to be promising. This was exemplified by the district heating network belonging to the Melaten campus, which the researchers modelled in simulations. The campus at RWTH Aachen University has about 193,000 m² of building area. A heating plant in the north of the campus supplies the buildings with heat. It also supplies other loads such as the laboratory areas and the University Hospital laundry. Depending on the load, several gas boilers generate up to 90 MW.

The six-kilometre-long district heating network connects the loads via two different hydraulic circuits with the CHP plant. Pumps generate a maximum flow rate of 1,000 m³/h of water.

The simulations capture only the sub-network that supplies the space heating and the laboratories. The temperatures in this circuit range between 90 and 130 °C. The second, not simulated circuit provides heat at a constant supply temperature to Aachen University Hospital.

In the simulation, the heat consumption of each building is recorded in tabular form in accordance with the ambient temperature, building type and building size. The scientists modelled the hydraulic circuit for the district heating network with transfer stations so that the heat and pressure losses can be calculated in the network. The complete system is controlled by a pressure difference at the ends of the network. The absolute pressure loss in the system is maintained at a constant 2 bar using pumps.

With these specifications, the researchers simulated the network both for a paraffin-water dispersion and for water. They reduced the temperature range relative to the actual district heating network, as otherwise the maximum phase change temperature of the paraffin would be exceeded. They chose a temperature of 70 °C as the melting point of the paraffin-water dispersion.

Hardly any efficiency gains with transfer stations

The simulations calculate a lower supply temperature and a higher return temperature for the paraffin-water dispersion relative to water (Fig. 2). In the balance, the heat losses in the network are reduced by 5 %.

However, the energy efficiency of the entire system increases by only 1.5 %, since the viscous dispersion requires higher pump outputs. For this reason and owing to the higher temperatures in the heating network, the exergy efficiency of the system is less than that for the water-based system. The exergy efficiency is mainly determined by the large temperature difference between the combustion temperature in the boiler and the required supply temperature. Therefore, the exergy efficiency of the paraffin-water dispersion could be greatly improved if renewable energy were to be used for the heat production.

An interesting effect is shown by the load distribution: not only does the entire energy generation shift but, in particular, the output peaks are also reduced (Fig. 4). The researchers see an opportunity here to smooth loads with ambitious schemes such as the "Smart Cities" project.

Greater efficiency with direct connection

The energy efficiency improves when the supply and return temperatures are lowered, as this reduces the heat losses. However, this is limited by the necessary temperature difference in the heat exchanger.

Heat transfer medium	*Energy consumption pump [MWh/p.a.]*	*Heat losses [%]*	*Energy efficiency [%]*	*Exergy efficiency [%]*
Water	*118*	*592*	*64.3*	*6.5*
PCS – 70 °C	*289*	*560*	*65.2*	*6.1*

Fig. 1 *Without adaptations to the heating network, phase change slurries (PCSs) do not improve the efficiency.*

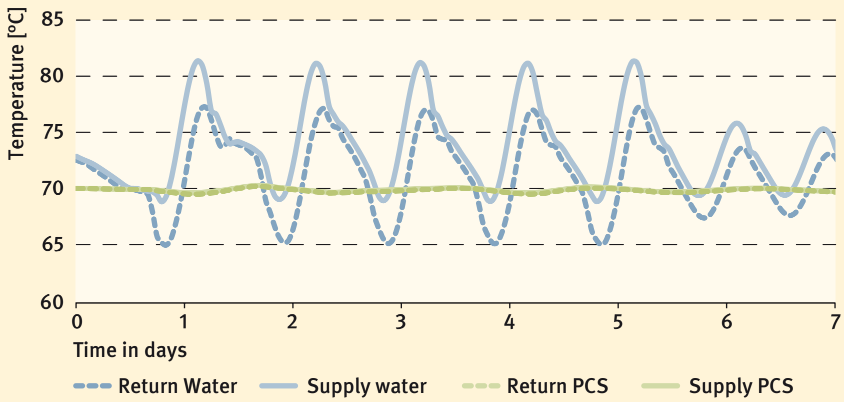

Fig. 2 *Supply and return temperatures for the district heating network for water and the paraffin-water dispersion*

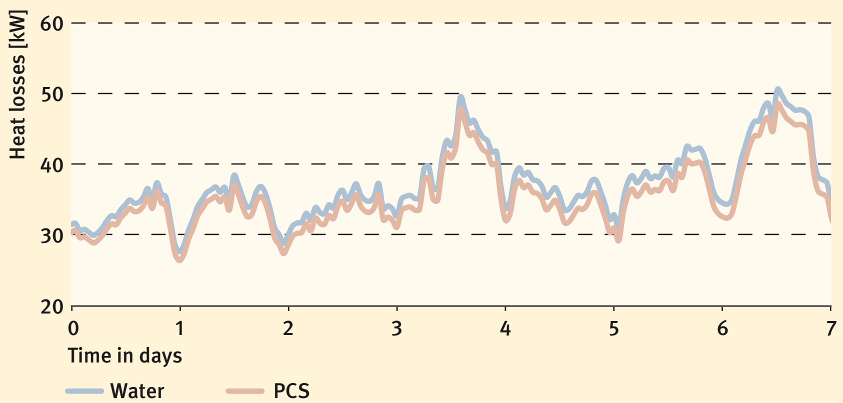

Fig. 3 *Heat losses from the district heating network for water and the paraffin-water dispersion*

