Keep cool

Researchers develop magnetic cooling cycle /
Cooperation between TU Darmstadt und Helmholtz-Zentrum Dresden-Rossendorf

Darmstadt/Dresden, Sept. 17, 2018. As a result of climate change, population growth, and rising expectations regarding quality of life, energy requirements for cooling processes are growing much faster worldwide than for heating. Another problem that besets today's refrigeration systems is that most coolants cause environmental and health damage. A novel technology could provide a solution: refrigeration using magnetic materials in magnetic fields. Researchers at the Technische Universität (TU) Darmstadt and the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) have developed the idea of a cooling cycle based on the 'magnetic memory' of special alloys. Relevant initial experimental results have now been published in the journal 'Nature Materials' (DOI: 10.1038/s41563-018-0166-6). The project is funded by the European Research Council (ERC).

The magnetic properties of metals can change when they are heated or cooled. "Iron, for example, is only ferromagnetic below 768 degrees Celsius; nickel's transformation temperature is 360 degrees Celsius," says Oliver Gutfleisch, Professor of Functional Materials at the TU Darmstadt. "Conversely, some alloys become ferromagnetic when they warm up. This phase transition is connected with the so-called magnetocaloric effect: when these shape-memory alloys are placed in an external magnetic field just below their transformation temperature, they spontaneously jump to their magnetic order and simultaneously cool down," explains Gutfleisch. "The stronger the magnetic field, the more they cool."

Dr. Tino Gottschall, who is now researching at the HZDR's Dresden High Magnetic Field Laboratory (HLD), and his colleagues have studied different shape-memory alloys and their properties in minute detail: "The application of a magnetic field can also change other properties, for example density – which is why some alloys increase their volume." The physicists discovered that externally applied pressure can indeed reverse the magnetization process, causing the alloy to heat up.

Slight pressure – big impact

Together with Prof. Antoni Planes and Prof. Lluís Mañosa from the University of Barcelona, the scientists succeeded in providing experimental proof: "We used an alloy of nickel, manganese, and indium for our

TU Darmstadt

Jörg Feuck
Head of Corporate Communications
Karolinenplatz 5
64289 Darmstadt
Phone: ++49 (0) 6151 16 - 20018
feuck@pvw.tu-darmstadt.de
www.tu-darmstadt.de/presse
presse@tu-darmstadt.de

Helmholtz-Zentrum Dresden-Rossendorf (HZDR)

Dr. Annegret Seemann
Science Editor
Communication und Media Relations
Phone: ++49 (0) 351 260-2515
a.seemann@hzdr.de
www.hzdr.de

experiments because its conversion can be triggered at room temperature", says Gottschall. The researchers generated the magnetic field using the strongest permanent magnets known to date – containing the rare-earth metal neodymium in addition to iron and boron. They can generate magnetic fields up to a flux density of 2 tesla – that is 40,000 times stronger than the Earth's magnetic field. "Under such conditions, our alloy cools down by several degrees," explains Gottschall. "Measurements we have made at the HLD have shown that a millisecond in the magnetic field is already enough for permanent transformation."

In the next step of the six-step cycle, the researchers removed the cooling element from the magnetic field, which retained its magnetization. In step three, the heat sink comes into contact with goods to be cooled down and absorbs its heat. The alloy even remains magnetic if the material returns to its original temperature. This can be remedied by mechanical pressure: in step four, a roller compresses the shape memory alloy. Under pressure, it switches to its denser, non-magnetic form and heats up in the process. When the pressure is removed in step five, the material retains its state and remains demagnetized. In the final step, the alloy releases heat into the environment until it has returned to its initial temperature and the cooling cycle can recommence.

Expensive raw materials

"Just a few years ago, alloys with a magnetic memory were regarded as unusable because they can only be cooled in the magnetic field once," explains Gutfleisch. "Global research, therefore, focused on materials that have no memory effect. However, refrigerators produced according to this principle come at a price." The largest item in the manufacturing costs are the necessary permanent magnets: "In the case of reversible magnetization, the cooling effect only lasts as long as the cooling element is exposed to the magnetic field. Even in the best-case scenario, half of the coolant must be placed between the magnets. This means that you need four times as much permanent magnet as cooling medium." Neodymium magnets are the most effective, but they are also the most expensive on the market. In addition, the rare-earth metal is a critical raw material, and considerable amounts of it are needed. The largest known deposits are in China, and its extraction causes considerable environmental pollution.

