

Cooling Processes Without Refrigerants

By Björn Palm

At the beginning of the summer, I was invited to speak at Thermag, a conference on alternative methods of generating cooling. Considerable research is being carried out on such processes, and the motivation is usually to find methods that provide a higher coefficient of performance and that are not dependent on environmentally harmful refrigerants. My task from the organizers was to describe the current state of development of the vapor-compression refrigeration process, and in particular to point out that in most applications it is possible to use natural refrigerants that have no negative impact on the global environment.

Which alternative cooling processes are then closest to achieving a breakthrough? And what performance can be expected from these processes? I will mention some of them here and briefly describe how they work.

A common feature of many processes, including vapor-compression refrigeration, is that they involve order and disorder at the molecular or atomic level. Order may, for example, concern how closely molecules or atoms are packed, or how fast they move (i.e. how high the temperature is). We use the term entropy as a measure of the disorder in a system: high order, low entropy; high disorder, high entropy. If the state of a substance is changed rapidly in some way (without heat exchange), the total entropy remains unchanged, but there may be a redistribution of the contributions to the entropy. When we compress a refrigerant, we increase the degree of order in one respect because the molecules are brought closer together. For the total entropy to remain constant, some other form of entropy must increase, and we know that the temperature rises during compression: the “thermal” contribution to the entropy increases.

Perhaps the most widely discussed alternative cooling process is the magnetocaloric process. Here, materials that are affected by magnetic fields are used. When the field is switched on, the magnetic dipoles align themselves with the direction of the field, which increases the order and tends to reduce the entropy. For the total entropy to remain constant, the “thermal” entropy must increase, i.e. the temperature rises. The material is then allowed to release heat to the surroundings, after which the magnetic field is switched off. This causes the atomic dipoles to return to a disordered state (the entropy tends to increase), which means that the temperature must decrease (the “thermal” entropy decreases) for the total entropy to remain constant. Heat can now be absorbed from the surroundings. By allowing, for example, water to flow back and forth through the material in synchrony with the magnetic field, heat can be “pumped” from a cold environment to a warm one, resulting in a refrigeration process, see Figure 1.

It is obvious that material selection is important: It is desirable for the temperature to change significantly when the field is switched on or off. Alloys of gadolinium are known to have a strong magnetocaloric effect. Research in this field focuses to a large extent on developing efficient materials that have a large magnetocaloric effect and that can also be processed and

remain stable, i.e. do not deteriorate. Since the heat is to be transferred to a heat-transfer fluid (water), the material must be thin or consist of small particles: heat must have time to conduct to or from the surface of the material during each cycle. Several companies [1, 2, 3, 4] have demonstrated working prototypes of “refrigerators” based on this principle, but it remains to be shown that such refrigerators can compete with vapor-compression refrigeration in terms of price and performance. The absence of a refrigerant is often used as an argument for introducing the new technology. What is not mentioned is that it requires alloys of rare metals, which may place an environmental burden on the areas where these metals are mined.

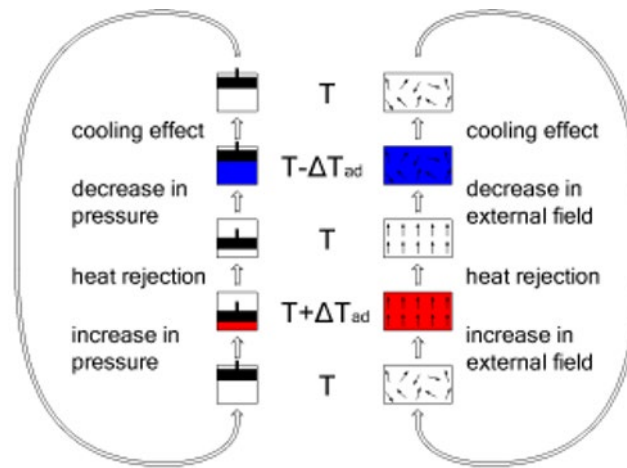


Figure 1: Similarities between a compression cycle and a magnetocaloric or electrocaloric process

A similar process is the electrocaloric process, in which an electric field rather than a magnetic field is used to create order at the molecular level. In this case, the materials must be ferroelectric. Ideally, they should produce a significant temperature change when the voltage is applied, but they must not be electrically conductive. Materials being investigated include ceramics and polymers [5]. Otherwise, the process works in the same way as the magnetocaloric process.

Another process that is the subject of extensive research is the elastocaloric process. Here, an elastic material is used to produce a temperature change: when the material is stretched, the degree of order increases and the material becomes warm. When it is then allowed to return to its original shape, the temperature decreases. The principle can easily be demonstrated by placing a strong rubber band against the lip while stretching and releasing it. The temperature change is clearly noticeable! In this case too, a heat-transfer fluid (water) is needed to transport the heat/cold so that the process becomes useful. The properties of the material are crucial to the performance and usability of the process. Various forms of shape-memory alloys are the most extensively studied materials, but polymers have also been tested. One challenge is to ensure that the material remains durable over a long period and through millions of compression and expansion cycles. Recently, research results were presented showing that a new type of shape-memory alloy, TiNiCuCo, can withstand at least 10 million cycles [6]. The prototype had a cooling capacity of 400 W and maintained a temperature difference of 41 degrees.

The processes described above are referred to as solid-state cooling because it is a solid material that changes temperature. A common disadvantage of all of these processes is that a heat-transfer fluid is required to utilize the process. Another disadvantage is that heat must be

conducted through the material to its surface before the heat-transfer fluid can transport it further. This means that the materials must be thin or small if a high process frequency is desired (which is desirable in order to achieve high capacity). It also entails a thermodynamic loss because it is not possible to utilize the entire temperature change that the material undergoes during the cycle. In addition, the efficiency of the materials may vary with temperature, which can be a problem in applications where the temperature on the cold and/or warm side varies.

The vapor-compression refrigeration process therefore has several advantages: It is the fluid, the refrigerant, that changes temperature, and heat transfer takes place during evaporation/condensation, which can occur close to the object that is to be cooled or heated. In addition, the process operates over a wide temperature range.

There are more alternative processes than those mentioned here: absorption/adsorption, thermoelectric, thermionic, thermoacoustic, as well as a relatively recently developed process called JTEC (Johnson Thermoelectric Converter). The latter can be used both to generate electricity from low-temperature heat and as a heat-pumping process. Most of these processes will be discussed in a report from IIR that is currently under review. It will soon be available for download from the IIR website [7].

In summary, it can be concluded that there are many processes for generating cooling. However, it is my firm opinion that there is currently no process that can be expected, in the near future, to compete with the vapor-compression refrigeration process in the vast majority of applications.

Read previous refrigeration columns on our website: www.energy.kth.se/kylaochvarme

References

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