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Refrigeration Technology Using Magnetic Force

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ABSTRACT

Magnetic refrigeration is a process of refrigeration based on the magnetocaloric effect. This effect, as covered in 1881, is defined as the response of a solid to an applied magnetic field which manifests as a change in the temperature of the solid. This effect is obeyed by all the transition metals and lanthanide-series elements. Gadolinium, a rare-earth metal, exhibits one of the largest known magnetocaloric effects. The main difference lies in this process being void of a compressor. The compressor is the most inefficient and expensive part of the conventional gas compression system. In place of the compressor are small beds containing the magnetocaloric material, a small pump to circulate the heat transfer fluid, and a drive shaft to move the beds in and out of the magnetic field.

***KEYWORDS:* Magnetocaloric, Ferromagnet cools, Rare-earth metal, Compressor.**

1. INTRODUCTION

Magnetic refrigeration is a process of refrigeration based on the magnetocaloric effect. This effect, discovered in 1881, is defined as the response of a solid to an applied magnetic field which is manifests as a change in temperature of the solid. This effect is obeyed by lanthanide series and all transition elements. Gadolinium, it is a rare earth metal, exhibits one of the largest known magnetocaloric effects. When a magnetic field is applied, these metals, called as Ferro-magnets, tends to heat up. As heat is applied, the magnetic moments align. When the field is removed, the Ferro-magnet cools down as the magnetic moments become randomly oriented. This magnetocaloric effect for refrigeration purposes was first investigated in the mid-1920's but is just now nearing a point where it could be useful on a commercial scale. The main difference associated with this process is that it is void of a compressor. The conventional gas compression system uses a part compressor which is very expensive and inefficient. In place of the compressor are small beds containing the magnetocaloric material, a small pump to circulate the heat transfer fluid, and a drive shaft to move the beds in and out of the magnetic field. The fluid used for heat transfer in this process is water mixed with ethanol instead of the traditional refrigerants that pose threats to the environment.

1.1 Magneto caloric Effect

In 1881, Emil Warburg, a German physicist, placed a piece of metal near a strong magnet. The metal warmed up. Present-day scientists and engineers hope to take advantage of that phenomenon not for heating, but the opposite: for building a new type of refrigerator that is quiet and efficient.

2. PRINCIPLE

Magnetocaloric effect causes a change in temperature when a certain metal is exposed to a magnetic field. All transition metals and lanthanide series elements obey this effect.

Magnetic refrigeration technology takes advantage of the magnetocaloric effect, the remarkable ability of a magnetic material to heat up in the presence of a magnetic field and cool when the field is removed. Magnetocaloric materials store heat energy in the way the atoms vibrate and in the way in which electrons spin within each atom. More heat energy increases the vibrations and also makes the spins more random. In other words, when the party heats up, things get a little crazy. Scientists refer to this "craziness" as entropy, which is a measure of thermodynamic disorder. When a strong magnetic field is applied to the coolant material, the magnetic moments of its atoms align, making the system more ordered. The more ordered material has lower entropy and compensates for the loss by heating up.

But when the strong magnetic field is removed, the party is forced to cool down. The magnetic moments return to their random directions, entropy increases and the material cools. Typically, the temperature of a material can drop by about 10 to 15 degrees Celsius (52 to 59 F), depending on the magnetic field strength.

2.1 Thermodynamic Concept

The reversible change of temperature is achieved through the change of magnetization of a ferromagnetic or paramagnetic material. Thermodynamic theory shows that, for an adiabatic change of field dH, the change of temp dT is given by,

$$(dT/dH) = - (T/CH)\ (dM/dT)H$$

Where CH is the specific heat per unit volume at constant H, and M is the magnetization. Except in antiferromagnets, (dM/dT)H is negative and an adiabatic decrease in H causes T to drop. This is the basis of the Giauque-Debye adiabatic demagnetization of paramagnetic salts, a technique that has achieved extremely low temperatures. Adiabatic demagnetization has been employed since 1933 to produce temperatures below those readily obtainable by using only liquid helium (i.e., below 1K).

