Vacuum-Magnetic Refrigerator

An Application Using Gadolinium Plates

[1]K.Krishna das, [2]S.Thamilarasu, [3]P.DuraiRaj
[1]UG research scholar, [2]Assistant Professor, [3]Assistant Professor
[1,2,3]Department of Mechanical engineering,
[1,2,3]SRM University, Vadapalani, Chennai, India

***Abstract*— this paper is about how gadolinium can be used as a refrigerant making use of magnetism. Initially the hot object is kept in a closed box that is almost like a refrigerator shelf. And the system is switched on which starts the vacuum pump creating a suction pressure. Now after reaching a particular pressure the air valves opens up one letting in the air from the box into the vacuum chamber at the same time this vacuum pressure is maintained by pumping out the air coming into the chamber using a motor. This air is now hot and is made to fall on gadolinium alloy kept in magnetic fields on a disc that will start to rotate when a particular temperature.**

***Index Terms*— gadolinium alloy, magnetic field, vacuum, pressure, hot air, cold air.**

I. INTRODUCTION

Today in the field of thermal engineering, cooling an object can be done in numerous ways, one such way is the invention of the refrigerator. During early days, refrigerators were considered a luxury even though in remote places such electronic devices have not yet taken their place in spite of we living in the 21st century. But there are places where the scenario is entirely different which means their life will be in great distress. This says more than a want a refrigerator is a need today.

II. REFRIGRATORS

A refrigerator (colloquially fridge) is a common household appliance that consists of a thermally insulated compartment and a heat pump (mechanical, electronic, or chemical) that transfers heat from the inside of the fridge to its external environment so that the inside of the fridge is cooled to a temperature below the ambient temperature of the room. Refrigeration is an essential food storage technique in developed countries. The lower temperature lowers the reproduction rate of bacteria, so the refrigerator reduces the rate of spoilage. A refrigerator maintains a temperature a few degrees above the freezing point of water. Optimum temperature range for perishable food storage is 3 to 5 °C (37 to 41 °F).[1] A similar device that maintains a temperature below the freezing point of water is called a freezer. The refrigerator replaced the icebox, which was a common household appliance for almost a century and a half prior. For his reason, a refrigerator is sometimes referred to as an icebox in American usage. The first cooling systems for food involved using ice. Artificial refrigeration began in the mid-1750s, and developed in the early 1800s. In 1834, the first working vapor-compression refrigeration system was built. The first commercial ice-making machine was invented in 1854. In 1913, refrigerators for home use were invented. In 1923 Frigidaire introduced the first self-contained unit. The introduction of Freon in the 1920s expanded the refrigerator market during the 1930s. Home freezers as separate compartments (larger than necessary just for ice cubes) were introduced in 1940. Frozen foods, previously a luxury item, became commonplace. Freezer units are used in households and in industry and commerce. Commercial refrigerator and freezer units were in use for almost 40 years prior to the common home models. Most households use the freezer-on-top-and-refrigerator-on-bottom style, which has been the basic style since the 1940s. A vapor compression cycle is used in most household refrigerators, refrigerator–freezers and freezers. Newer refrigerators may include automatic defrosting, chilled water and ice from a dispenser in the door. Disposal of discarded refrigerators is regulated, often mandating the removal of doors; children playing hide-and-seek have been asphyxiated while hiding inside discarded refrigerators, particularly older models with latching doors. Domestic refrigerators and freezers for food storage are made in a range of sizes. Among the smallest is a 4 L Peltier refrigerator advertised as being able to hold 6 cans of beer. A large domestic refrigerator stands as tall as a person and may be about 1 m wide with a capacity of 600 L. Refrigerators and freezers may be free-standing, or built into a kitchen. The refrigerator allows the modern family to keep food fresh for longer than before. Freezers allow people to buy food in bulk and eat it at leisure, and bulk purchases save money.

