Study of Magnetic Refrigeration

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Abstract

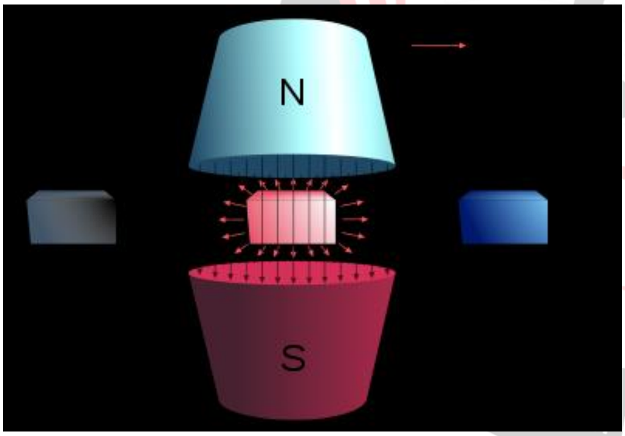
Now a days, there is a need to find alternative methods for refrigeration systems because of various reasons. So, this review paper contains the study of such an alternative method for conventional refrigeration system, i.e. Magnetic Refrigeration System and contribution of different scientists in the study of this system.

Keywords: Magneto-Caloric Effect, Thermodynamic Cycle.

1. Introduction

Magnetic refrigeration is a cooling technology based on the **magneto caloric effect**. This technique can be used to attain extremely low temperatures (well below 1 K). It can be also used for normal temperature refrigeration.

The German scientist Emil Warburg first studied this effect in late 1900's. Debye and Nobel Laureate Giauque proposed the fundamental principle for magnetic refrigeration in 1926 and 1927 respectively. It is the first method which can be used for cooling below 1 kelvin temperature. It is suitable for cryogenics.



German physicist Emil Warburg (1880)discovered this effect first, followed by French physicist P. Weiss and Swiss physicist A. Piccard in 1917.

When Peter Debye independently proposed the cooling by Adiabatic Demagnetization in 1926, Major Advances appeared in this field. Chemistry Nobel Laureate William F. Giauque in 1927 also studied and proposed adiabatic demagnetization.

Nobel Laureate Giauque and his colleague D.P.Macdougall first demonstrated this effect experimentally in 1933 for cryogenic purposes. They reached upto 0.25 K. Further advances in MCE occurred between 1933 and 1997.

In 1997, Karl A. Gschneidner, Jr. by the Iowa State University demonstrated the first near room-temperature proof of concept magnetic refrigerator at Ames Laboratory. This event attracted interest from scientists and companies worldwide . Later, they started developing new kinds of room temperature materials and magnetic refrigerator designs.

A major breakthrough came 2002 when a group at the University of Amsterdam demonstrated the giant magneto-caloric effect. They used the material as Mn-Fe alloys.

Using magnetic field up to 0.6 T to 10 T, MCE based Refrigerators are demonstrated in various laboratories. It is difficult to produce magnetic effect above 2T with permanent magnets. They are produced by a superconducting magnet. (1T = 20000 times the earth's magnetic field

2. General Principle:

Magnetic refrigeration is based on the Magneto caloric Effect (MCE).

The MCE tells that the temperature of suitable materials (Magneto caloric Materials, MCM) increases when they are uncovered to a magnetic field and decreases when they are separated from it, that is, the effect is reversible and almost immediate.

The temperature with the strongest effect (the Curie temperature) depends on the properties of each material. The power generated by the arrangement depends on the type of materials and their features (mass and shape).

All magnets bear a property called Curie Effect .i.e. If the temperature of magnet is increased from lower to higher range at certain temperature, magnet looses the magnetic field.

The magnetocaloric effect (MCE, from *magnet* and *calorie*) is a magneto-J 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 magneto caloric 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 drops. 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.

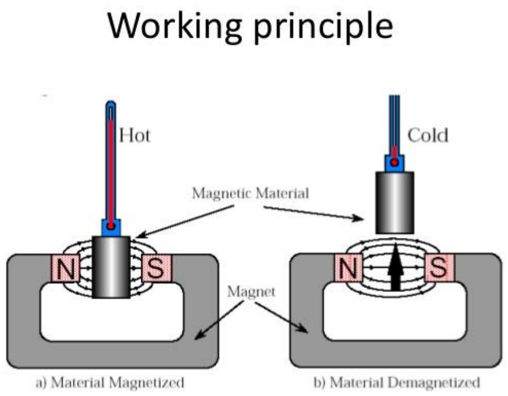
In actual Practice, following things happen in order to produce desired cooling effect:

