A Review Paper on Magnetic Refrigeration

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Abstract- *On a summer day, one may reach for a glass of cool water from one's refrigerator while sitting down inside one's cool home. While this setting seems simple enough to the common consumer, the engineer sees specifically engineered cooling systems allowing such climate control. A cooling system consists of a device or devices used to lower the temperature of a defined region in space through some cooling process. Currently, the most popular commercial cooling agent is the refrigerant. A refrigerant in its general sense is what makes refrigerator cool foods, and it also makes air conditioners and other appliances perform their respective duties. A typical consumer based refrigerator lowers temperatures by modulating a gas compression-expansion cycle, to cool a refrigerant fluid which has been warmed by the contents of the refrigerator (i.e. the food inside). Typical refrigerants used in refrigerators from the late 1800's through 1929 included ammonia, methyl chloride, and sulfur dioxide, all of which are toxic. To mitigate the risks associated with toxic refrigerants, a collaboration by Frigidaire, General Motors, and DuPont netted the development of Freon (or R12), a chlorofluorocarbon. Freon is a non-flammable and non-toxic, but ozone-depleting gas(1) . There has been much research done as of late by the group of Karl Gschneidner Jr., Vitalij Pecharsky, and David Jiles at Ames Laboratory, run by the Department of Energy, working in collaboration with the Astronautics Corporation of America. Their research has focused on the materials suitable for a magnetic refrigeration process and the 3 design of a suitable prototype. However with a drop off in funding from the Department of Energy, such efforts have been prolonged and have taken greater amounts of time than were initially expected. There are two attractive reasons why magnetic refrigeration research continues. While a magnetic refrigerator would cost more than today's refrigerator at purchase, it could conserve over and above 20% more energy than current expansion-compression refrigerators, drastically reducing operating costs.*

I. INTRODUCTION

The magnetocaloric effect (MCE), or adiabatic temperature change (ΔTad), which is detected as the heating or the cooling of magnetic materials due to a varying magnetic field, was originally discovered in iron by Warburg in 1881. In 1890 Tesla and in 1892 Edison independently and unsuccessfully tried to benefit from this effect by running heat engines. In 1918 Weissand Piccard explained the magnetocaloric effect. Later, Debye and Giauque proposed a method of magnetic refrigeration for lowtemperature physics in order to obtain sub-Kelvin temperatures. In 1933 Giauque and MacDougall successfully verified the method by experiment. Since the 1930s magnetic refrigeration has been a standard technique in low-temperature physics. In 1976 Brown designed the first magnetic refrigerator working at room temperature. About 15 years later, Green et al. built a device which actually cooled a load other than the magnetocaloric material itself and the heat exchange fluid. The major breakthrough, however, occurred in 1997 when the Ames Laboratory/Astronautics proofof-principle refrigerator showed that magnetic refrigeration could be competitive with conventional gas-compression cooling. The early prototypes were able to reach high magnetic flux densities in the magnetocaloric material only if superconducting magnets were applied. The first "room-temperature magnetic refrigerator" containing permanent magnets was designed and built in 2001 by the same group at Astronautics Corporation.[1] Later, numerous prototypes based on permanent magnets were built [9]. Research today is focused on improvements to magnetocaloric materials, magnets and the optimal design of devices. The interest in magnetic refrigeration as a new solid-state cooling technology competitive with the conventional vapor-compression approach has grown considerably over the past 10 years, coinciding with rising international concerns about global warming due to an ever-increasing energy consumption. As shown in Fig. (1), the number of published papers per annum on the magnetocaloric effect has grown at an exponential rate in the past 10 years.

II. HISTORY OF MAGNETO CALORIC REFRIGERATION

The MagnetoCaloric Effect was only limited at extremely low temperatures, The use of Magnetocaloric Effect was made possible due to discovery of New Magneto-Caloric Materials which showed effect at even room temperatures.

III. MAGNETO CALORIC EFFECT

MCE is "the response of a magnetic solid to a changing magnetic field which is evident as a change in its temperature" (Gschneidner)2 . When a magnetic field is applied to a magnetic material, the unpaired spins partially comprising the material’s magnetic moment are aligned parallel to the magnetic field. This spin ordering lowers the entropy of the system since disorder has decreased. To compensate for the aligned spins, the atoms of the material begin to vibrate, perhaps in an attempt to randomize the spins and lower the entropy of the system again. In doing so, the temperature of the material increases. Conversely, outside the presence of a file, the spins can return to their more chaotic, higher entropy states, and one then observes a decrease in the material’s temperature. The warming and cooling process can be likened to a standard refrigerator which implements compressing and expanding gases for variations in heat exchange and surrounding temperature.

