PERSPECTIVE

Magnetic Refrigeration: An Environment-friendly Cooling Technology

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Since the last few decades, global warming has threatened the sustainable ecology and environment. Its dominance on climate change is well known and largely discussed agenda at most of the international meets. However, the existing conventional vapor compression based refrigeration technology, which typically uses coolant gas like chlorofluorocarbons, tetrafluoroethane, freon, isobutene, etc., has considerable direct/ passive roles in global warming. Hence, the universal technique involved in refrigerators and air conditioners, an essential part of our daily life, is deteriorating the issues. Furthermore, the traditional vapour compression refrigeration technique has its limitation in energy efficiency with the high capital cost of the compressor and the electricity needed to operate the compressor.

Magnetic refrigeration (MR) is an emerging technology using solid, non-volatile, non-toxic magnetic materials as the active components and water or alcohol as the medium for heat transport. It is an efficient technique with great potential because of low energy consumption and environment-friendly cooling at a competitive cost [1-2]. The most promising use of MR is that it can be used 'in reverse' as a heat pump. Using environment-friendly materials rather than toxic gases enables this technology to zero carbon emissions. Solid-state nature and more energy efficiency with better adaptability are the significant advantages of MR over other colling techniques. This technology functions based on a thermodynamic property of magnetic materials. This is commonly known as the magnetocaloric effect (MCE), which causes a temperature change if the material is subjected to a magnetic field under adiabatic conditions. It should be mentioned that MCE was discovered in 1881 by E. Warburg; later, the fundamental principle of MCE for practical purpose was interpreted individually by Debye (1926) and Giauque (1927). Figure 1 illustrates the working principle of MR consisting of the following steps. In step 1, a magnetic material is exposed to a sufficiently high magnetic field, and the magnetic moments of the constituent atoms become oriented along the magnetic field direction. If the magnetic field is applied adiabatically, in other way, if the material is suddenly placed inside a magnetic field, its magnetic moments become ordered. As a result, the magnetic entropy decreases due to magnetic ordering. Therefore, the crystalline lattice entropy will increase to compensate for the loss of magnetic entropy to keep the total entropy constant in the adiabatic process. Consequently, the temperature of the material rises. In step 2, this increased heat can then be removed by cooling the material, keeping the magnetic field constant. These two steps can be performed simultaneously by magnetizing the material isothermally. In that case, the magnetic moments will get ordered, but the temperature will not enhance. The isothermal magnetization process, however, will take a long time to release the heat into the environment without a coolant. In step 3, the applied magnetic field is removed adiabatically, i.e., the material is removed suddenly from the magnetic field. Eventually, the exact opposite phenomena of the first step will occur. The ordered magnetic moments will try to get disorder immediately, and as a result, the temperature of the material will reduce. At the same time, the material is placed in thermal contact with the environment to be refrigerated. As the working material is cooler than the refrigerated environment, heat will be absorbed by the working material. Consequently, the refrigerated substance gets cooled, and the working material will again be in the disordered state, the same as the initial but at less

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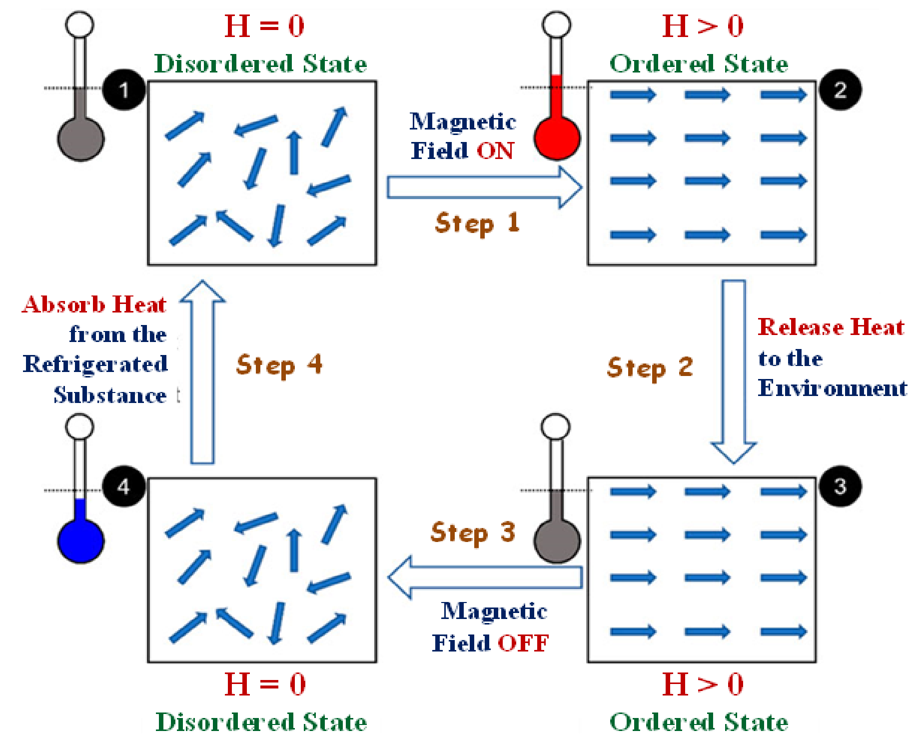