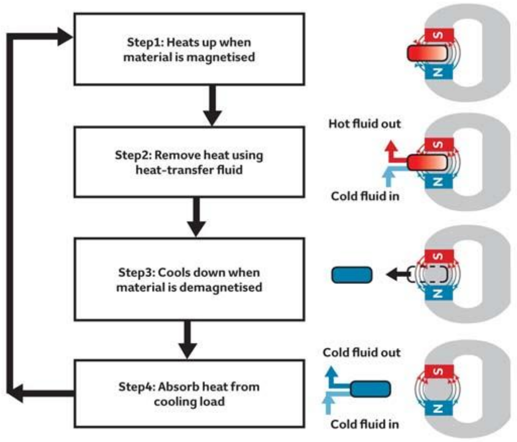
Magnetic field is provided to a magneto caloric material. This increases the temperature of the material.

Now to attain Equilibrium, the material transfers the heat to the surroundings until the temperatures of material and surroundings become equal.

At this point, magnetic field is removed from the material. So according to Magneto caloric Properties of material, the temperature of material decreases further below the surrounding temp.

That is the desired refrigeration effect.





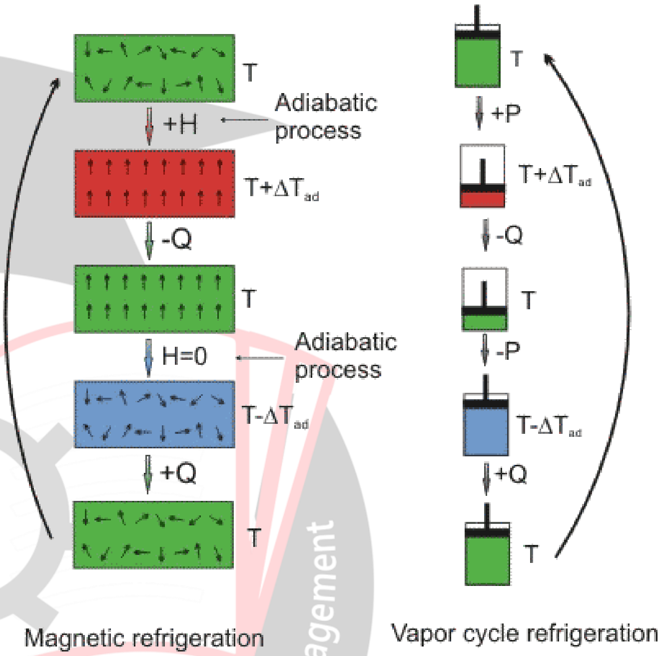
3. **Thermodynamic Cycle :**

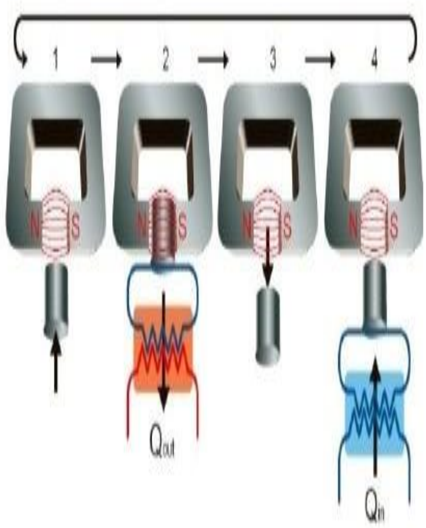
DETAILS OF THERMODYNAMIC CYCLE:

Process is similar to gas compression and expansion cycle as used in regular refrigeration cycle.

Steps of the cycle are as follow:

1. **Adiabatic Magnetization.**
2. **Isomagnetic Enthalpy Transfer.**
3. **Adiabatic Demagnetization.**
4. **Isomagnetic Entropy Transfer.**





ADIABATIC MAGNETIZATION :

- Substance is placed in insulated environment.
- Magnetic field +H is increased.
- This causes the magnetic dipoles of the atoms to

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align

- The net result is, the item heats up(T+ΔTad.)

ISOMAGNETIC ENTHALPY TRANSFER :

- Added heat is removed by a fluid like water or helium.
- Magnetic field is held constant to prevent the dipoles from reabsorbing the heat.
- After a sufficient cooling, Magneto Caloric material and coolant are separated.

