MAGNETIC REFRIGERATION NEAR ROOM TEMPERATURE: 60 YEARS OF RESEARCH AND TECHNOLOGICAL DEVELOPMENT

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SUMMARY

The work briefly presents the state of the art on magnetic refrigeration at room temperature (RTMR) and brings into discussion the limits that still hinder its spread on the refrigeration market as a valid alternative to traditional vapour compression systems.

DISCUSSION

Magnetic refrigeration uses the magneto caloric effect (MCE), the change in entropy of a magnetic material as the magnetic moments of the atoms respond to a magnetic field. Under isothermal conditions, the MCE is the isothermal entropy change, ΔS_T, and is observed as a release or absorption of heat. Under adiabatic conditions, the MCE is observed as the adiabatic temperature change, ΔT_S. This temperature change can be exploited to structure a magnetic refrigerator.

The working principle is described in Figure 1, comparing the traditional gas inverse cycle to the Magnetic Refrigeration cycle.

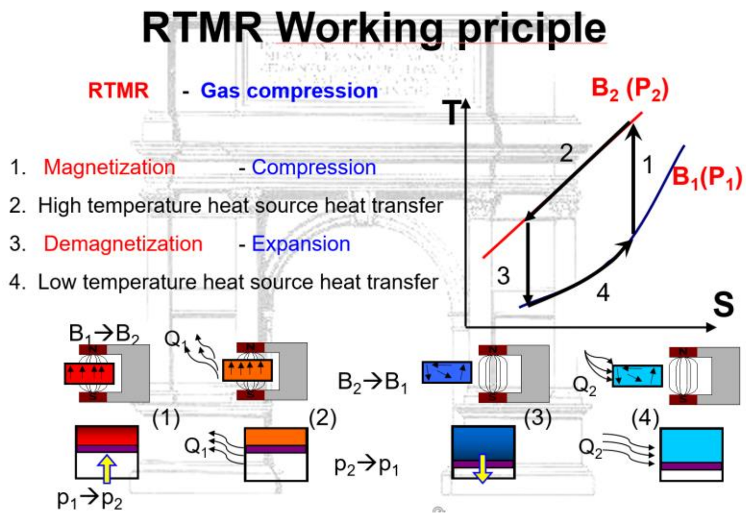

Figure 1. The Magnetic refrigeration at Room Temperature (RTMR) working principle, compared to gas refrigeration cycle.

The main components of a RTMR needed to perform in a coordinate and synchronized manner the processes as sketched in Figure 1 are briefly:

1) The high temperature and low temperature heat exchangers

2) The MCM core (usually a highly compact regenerative gadolinium bed) which must be cyclically magnetized and demagnetized, with flow of the intermediate fluid (water or other) at the same time
3) The magnet (usually a Neodimium iron borum – NdFeb - permanent magnets)
4) The measurement and control system able to drive the flow across each component.

In recent years a lot of research has been developed, all around the possibility to achieve room temperature applications (RTMR) in the field of air conditioning systems, however several difficulties are still opposing a wide spread of the technology, despite its high potential in terms of efficiency and environmental impact reduction [1].

The expected performance of regenerative gadolinium-bed (or similar materials) magnetic refrigerators are quite encouraging, and a lot of papers and highly performing prototypes have been built and patented in the last decades, as shown in Figure 2. Up to now, more than one hundred prototypes are working all over the word, including some in Italy [2, 3].

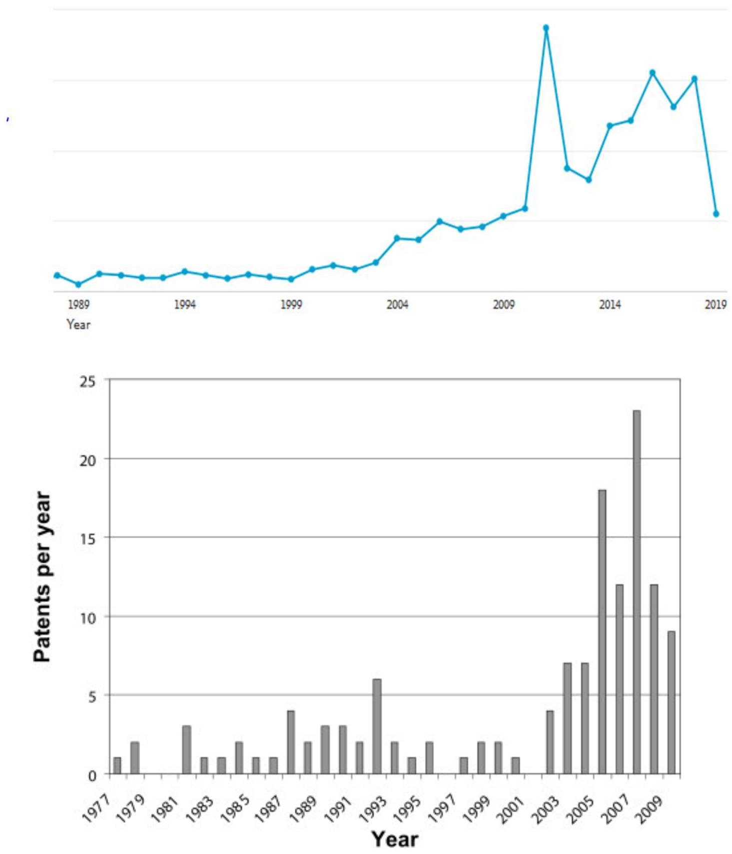

Figure 2. Number of documents on magnetic refrigeration since year 1989 (source: Scopus) and number of patents per year for magnetic refrigerators and magnetic heat pumps operating at or near the room temperature (period: 1976–2009).