In a further simulation, the scientists therefore investigated the possibility of feeding heat from the heating network directly into the underfloor heating without using heat exchangers. After adapting the system, they reduced the supply temperature and the melting point of the paraffin-water dispersion to 40 °C. With this configuration, the efficiency increased by up to 25 %. However, the results cannot be transferred directly into practice because the district heating network is operated at a different pressure level than the heating systems in the buildings. This would mean that a separate pumping system would have to be installed at each load, which would initially throttle the pressure from the district heating network and then increase it later in the return system.

The additional costs would be offset by eliminating the need for heat exchangers. The large main pumps for maintaining the pressure could also be eliminated. The effects of the different pump and pressure systems can only be conclusively clarified, however, through further investigations.

A home is simulated

A fictional house in the Aachen climatic region was used to demonstrate the effects of paraffin dispersions in underfloor heating, as brine in a heat

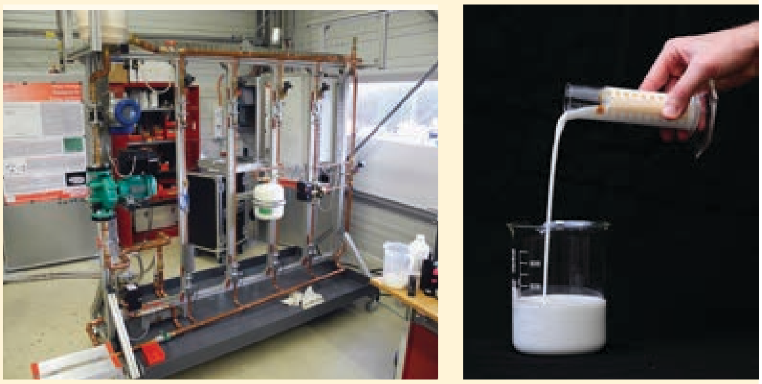

Fig. 4 *Test rig for testing the dispersions with different heating technology components*

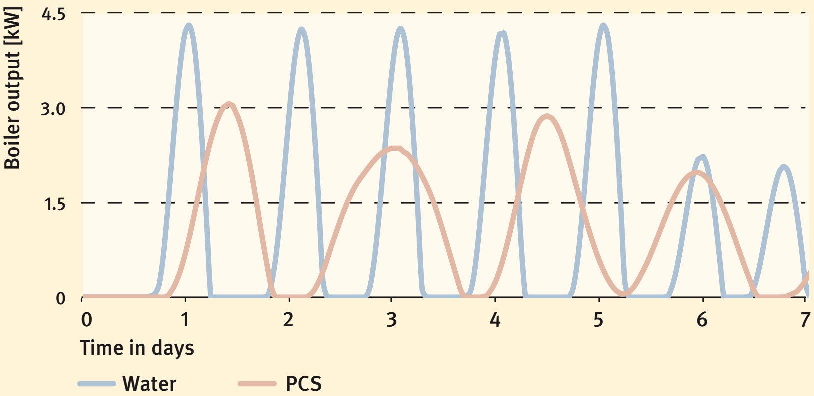

Fig. 5 *Comparison of the boiler output for the heating network for water and the paraffin-water dispersion*

Heat transfer medium	*Heat losses [%]*	*Energy efficiency [%]*	*Exergy efficiency [%]*
PCS – 70 °C	*560*	*65.2*	*6.1*
PCS – 40 °C	*237*	*80.6*	*6.8*

Fig. 6 *Heating losses and efficiencies with a direct heating connection and a paraffin-water dispersion*

pump system or as solar fluid in a solar thermal system. The house is insulated according to the German Energy Savings Ordinance from 2009 and, with an area of 132 m², has a standard heating load of 5 kW.
Characteristic periods from different seasons were simulated: 10 days in February with low solar irradiance, 10 days in April with high solar irradiance and average outside temperatures, and one week in July with high temperatures and high solar irradiance. When comparing the dispersions as an alternative to water, the scientists investigated both the energy and exergy efficiency. This assesses, for example, the electricity consumption of the circulating pumps for the different viscous media.

Underfloor heating

The researchers investigated the underfloor heating system with supply temperatures of 46 and 36 °C respectively and with different control strategies. The use of a paraffin-water dispersion only provided energy efficiency benefits with the low supply temperature and with low mass flows. In exergy terms, the advantages relative to water are almost completely negligible. As a positive side effect, the higher storage capacity of the slurry reduced the on/off cycling of the heating system.