IV. MAGNETOCALORIC MATERIALS

MCE works only in the vicinity of a material's transition temperature. It reaches a maximum value at a material's Curie temperature, the temperature above which a ferromagnetic material becomes paramagnetic due to the noise generated by atomic vibrations. The range of temperatures about which a material experiences a substantial MCE and adiabatic temperature drop is typically +/- 20 C around the Curie temperature. Gadolinium has a Curie temperature of 20 C, near room temperature making it an excellent candidate for research in the area. Thus, Gd is a suitable magnetic material for refrigeration (though not for freezing) since it has a substantial MCE for temperature ranges roughly between 0 C and 40 C.4

Some materials were observed to have unusually large magnetocaloric effects, and this discovery made it much more feasible to develop a machine at lower costs. It was observed first in Gd alloys, most notably Gd5(Si2Ge2), "due to a simultaneous magnetic and crystallographic first order transition. The adiabatic temperature rise for the material was 30% higher than that of just Gd and 200-600% higher than the previous refrigerant materials, DyAl2, GdAl2, and Gd0.73Dy0.27. " (Gschneidner)2 . The magnetic entropy change approached a 100% increase over Gd.

It 7 was, thus, discovered that Gd5(Si2Ge2) fared much better as a magnetic material for magnetic refrigeration than the previously considered materials.

V. REGENERATORS

Magnetic refrigeration requires an excellent heat transfer to and from the solid magnetocaloric material .efficient heat transfer requires the large surface areas offered by porous materials. These porous refrigerators are referred to as REGENERATORS.

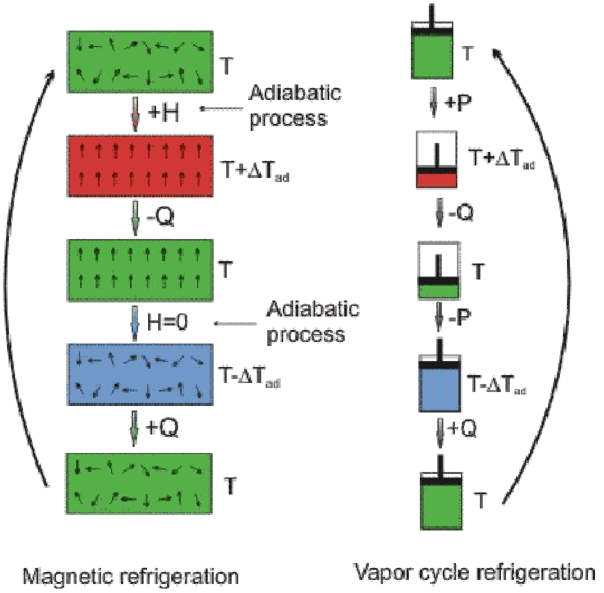
VI. OPERATION OF MAGNETIC REFRIGERATOR

The magneto caloric refrigerator consist of a magneto caloric material in the form of a porous structure also called as (AMR)Active Magnetic Regenerator.AMR works as a refrigerant and also as a regenerator for generating heat.The structure of the refrigerator should be such that to utilize the complete refrigeration without any losses.

Generally rotary type of magnetic refrigerator is the most efficient in which the AMR is rotated in the cavity provided by electro magnets.Superconducting magnets can also be used but because of their high cost we are unable to use them.

The thermodynamics of magnetic refrigeration by Maxwell’s equation is given in (5)

Thermodynamic cycle



(Analogy between magnetic refrigeration and vapor cycle or conventional refrigeration.) H = externally applied magnetic field; Q = heat quantity; P = pressure; ΔT_{ad} = adiabatic temperature variation

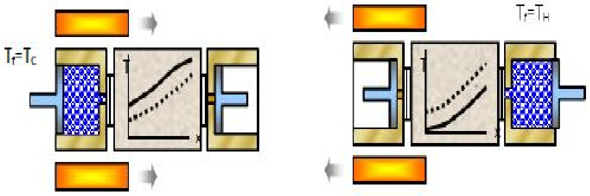
The cycle is performed as a refrigeration cycle that is analogous to the Carnot refrigeration cycle, but with increases and decreases in magnetic field strength instead of increases and decreases in pressure. It can be described at a starting point whereby the chosen working substance is introduced into a magnetic field, i.e., the magnetic flux density is increased. The working material is the refrigerant, and starts in thermal equilibrium with the refrigerated environment.