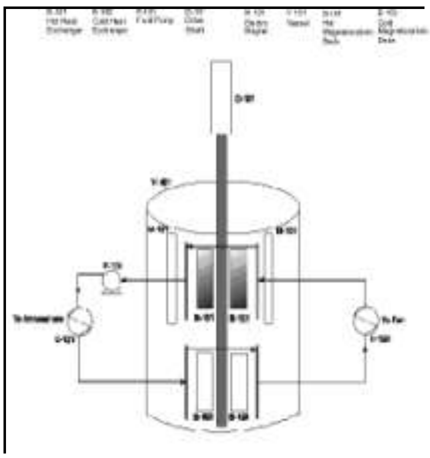
3. MAGNETIC REFRIGERATOR

3.1 Construction and Working

The magnetic refrigerator based on magnetocaloric effect is shown in fig.2. It has two rotating cylinders containing powdered gadolinium – a dense, grey, rare earth metal and a superconducting magnet. Gadolinium has a favorable magneto caloric coefficient. Each atom of gadolinium has seven unpaired electrons in an intermediate shell, which gives the element a strong magnetic moment. This type of refrigerator is reported to work at near-room temperature to produce substantial amount of cooling power. At a fixed temperature, the entropy of a magnetic system gets lowered as the spins align with an applied magnetic field. When a ferromagnetic material, such as gadolinium, is placed in a magnetic field, the magnetic moments of its atoms become aligned, making the material more ordered. But, the amount of entropy in the magnet must be made conserved, so the atoms vibrate more rapidly, raising the material temperature. Conversely, when gadolinium is taken out of the magnetic field, the material cools. This magnetocaloric effect typically produces a temperature arrangement should be made such that, water is pumped into one of the cylinders of gadolinium immediately after it moves out of the magnetic field. The water cools as it flows through the porous bed of demagnetized gadolinium, and through a heat exchanger. Next, the water passes through the cylinder of gadolinium that is inside the magnetic field. This stream of water heats up and flows through another exchanger and cooling the other. After a preset time interval, the two cylinders of gadolinium compound switch places, and the flow of water is reversed. Besides, antifreeze can be added to the water to allow the machine to cool below zero degrees Celsius.

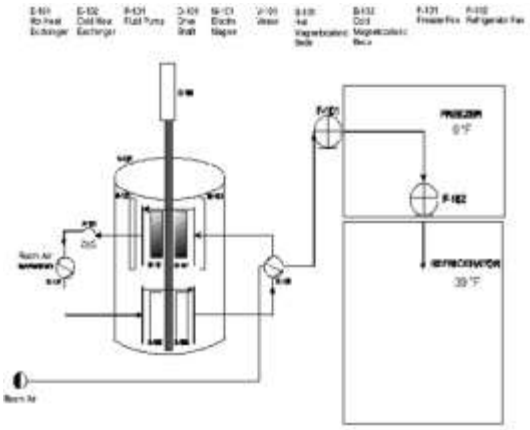
3.2 Process Flow Diagrams

The process flow diagram for the magnetic refrigeration system is shown in Fig.3. A mixture of water and ethanol serves as the heat transfer fluid for the system. The fluid first passes through the hot heat exchanger, which uses air to transfer heat to the atmosphere. The fluid then passes through the copper plates attached to the non-magnetized cooler magnetocaloric beds and loses heat.



A fan blows air past this cold fluid into the freezer to keep the freezer temperature at approximately 0°F. The heat transfer fluid then gets heated up to 80°F as it passes through the copper plates adjoined by the magnetized warmer magnetocaloric beds, where it continues to cycle around the loop. However, the magnetocaloric beds simultaneously move up and down, into and out of the magnetic field.

The temperature of the fluid throughout the cycle ranges from –12°F to 80°F. The heat transfer fluid at approximately 70°F gets cooled to –12°F by the non-magnetized cold set of beds. This cooled fluid is then sent to the cold heat exchanger, E-102, where it absorbs the excess heat from the freezer. This fluid leaves the freezer at 0°F. The warm fluid then flows through the opposite magnetized set of beds, where it is heated up to 80°F. This hot stream is now cooled by room temperature air in the hot heat exchanger, E-101, to 70°F. The cycle then repeats itself every three seconds after the beds have switched positions. Copper tubing is used throughout the loop and in the two heat exchangers. The two sets of beds, B-101 and B-102, contain the small spheres of magnetocaloric material. The size of the beds resembles that of half of a soda can. The beds are alternated in and out of the magnetic field using a chain and sprocket drive shaft. The drive shaft rotates the beds back and forth while still keeping them in
contact with the heat transfer plates.



The mixture used in the design consists of 60 % ethanol and 40 % water. This mixture has a freezing point of –40°F6, assuring that the mixture does not freeze at the set operating temperatures.

4. CONCLUSION

The ecofriendly alternate refrigeration technologies described in this seminar are still in the stage of infancy. But there is a strong support of the principle used in this technology. Moreover, rapid developments are taking place in various fields of science and technology. Therefore, scientists and technologists are confident that the ecofriendly, reliable, simple and convenient technologies of refrigeration described in this article will be used for domestic and commercial purposes in the near future. Although at present this technology look very ecofriendly, same as mechanical refrigeration systems were before the development of CFCs and HCFCs as refrigerants, further developmental efforts should always be checked from the environmental point of view before they are implemented. The major advantages to the magnetic refrigeration technology over compressor based refrigeration are the design technology, environmental impact, and operating cost savings. Recent developments in MR design by the Ames Laboratory and the Astronautics Corporation of America plus the discovery of a new family of giant magnetocaloric effect materials could soon bring the potential for widespread commercialization of magnetic refrigeration technology close to realization.

5. REFERENCES

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