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New Eco-friendly Magnetic Refrigeration System

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Abstract - *Most cooling equipment uses a vapor compression cycle, which relies on the physical phenomenon of increasing the pressure of a vapor to raise the condensing temperature at which it releases heat and, subsequently, lowering the pressure of the vapor to decrease the temperature at which it boils and absorbs heat. On the other hand, refrigeration cycles or heat pumping de- vices can be based on a range of physical phenomena besides the vapor compression cycle, including a range of gas compression expansion cycles .With respect to the coefficient of performance (COP), i.e., the ratio of the heat pumped to the work input, the idealized Carnot cycle represents the thermodynamic maximum COP for pumping heat from a low-temperature heat source to a higher temperature heat sink. Thus, when seeking an efficient refrigeration cycle, cycles whose ideal embodiment match or closely approach the Carnot limit are clearly desirable. The magneto caloric effect is a thermodynamically reversible phenomenon that can be used for heat pumping. It is observed in a small range of magnetic materials close to their Curie temperature points.*

When a magneto caloric material is subjected to a strong magnetic field (measured in Tesla, T), the electron spins within the material are forced into alignment with the magnetic field. That is, the magnetic field does work to align the electron spins into what is, thermodynamically, a more highly ordered, lower energy state. The energy released during this process causes the temperature of the material to rise. When the magnetic field is lowered, the electron spins return to their more random, higher energy state, absorbing heat from the material and causing the temperature to fall.

Key Words: Magnetic refrigeration, Thermodynamics, Magneto Caloric effect, Magnetic field, Vapour compression, Vapour absorption, etc.

1.INTRODUCTION

The Magneto caloric effect (MCE, from magnet and calorie) is a magneto-thermodynamic phenomenon in which a reversible change in temperature of a suitable material is caused by exposing the material to a changing magnetic field. This is also known as adiabatic demagnetization by low temperature physicists, due to the application of the process specifically to affect a temperature drop. In that part of the overall refrigeration process, a decrease in the strength of an externally applied magnetic field allows the magnetic domains of a chosen (magnetocaloric) material to become disoriented from the magnetic field by the agitating action of the thermal energy (phonons) present in the material. If the material is isolated so that no energy is allowed to (e) migrate into the material during this time (i.e. an adiabatic process), the temperature drops as the domains absorb the thermal energy to perform their reorientation. The randomization of the domains occurs in a similar fashion to the randomization at the curie temperature, except that magnetic dipoles overcome a decreasing external magnetic field while energy remains constant, instead of magnetic domains being disrupted from internal ferromagnetism as energy is added. One of the most notable examples of the magnetocaloric effect is in the chemical element gadolinium and some of its alloys. Gadolinium's temperature is observed to increase when it enters certain magnetic fields. When it leaves the magnetic field, the temperature returns to normal. The effect is considerably stronger for the gadolinium alloy $Gd_5(Si_2Ge_2)$. Praseodymium alloyed with nickel ($PrNi_5$) has such a strong magnetocaloric effect that it has allowed scientists to approach within one thousandth of a degree of absolute zero. Magnetic Refrigeration is also called as Adiabatic Magnetization

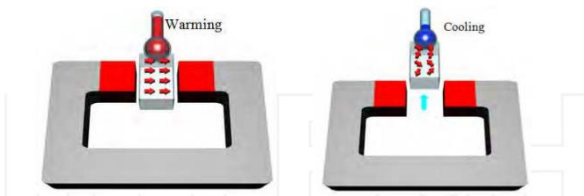

Fig -1: Magneto Caloric Effect

2. LITERATURE SURVEY

Following literature are gives reviews on magnetic refrigeration.