ADIABATIC DEMAGNETIZATON :

- Substance returns to another adiabatic(insulated) condition.
- Entropy remains constant.
- Magnetic field is decreased.
- Thermal energy causes the magnetic moments to overcome the field and sample cools(adiabatic temperature change.)
- Energy transfers from thermal entropy to magnetic entropy (disorder of the magnetic dipoles.)

ISOMAGNETIC ENTROPIC TRANSFER :

- Material is placed in thermal contact with the environment being refrigerated.
- Magnetic field is held constant to prevent material from heating back up.
- Because the working material is cooler than the refrigerated environment, heat energy migrates into the working environment.
- Once the refrigerant and refrigerated environment are in thermal equilibrium, the cycle continues.

4. Applied Technique:

The basic operating principle of an adiabatic demagnetization refrigerator (ADR) is the use of a strong magnetic field to control the entropy of a sample of material, often called the "refrigerant". Magnetic field constrains the orientation of magnetic dipoles in the refrigerant. The stronger the magnetic field, the more aligned the dipoles are, and this corresponds to lower entropy and heat capacity because the material has (effectively) lost some of its internal degrees of freedom. If the refrigerant is kept at a constant temperature through thermal contact with a heat sink (usually liquid helium) while the magnetic field is switched on, the refrigerant must lose some energy because it is equilibrated with the heat sink. When the magnetic field is subsequently switched off, the heat capacity of the refrigerant rises again because the degrees of freedom associated with orientation of the dipoles are once again liberated, pulling their share of equipartitioned energy from the motion of the molecules, thereby lowering the overall temperature of a system with decreased energy. Since the system is now insulated when the magnetic field is switched off, the process is adiabatic, *i.e.*, the system can no longer exchange energy with its surroundings (the heat sink), and its temperature decreases below its initial value, that of the heat sink.

The operation of a standard ADR proceeds roughly as follows. First, a strong magnetic field is applied to the refrigerant, forcing its various magnetic dipoles to align and putting these degrees of freedom of the refrigerant into a state of lowered entropy. The heat sink then absorbs the heat released by the refrigerant due to its loss of entropy. Thermal contact with the heat sink is then broken so that the system is insulated, and the magnetic field is switched off, increasing the heat capacity of the refrigerant, thus decreasing its temperature below the temperature of the helium heat sink. In practice, the magnetic field is decreased slowly in order to provide continuous cooling and keep the sample at an approximately constant low temperature. Once the field falls to zero or to some low limiting value determined by the properties of the refrigerant, the cooling power of the ADR vanishes, and heat leaks will cause the refrigerant to warm up.

5. Working Materials:

The magnetocaloric 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 ferromagnets which undergo a second order magnetic transition; and it is generally the largest for a ferromagnet which undergoes a first order magnetic transition.

Also, crystalline electric fields and pressure can have a substantial influence on magnetic entropy and 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.

Recent research on materials that exhibit a giant entropy change showed that $Gd_5(Si_xGe_{1-x})_4$, $La(Fe_xSi_{1-x})_{13}H_x$ and $MnFeP_{1-x}As_x$ alloys, for example, are some of the most promising substitutes for gadolinium and its alloys — GdDy, GdTy, etc. These materials are called giant magnetocaloric effect materials (GMCE).

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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.

6. **Future Applications:**

At the present stage of the development of magnetic refrigerators by using permanent magnets, any high freezing applications are hardly possible. Some of the future applications are as follows:

- Magnetic household refrigerating appliances.
- Magnetic cooling and refrigeration systems in building and houses.
- Central cooling system.
- Cooling in food industry and storage.
- Cooling in transportation.
- Cooling in electronic equipments.

Advantages:

- Running costs are 20% less than the conventional refrigeration.
- Life cycle cost is much lesser.
- Ozone depleting refrigerants are absent. Hence, the system is Eco-Friendly.
- The efficiency of magnetic refrigerators is 60% to 70% as that of Carnot Cycle.
- The system is totally maintenance free and mechanically simple in construction.

Disadvantages:

- Initial cost is more than the conventional system.
- As Magneto Caloric Effect is well established in Rare Earth Metals like Gadolinium, installing of system using such materials become difficult.

6.Conclusion:

- It is the technology that has proven to be environmentally safe. Computer models have shown 25% efficiency improvements over vapour compression System.
- In order to make the magnetic refrigeration commercially viable, scientists need to know how to achieve larger temperature swings and also permanent magnets which can produce strong magnetic fields of order 10 Tesla.
- There are still some thermal and magnetic hysteresis problems to be solved for the materials that exhibit the MCE to become really useful.

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