III. THE REFRIGERATION TECHNOLOGY

Before the invention of the refrigerator, icehouses were used to provide cool storage for most of the year. Placed near freshwater lakes or packed with snow and ice during the winter, they were once very common. Natural means are still used to cool foods today. On mountainsides, runoff from melting snow is a convenient way to cool drinks, and during the winter one can keep milk fresh much longer just by keeping it outdoors. The word "refrigeratory" was used as early at least as the 17th century.[2] The history of artificial refrigeration began when Scottish professor William Cullen designed a small refrigerating machine in 1755. Cullen used a pump to create a partial vacuum over a container of diethyl ether, which then boiled, absorbing heat from the surrounding air.[3] The experiment even created a small amount of ice, but had no practical application at that time. In 1805, American inventor Oliver Evans described a closed vapour-compression refrigeration cycle for the production of ice by ether under vacuum. In 1820, the British scientist Michael Faraday liquefied ammonia and other gases by using high pressures and low temperatures, and in 1834, an American expatriate to Great Britain, Jacob Perkins, built the first working vapor-compression refrigeration system in the world. It was a closed-cycle device that could operate continuously.[4] A similar attempt was made in 1842, by American physician, John Gorrie,[5] who built a working prototype, but it was a commercial failure. American engineer Alexander Twining took out a British patent in 1850 for a vapour compression system that used ether. The first practical vapor compression refrigeration system was built by James Harrison, a British journalist who had emigrated to Australia. His 1856 patent was for a vapour compression system using ether, alcohol or ammonia. He built a mechanical ice-making machine in 1851 on the banks of the Barwon River at Rocky Point in Geelong, Victoria, and his first commercial ice-making machine followed in 1854. Harrison also introduced commercial vapour-compression refrigeration to breweries and meat packing houses, and by 1861, a dozen of his systems were in operation. The first gas absorption refrigeration system using gaseous ammonia dissolved in water (referred to as "aqua ammonia") was developed by Ferdinand Carré of France in 1859 and patented in 1860.Carl von Linde, an engineering professor at the Technological University Munich in Germany, patented an improved method of liquefying gases in 1876. His new process made possible the use of gases such as ammonia, sulphur dioxide (SO2) and methyl chloride (CH_3Cl) as refrigerants and they were widely used for that purpose until the late 1920s.

IV. GADOLINIUM

Gadolinium is a chemical element with symbol Gd and atomic number 64. It is a silvery-white, malleable and ductile rare-earth metal. It is found in nature only in combined (salt) form. Gadolinium was first detected spectroscopically in 1880 by de Marignac who separated its oxide and is credited with its discovery. It is named for gadolinite, one of the minerals in which it was found, in turn named for chemist Johan Gadolin. The metal was isolated by Paul Emile Lecoq de Boisbaudran in 1886. Gadolinium metal possesses unusual metallurgic properties, to the extent that as little as 1% gadolinium can significantly improve the workability and resistance to high temperature oxidation of iron, chromium, and related alloys. Gadolinium as a metal or salt has exceptionally high absorption of neutrons and therefore is used for shielding in neutron radiography and in nuclear reactors. Like most rare earths, gadolinium forms trivalent ions which have fluorescent properties. Gadolinium (III) salts have therefore been used as green phosphors in various applications. The gadolinium (III) ion occurring in water-soluble salts is quite toxic to mammals. However, chelated gadolinium (III) compounds are far less toxic because they carry gadolinium (III) through the kidneys and out of the body before the free ion can be released into tissue. Because of ts paramagnetic properties, solutions of chelated organic gadolinium complexes are used as intravenously ministered gadolinium-based MRI contrast agents in medical magnetic resonance imaging. However, in a small minority of patients with renal failure, at least four such agents have been associated with development of the rare nodular inflammatory disease nephrogenic systemic fibrosis. This is thought to be due to the gadolinium ion itself, since gadolinium (III) carrier molecules associated with the disease differ.[6]

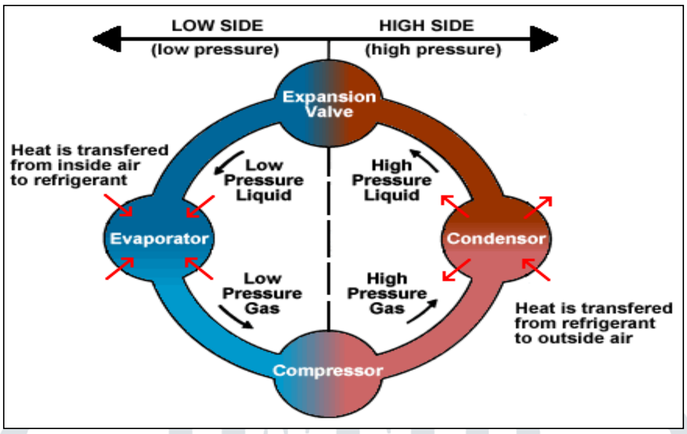
V. MAGNETIC REFRIGERATION

Magnetic refrigeration is a cooling technology based on the magneto caloric effect. This technique can be used to attain extremely low temperatures, as well as the ranges used in common refrigerators. The effect was first observed by French physicist P. Weiss and Swiss physicist A. Piccard in 1917.[7] The fundamental principle was suggested by P. Debye (1926) and W. Giauque (1927).[8] The first working magnetic refrigerators were constructed by several groups beginning in 1933. Magnetic refrigeration was the first method developed for cooling below about 0.3K (a temperature attainable by He^3 refrigeration, that is pumping on the He^3 vapors). The magnetocaloric effect (MCE, from *magnet* and *calorie*) is a magneto-thermodynamic phenomenon in which a temperature change of a suitable material is caused by exposing the material to a changing magnetic field. This is also known by low temperature physicists as *adiabatic demagnetization*. In that part of the refrigeration process, a decrease in the strength of an externally applied magnetic field allows the magnetic domains of a 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 (re)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 of a ferromagnetic material, 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 increases 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^2 Ge^2).[9] Praseodymium alloyed with nickel ($PrNi_5$) has such a strong magnetocaloric effect that it has allowed scientists to approach to within one milliKelvin, one thousandth of a degree of absolute zero.[10]