The effect was discovered in pure iron in 1881 by E. Warburg. Originally, the cooling effect varied between 0.5 to 2 K/T.
Major advances first appeared in the late 1920s when cooling via adiabatic demagnetization was independently

proposed by two scientists: Debye (1926) and Giauque (1927). The process was demonstrated a few years later when Giauque and MacDougall in 1933 used it to reach a temperature of 0.25 K. Between 1933 and 1997, a number of advances in utilization of the MCE for cooling occurred. This cooling technology was first demonstrated experimentally by chemist Nobel Laureate William F. Giauque and his colleague Dr. D.P. MacDougall in 1933 for cryogenic purposes (they reached 0.25K). Between 1933 and 1997, a number of advances occurred which have been described in some reviews. In 1997, the first near room temperature proof of concept magnetic refrigerator was demonstrated by Prof. Karl A. Gschneidner, Jr. by the Iowa State University at Ames Laboratory. This event attracted interest from scientists and companies worldwide that started developing new kinds of room temperature materials and magnetic refrigerator designs.

3. PROCESS PRINCIPLE

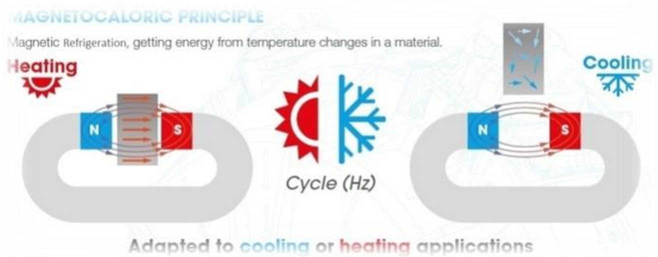

Fig -2: Process Principle

As shown in the figure above, when the magnetic material is placed in the magnetic field, the thermometer attached to it shows a high temperature as the temperature of it increases. But on the other side when the magnetic material is removed from the magnetic field, the thermometer shows low temperature as its temperature decreases

4. CRITERIA FOR SELECTING ROOM TEMPRATURE MAGNETIC MATERIAL

On the basis of the corresponding theoretical analysis and the nature of MCE, magnetic materials in magnetic refrigeration should satisfy several features for application, including [5,6, 7]: (1) the large ΔSM and ΔT ad (i.e. large total angular momentum number (J) and Lande factor (g) for
ferromagnetic material); (2) the large density of magnetic entropy, which is an important factor contributing to the working efficiency of materials; (3) the small lattice entropy (i.e. the high Debye temperature); (4) the modest Curie temperature (TC) in the vicinity of room temperature to guarantee that the large magnetic entropy change can be obtained in the whole temperature range of the cycle; (5) the nearly zero magnetic hysteresis; (6) the very small thermal hysteresis; (7) the small specific heat and large thermal conductivity, which ensure remarkable temperature change and rapid heat exchange; (8) the large electric resistance (i.e. the lowering eddy current heating or the small eddy current loss); (9) the high chemical stability and simple sample synthetic route

5. MAGNETIC MATERIAL

The magneto caloric effect is an intrinsic property of a magnetic solid. This thermal response of a solid to the application or removal of magnetic fields is maximized when the solid is near its magnetic ordering temperature. The magnitudes of the magnetic entropy and the adiabatic temperature changes are strongly dependent upon the magnetic order process: the magnitude is generally small in antiferromagnets, ferrimagnets and spin glass systems; it can be substantial for normal ferrimagnet's which undergo a second order magnetic transition; and it is generally the largest for a ferrimagnet which undergoes a first order magnetic-transition. Also, crystalline electric fields and pressure can have a substantial influence on magnetic entropy & adiabatic temperature changes. Currently, alloys of gadolinium producing 3 to 4 K per tesla (K/T) of change in a magnetic field can be used for magnetic refrigeration or power generation. Recent research on materials that exhibit a giant entropy change showed that $Gd5(SixGe1{-}x)4$, $La(FexSi1{-}x)13Hx$ and $MnFeP1{-}xAsx$ alloys, for example, are some of the most promising substitutes for gadolinium and its alloys-GdDy, GdTy, etc. These materials are called giant magneto caloric-effect materials (GMCE). Gadolinium and its alloys are the best material available today for magnetic refrigeration near room temperature since they undergo second-order phase transitions which have no magnetic or thermal hysteresis involved.