Electromagnets cannot be used for magnetic cooling. For physical reasons, the level of efficiency would be lower than with vapor compression, which is used in billions of refrigerators and air conditioners. However, the researchers are convinced that this cooling technology no longer has a future: "There are simply no suitable cooling liquids," says Gottschall. "The coolants commonly used today are highly effective as heat-transfer media, but their greenhouse impact is a thousand times greater than that of carbon dioxide. The production licenses for most of them in Europe will expire in the near future. Propane or butane are effective coolants, but form highly explosive mixtures in contact with the air. Ammonia is toxic and corrosive. Carbon dioxide is not especially efficient as a coolant."

Using rare earths sparingly

Oliver Gutfleisch is also convinced that the future belongs to solid coolants. "We have been able to show that shape-memory alloys are highly suitable for cooling cycles," says the functional materials expert: "We need far fewer neodymium magnets but can nevertheless generate stronger fields and a correspondingly greater cooling effect." By 2022, he intends to build a demonstrator at the TU Darmstadt that makes it possible to estimate both the actual cooling capacity under real-life conditions and the energy efficiency of the process. For this, he has received an ERC Advanced Grant from the European Research Council worth a total of 2.5 million euros over five years. The collaboration between the TU Darmstadt and the HZDR could help make the principle suitable for mass use: "In the meantime, we have found alloys that combine all the desired properties, including a large magnetocaloric effect, without using any rare earths or other critical raw materials at all," says Tino Gottschall, who wants to explore the physical limits of these materials at the HLD.

Further information
Publication: T. Gottschall, A. Gràcia-Condal, M. Fries, A. Taubel, L. Pfeuffer, L. Mañosa, A. Planes, K.P. Skokov, O. Gutfleisch: 'A multicaloric cooling cycle that exploits thermal hysteresis', Nature Materials 2018 (DOI: 10.1038/s41563-018-0166-6)

Pictures: https://bit.ly/2NGSLOs

Contact:
Prof. Oliver Gutfleisch
Materials Sciences; Institute of Functional Materials, Technische Universität Darmstadt
Phone ++49 6151 1622140
Email: gutfleisch@fm.tu-darmstadt.de

Dr. Tino Gottschall
Dresden High Magnetic Field Laboratory at Helmholtz-Zentrum Dresden-Rossendorf
Phone ++49 351 260-3344
Email: t.gottschall@hzdr.de

The Technische Universität (TU) Darmstadt is one of Germany's leading technical universities. TU Darmstadt incorporates diverse science cultures to create its characteristic profile. The focus is set on engineering and natural sciences, which cooperate closely with outstanding humanities and social sciences. We are enjoying a worldwide reputation for excellent research in our highly-relevant, focused profile areas: cybersecurity, internet and digitalisation, nuclear physics, fluid dynamics and heat- and mass transfer, energy systems and new materials for product innovation. We dynamically develop our portfolio of research and teaching, innovation and transfer, in order to continue opening up important opportunities for the future of society. Our 312 professors, 4,450 scientific and administrative employees and close to 26,000 students devote their talents and best efforts to this goal. Together with Goethe University Frankfurt and Johannes Gutenberg University Mainz, TU Darmstadt has formed the strategic Rhine-Main Universities alliance.

The Helmholtz-Zentrum Dresden-Rossendorf (HZDR) carries out research in the areas of Energy, Health and Matter. The following questions are key:
- How can energy and resources be utilized in an efficient, safe, and sustainable way?
- How can malignant tumors be more precisely visualized, characterized, and more effectively treated?
- How do matter and materials behave under the influence of strong fields and in smallest dimensions?

To answer these scientific questions, the HZDR operates large-scale infrastructures that are also available to external users, such as the Ion Beam Center (IBC), the Dresden High Magnetic Field Laboratory (HLD) and the Elbe Center for High-Power Radiation Sources.
HZDR is a member of the Helmholtz Association and has five sites (Dresden, Freiberg, Grenoble, Leipzig, Schenefeld near Hamburg) with almost 1,200 members of staff, of whom about 500 are scientists, including 150 Ph.D. candidates.

MI-Nr. 49en/2018, HZDR/TU