New libraries for Modelica

To simulate the different energy systems, the scientists are using the Modelica language. The programming environment is freely available and allows the simulation of complex physical systems, including the transport of heat in hydraulic systems. However, paraffin-water dispersions have special characteristics that were not previously recognised in the program libraries. The fluids belong to the non-Newtonian fluids, whose flow behaviour depends on the acting pressure. The simulations were also previously unable to accurately describe the phase change of the paraffin. The dispersions tend to supercool, in other words they behave differently during heating and cooling.
With a specially constructed test facility on a laboratory scale, the researchers identified the properties of the dispersions. With their measured data, they expanded the library to include functions such as pressure loss, heat transfer, enthalpy, density and entropy for non-Newtonian fluids.

Heat pumps do not benefit

In the Aachen model example, the efficiency of a monovalent heat pump changed only slightly when the brine for the borehole heat exchanger was replaced with the paraffin-water dispersion. The flow through the borehole heat exchanger was able to be reduced by two thirds owing to the greater heat capacity of the fluid. However, even under optimised conditions with adjusted mass flows, the performance factor only improved by less than 1 %.

Solar thermal system increases coverage in winter

The reference house was then equipped with flat-plate collectors in combination with a thermal energy storage system. If the heating power is insufficient, an electric water heater can be switched on to meet demand. In theory, the higher thermal capacity of the fluid should increase the collector efficiency significantly, since the temperature in the collector decreases. The solar fraction does in fact increase in winter by up to 19 %. In the transitional period, however, it does not improve, since the phase change in the working fluid is not fully completed. This is also confirmed by experimental investigations. The researchers conclude that the dispersions can only be used effectively if the collector temperatures do not vary considerably.

Cooling ceilings become more efficient

The researchers modelled the use of dispersions in cooling systems using the example of a 10 m² cooling ceiling. At night, this disperses the absorbed heat via a solar collector surface. The simulations demonstrate the considerable degree to which the efficiency of the slurries depends on an optimal system design: when the melting range of the paraffin-water dispersion is around 22 °C, the cooling capacity of the system increases by 20 %. At lower melting points, however, the energy efficiency reduces until it is less than that of water, since the dispersion cannot completely solidify at night.

From research into practice

Paraffin slurries are starting to find their way from research into practical use. A prerequisite is that stable dispersions for different temperature ranges are available at competitive production costs. The researchers tested the cooling of an actual building using the Counter Entropy House. The 46 m^2 solar house was built by Aachen students as their competition entry for Solar Decathlon 2012, which was held during the summer in Madrid. The building's entire living space is furnished with a ceiling of cooling panels. During the day, a paraffin-water dispersion absorbs the heat from the rooms and stores it in three tanks. At night, the solar collectors dissipate the stored heat. The cooling concept worked and the paraffin-water dispersion proved to be stable.

The researchers at Fraunhofer UMSICHT now offer customised dispersions for transporting cooling and heating energy under the brand name CryoSol®plus. A variant of the fluids was developed for temperatures between 5 and 20 °C as an alternative to cold water in cooling systems. In other compositions, the dispersions cover the temperature range from 25 to 45 °C and are designed for transporting or storing low-temperature heat.

Scientists at Fraunhofer ISE are also working on new paraffin dispersions with phase change temperatures between 6 and 30 °C. The German Federal Ministry for Economic Affairs and Energy is funding the KOLAN project as part of the Energy Storage research initiative. The research work is continuing until September 2016. The scientists want to develop cost-effective phase change emulsions with a high storage capacity and good stability. The emulsions are being tested and evaluated in a pilot plant at Imtech -Deutschland GmbH under realistic conditions.

Project participants

- **Experimental testing and simulations:** RWTH Aachen University. E.ON Energy Research Centre, Univ.-Prof. Dr.-Ing. Dirk Müller, Pooyan Jahangiri
- **Development of paraffin-water dispersions:** Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT, Oberhausen, Dr.-Ing. Clemens Pollerberg

Links und literature (in German)

- Müller, D.; Jahangiri, P.; Knels, A. u. a.: Emulsionen aus Paraffinen und Wasser für Anwendungen in Versorgungssystemen der Gebäudetechnik in Kombination mit Reibungsminderern bei der Energieverteilung. Abschlussbericht Eneff:Wärme. FKZ 0327471A/B. RWTH Aachen University. E.ON Energieforschungszentrum Lehrstuhl für Gebäude- und Raumklimatechnik (Hrsg.); Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik UMSICHT, Oberhausen (Hrsg.). Juli 2014
- E.ON Energy Research Centre, RWTH Aachen, www.eonerc.rwth-aachen.de
- Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT, www.umsicht.fraunhofer.de

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