TYPES OF MATERIAL:

1. Gadolinium
2. Gadolinium + alloys
3. Germanium +alloy
4. Holmium

6. ADVANTAGES OF MAGNETO CALORIC EFFECT

Magnetic refrigeration based on the magnetocaloric effect (MCE) in magnetic materials has been demonstrated to be a promising alternative to conventional gas compression refrigeration because:

a. The cooling efficiency of a proof-of-principle magnetic refrigerator working with Gd reaches 60% of the theore tical limit, whereas the best gas compression refrigerator reaches only 40%.

b. Magnetic refrigeration (MR) is an environmentally fr iendly and cost effective technology with considerable energy saving, up to 30% in comparison with conventional gas compression technology.

c. The use of highly energy efficient MR will reduce consumption of fossil fuels, hence reducing CO2 emissions.
d. It also avoids the use of ozone depleting chemicals such as chloroflurocarbons (CFCs), Greenhouse gases, and hazardous chemicals (NH3).

7. APPLICATIONS OF MAGNETO CALORIC EFFECT

Following are some of the important applications of Magneto caloric effect in magnetic refrigeration:

1. Magnetic household refrigeration appliances
2. Magnetic cooling and air conditioning in buildings & houses
3. Central cooling system
4. Refrigeration in medicine
5. Cooling in food industry and storage
6. Cooling in food industry and storage
7. Cooling of electronics

8. FUTURE ASPECTS

In general, at the present stage of the development of magnetic refrigerators with permanent magnets, hardly any freezing applications are feasible. These results, because large temperature spans occur between the heat source and the heat sink. An option to realize magnetic freezing applications could be the use of superconducting magnets. However, this may only be economic in the case of rather large refrigeration units. Such are used for freezing, e.g. in cooling plants in the food industry or in large marine freezing applications
There are still some thermal and magnetic hysteresis problems to be solved for these first-order phase transition materials that exhibit the GMCE to become really useful; this is a subject of current research. A useful review on magneto caloric materials published in 2005 is entitled "Recent developments in magneto caloric materials" by Dr. Karl A. Gschneidner, .This effect is currently being explored to produce better refrigeration techniques, especially for use in spacecraft. This technique is already used to achieve cryogenic temperatures in the laboratory setting (below 10K). As an object displaying MCE is moved into a magnetic field, the magnetic spins align, lowering the entropy. Moving that object out of the field allows the object to increase its entropy by absorbing heat from the environment and disordering the spins. In this way, heat can be taken from one area to another. Should materials be found to display this effect near room temperature, refrigeration without the need for compression may be possible, increasing energy efficiency. In addition, magnetic refrigeration could also be used in domestic refrigerators. In 2006, a research group led by Karl Sandman at the University of Cambridge made a new alloy, composed of cobalt, manganese, silicon and germanium that can be used for magnetic refrigeration. This has made the use of the expensive material gadolinium redundant, and made the creation of domestic magnetic refrigerators possible. The use of this technology for domestic refrigerators though is very remote due to the high efficiency of current Vapor-compression refrigeration in the range of 60% of Carnot efficiency. Gas molecules are responsible for heat transfer, they absorb heat in the inner side of the refrigerator by expanding and release this heat in the outside by condensing. The work provided to do this work is a cheap and highly efficient compressor, driven by an electric motor that is more than 80% efficient. This technology could eventually compete with other cryogenic heat pumps for gas liquefaction purposes.

9. CONCLUSION

Magnetic refrigeration is a technology that has proven to be environmentally safe. Models have shown 25% efficiency improvement over vapor compression systems. In order to make the Magnetic Refrigerator commercially viable, scientists need to know how to achieve larger temperature swings. Two advantages to using Magnetic Refrigeration over vapor compressed systems are no hazardous chemicals used and they can be up to 60% efficient.
There are still some thermal and magnetic hysteresis problems to be solved for these first-order phase transition materials that exhibit the GMCE to become really useful; this is a subject of current research. This effect is currently being explored to produce better refrigeration techniques, especially for use in spacecraft.

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