A survey on RTMR prototypes is available in [4], while very interesting perspectives are indeed open in the very low temperature ranges for cryogenic applications [5].

To understand how magnetic refrigeration can substitute conventional vapour compression refrigeration systems, and which actual operating limits are, a brief comparison between the two technologies is reported in Figure 3.

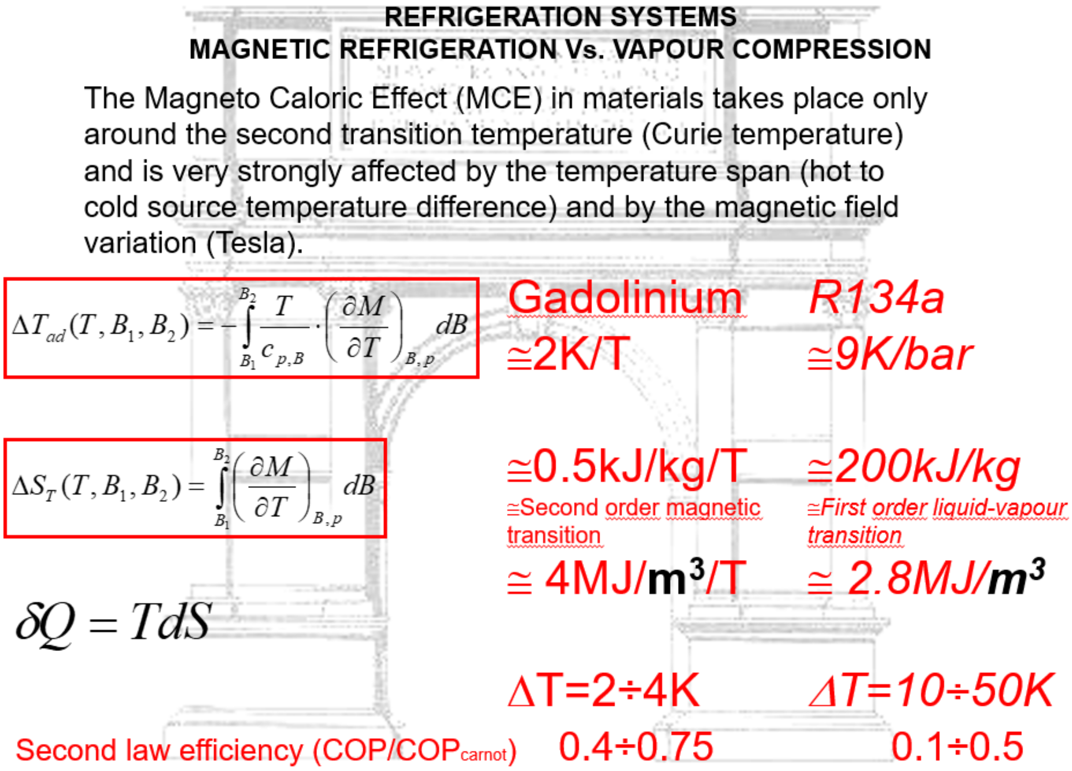

Figure 3. Comparison between RTMR and vapour compression systems. The driving gradient is magnetic field (Tesla) against pressure (bar), the main difference is temperature span (hot-to-cold source temperature difference) without regeneration.

Despite the very much interesting features, the evolution from engineered prototypes to commercial solution is still very difficult, as shown by figures 2 and 4, from which we can argue the following observations:

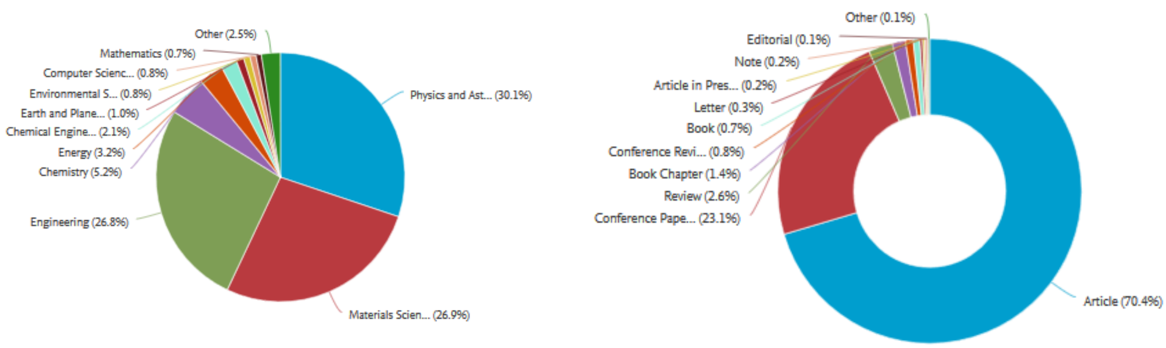

Figure 4. Documents analysis by subject area (left) and source (right)

a) a big interest was grown in the first years 2000, after the diffusion of gadolinium and other MCM material able to perform good refrigeration effects at temperatures near the ambient temperature. The increasing number of scientific papers and patents demonstrates such interest growth until the years 2005-2007.
b) In recent years, some difficulties were still evident, reducing the initial enthusiasm. Such trend is demonstrated by a bit decrease in the slope of the curves, and by the fact (Figure 4) that only 25% of the papers involve engineering activities, while the main studies are still devoted to basic physics and material science.

CONCLUSIONS

Magnetic refrigeration is a very interesting alternative to vapour compression systems, promising better performance, lower environmental impact, noise reduction and reliability. Its application in the field of cryogenic systems has a long-time history. The technological development needed to put in engineering the basic operation concepts for room temperature magnetic refrigeration are available, but some difficulties are still unresolved regarding MCE materials and costs.

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