- ***Adiabatic magnetization**:* A Magnetocaloric substance is placed in an insulated environment. The increasing external magnetic field (+*H*) causes the magnetic dipoles of the atoms to align, thereby decreasing the material's magnetic entropy and heat capacity. Since overall energy is not lost (yet) and therefore total entropy is not reduced (according to thermodynamic laws), the net result is that the substance is heated ($T + \Delta T_{ad}$).
- ***Isomagnetic enthalpic transfer**:* This added heat can then be removed (-*Q*) by a fluid or gas — gaseous or liquid helium, for example. The magnetic field is held constant to prevent the dipoles from reabsorbing the heat. Once sufficiently cooled, the magnetocaloric substance and the coolant are separated (*H*=0).
- ***Adiabatic demagnetization**:* The substance is returned to another adiabatic (insulated) condition so the total entropy remains constant. However, this time the magnetic field is decreased, the thermal energy causes the magnetic moments to overcome the field, and thus the sample cools, i.e., an adiabatic temperature change. Energy (and entropy) transfers from thermal entropy to magnetic entropy, measuring the disorder of the magnetic dipoles.[10]
- ***Isomagnetic entropic transfer**:* The magnetic field is held constant to prevent the material from reheating. The material is placed in thermal contact with the environment to be refrigerated. Because the working material is cooler than the refrigerated environment (by design), heat energy migrates into the working material (+*Q*).

Once the refrigerant and refrigerated environment are in thermal equilibrium, the cycle can restart.

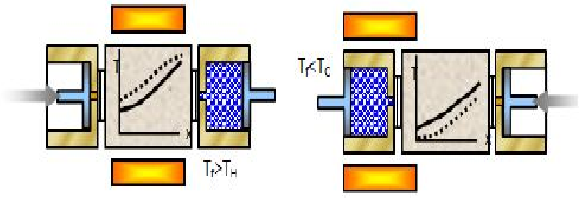
The practical model can be studied in paper by aedah.m(4).

The numerical study of the magnetic refrigerator can be found in (6)



a) Magnetization

c) Demagnetization



b) Isofield cooling process

d) Isofield heating process

The Standard Adiabatic magnetization can be achieved by following the steps as:

(i) Apply a strong magnetic field to the magnetization material (refrigerant) in the thermally isolated condition with no fluid flow, forcing its various magnetic dipoles to align, gives out heat energy and increase its temperature. At the beginning of the cycle, the fluid is at the cold temperature Tc .

(ii) Maintaining the applied field, the fluid is circulated through the regenerator. The fluid absorbs heat from the material and transports it to the hot heat exchanger till its temperature is raised above the heat rejection temperature Th.

(iii) Keeping the refrigerant thermally insulated in the magnetized condition, the magnetic field is removed in

(iv) the absence of the fluid flow. Disordering being endothermic decreases its temperature much below the temperature of the heat sink.

(v) Now circulate the fluid for getting cooled and the cooled fluid is circulated in the space to be cooled as is conventional in central air conditioning system. Thus refrigeration will be obtained. These four steps will be repeated time and again for continuous cooling.

VII. MERITS OF MAGNETIC REFRIGERATION

(i) It is more efficient and reduces the power consumption by 20 to 30 %

(ii) Magnetic refrigeration is eco-friendly as these do not cause Global Warming and Ozone Depletion.

(iii) There is no leakage or contamination of the refrigerant.

(iv) This system is simple, safe and durable
(v) It has fewer maintenance problems because there is no moving part.
(vi) Disposal of such systems will be simple and cost effective.

VIII. DEMERITS OF MAGNETIC REFRIGERATION

(i) Strong magnets are required which are Expensive.
(ii) Magneto caloric materials till date are costly.
(iii) System will be overall bulky(volume 2 to 3 times), heavy (weight 3 to 4 times) and costly (2 to 3 times).
(iv) Performance will decrease gradually due to use of solid refrigerants.