Figure 1. Schematic diagram showing the basic principle of the magnetic refrigeration cycle. Step 1: Magnatic field is ON, Step 2: Release heat to the environment, Step 3: Magnetic field is OFF, and Step 4: Absorb heat from the refrigerated substance. This is a cyclic process.

temperature than the initial. Once the refrigerant and refrigerated environments are in thermal equilibrium, the cycle can restart. Repeating the similar cycle of subsequent application and removal of the external magnetic field with transferring heat energy can somewhat decrease the temperature of the refrigerated substance and the working material.

A good magnetocaloric material (MCM) can be defined in terms of the change in magnetic entropy of a material as a function of temperature and magnetic field change. In a simpler way, it specifies the ability to decrease the temperature in one cycle for a given magnetic field. Additionally, the most efficient cooling produced by an MCM is restricted to its magnetic ordering temperature. However, for the materials exhibiting first-order magnetic transitions (sharp transitions) with temperature, the change in magnetic entropy value is significant, but the working region is usually narrow. On the other hand, in the case of the materials with second-order magnetic transition (broad in nature), the change in magnetic entropy is small, but the transition regime is wide. Therefore, the proper selection of new MCM and their synthesis are crucial for designing a new cooling system, which will operate with moderate magnetic entropy change and maximum working temperature region. However, there are apparent issues in constructing and manufacturing magnetocaloric parts due to the scarcity of basic MCMs. In view of searching for active magnetic refrigerant materials, rare-earth-based compounds have been extensively studied in the recent past. Some of them have emerged as potential refrigerant materials near room temperature, such as Gd (element), $Gd_5Si_{2.3}Ge_{1.7}$, (La, Ca, Sr)MnO_3, etc. [3-5] and Er_3Pd_2, $ErRu_2Si_2$, $HoNiAl_2$, $ErNiAl_2$, etc. at low temperature [6-8].

Despite having cutting-edge technologies, MR is still not a well-established and well-circulated technique for refrigeration due to the unavailability of suitable cheap working materials. Some products have been launched in the market recently but are inaccessible to most consumers due to their high prices. To make it affordable for household appliances, intensive work on MR is being carried out by various laboratories, universities and R&D companies worldwide, including CRADA, Cooltech Applications, Whirlpool, Electrolux, Astronautics, GE Appliances, Samsung, Erasteel, Sanden, Chubu, BASF, VAC, and many more. In India, researchers/ scientists from Bhabha Atomic Research Centre have built a prototype of MR, and they managed to decrease the working temperature to a certain extent. Further research and development of magnetic refrigeration can encourage the manufacturing of a new energy-saving cooling appliance at an affordable cost, and therefore it can be a reliable technology. This results into a cost-effective and readily available technology to the mass population and, thus, extend its effectiveness to promote eco-friendly cooling device by eliminating excess energy consumption at a larger scale.

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Author's biography

Dr. Mantu Modak obatined his PhD in Experimental Condensed Matter Physics from Saha Institute of Nuclear Physics, India in 2020. Currently, he is working as a Research Associate at Bhabha Atomic Research Centre, India. His research interest is magnetic, transport and magnetocaloric properties of rare-earth-based alloys; and pressure induced structural transitions in rare-earth-based pyrochlore oxides. He has published many international journal papers and presented his research work in various international conferences.