IX. CONCLUSION

- Magnetic cooling devices can offer a similar or improved performance than traditional vapor compression refrigeration systems
- Extremely Low temperatures can be obtained by magnetic refrigeration
- The performance is best achieved at the curie temperatures
- The combination of VCR cycle and the MCE cycle can give a high performance for military uses and portable purposes.
- The future of magnetic refrigeration appears bright .huge research is being done on the topic primarily to overcome pollution, and seconadarily to reduce the power consumption.
- The Cost of the system can be reduced by inventing a cheap, easily available magneto caloric material.
- The system can be optimized to be used in commercial plants,and air-conditioning applications due to development of operation of refrigerator at room temperatures

REFERENCES

[1] “Magnetic cooling-Development of magnetic Refrigerator”{jaka-tusek-samo zupan-ivan prebil-aloj poredos,university of Ljubljana,Faculty of Mechanical Engineering.}

[2] (“MAGNETIC REFRIGERATION –A BOON FOR COMING GENERATIONS”)Dr. L.C.SINGAL,AISHA MAHAJAN,RAJWINDER SINGH.

[3] “THERMODYNAMICS OF MAGNETIC REFRIGERATION” ‘Andrej Kitanovski,Peter W. Egolf’

[4] MAGNETOCALORIC REFRIGERATION REASERCH AT THE INCT IN COOLING AND THERMOPHYSICS “Jader barbosa,jaime lonazo,Paulo trevizoli”

[5] PRACTICAL STUDY OF MAGNETIC REFRIGERATION PERFORMANCE AND OPTIMIZATION”AEDAH M.,Jawad mahdy, wahid mohammad,talib k.mortada”

[6] MAGNETOCALORIC EFFECT AND MAGNETIC REFRIGERATION :ANALYTIC

[7] AND NUMERICAL STUDY {A.Boubekri,M.Y.EL hafifdi, and M eEL hafidi}

[8] About.com. “Refrigeration”. http://inventors.about.com/library/inventors/blfreon.htm

[9] Gschneidner K., Pecharsky. "Magnetic Refrigeration Materials". "Journal of Applied Physics". vol.85, no.8,15. April 1999. pp.5365-5368

[10] Bohigas X. "Tunable Magnetocaloric Effect in Ceramic Perovskites". "Applied Physics Letters". vol. 73. no. 3,20. July 1998. pp.390-392.

[11] Gschneidner Jr., Karl. “Magnetic Refrigeration”. Rare Earths: Science, Technology and Application III. The Minerals, Metals & Materials Society. 1997.

[12] 5. "Journal of Magnetism and Magnetic Materials". "Composition Dependence of magnetic Properties in Amorphous Rare-Earth Metal-Based Alloys". vol. 174. no. 3. October 1999, pp.295-308.

[13] Korte B. "The Correlation of the Magnetic Properties and the Magnetocaloric Effect in Gd, Er NiAl Alloys". "Journal of Applied Physics". vol. 84, no.10,15. Nov. 1998, pp. 5677-5685.

[14] Wada H. "Magnetocaloric EfFect of ErCo2". "Journal of Magnetism and Magnetic Materials". May 1999. pp.689-700.

[15] Bisio G, Department of Energy. Intersociety Energy Conversion Engineering Conference. "Thermodynamics of Magnetic Systems and Some Applications". 1999.

[16] Materials Technology. "New Materials for Magnetic Refrigeration Promise Cost Effective, Environmentally Sound Air Conditioners, Refrigerators/Freezers, and Gas Liquefiers". September, 1999.

[17] Bisio G, Rubbatto G. "Magnetic Systems Depending on 3 or 2 variables; Thermodynamic Analysis and Some Exciting and Possible Applications". "Energy Conversion and Management". vol. 40, no. 12. August 1999. pp.1267-1286.

[18] Gschneidner Jr., Karl et al. Proceedings Domotechnica Appliance Engineering Conference. ”Magnetic Refrigerators/Freezers and Air Conditioners”. P. 170 - 182. 2001. 12. Gschneidner Jr., Karl et al. Personal Correspondence. “Status of Magnetic Refrigeration - April 23, 2003