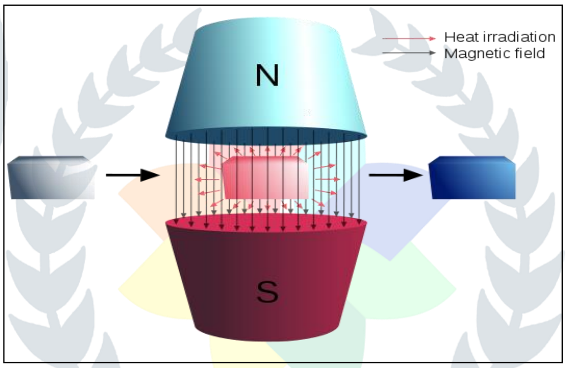
VI. THE CONCEPT

Initially as the hot body is placed inside the box that is closed. And the system is switched thereby initiating the vacuum pump and when a particular vacuum pressure is reached, safety valves open up one sucking the air and another compressor taking out this air and pushing it out(it is fixed along with a one way non-return valve in order to prevent back flow of air into the vacuum tank. Then this hot air is let on to a gadolinium alloy plate absorbs the heat and comes into the magnetic fields of the field magnets placed over and below the disc which rotates periodically as the temperature increases. Hence due to magnetocaloric effect the alloy plate gets cooled as it comes out of the magnetic field. Now the fresh air is again collected from the atmosphere and let into the main tank to undergo the cycle. The need vacuum pressure is that it sucks the air in faster. Moreover it is known to us that only hot rises higher at a quicker rate. So, when the body is showered with fresh circulating air, there are very less chances of even any chemical reactions to take place as there is not much time for it to react with because the air is sucked as it comes in.

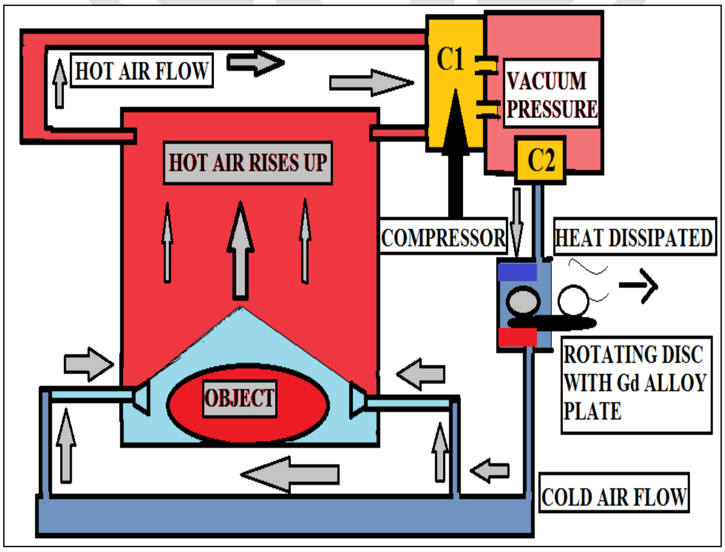
VII. DIAGRAM



REFRIGRATION CYCLE OF THE EXISTING REFRIGERATORS[11]



MAGNETIC REFRIGERATION PRICIPLE DIAGRAM[12]



THE PROPOSED MODEL OF MAGNETIC POWERED-VACUUM ASSISTED REFRIGERATOR

VIII. CALCULATION

Let the vacuum pressure be 50.80 KPa which is almost 50%

Mass flow rate is .

PV = nRT,

n = (PV)/(RT) [since, T=273+25=298K, R=0.0821, V=28.32L]

= (0.0821×28.32)/(298×1)

= 1.2 Mole of Gas.

Air is 78.03% Nitrogen, 20.99% Oxygen and 0.93% Argon.

So,

Nitrogen - .78 x 1.20 = 0.963 Moles

Oxygen - .21 x 1.20 = 0.252 Moles

Argon - .093 x 1.20 = 0.1116 Moles

We know that,

1 Mole N2 = 28.02 g

1 Mole O2 = 32.0 g

1 Mole Ar = 39.95 g

So,

0.963 x 28.02 = 26.98 g Nitrogen

0.252 x 32 = 8.064 g Oxygen

0.093 x 39.95 = 3.72 g Argon

Adding up the weight and we get 38.76 g

So, mass of 1 m^3 of air = 0.03876 kg.

Area of duct = 10 cm^2 = 0.001 m^2

Therefore, mass flow rate = (387/0.5) = 774 kg/m^2.

IX. DEFINITIONS

Atmosphere: The atmosphere of Earth is a layer of gases surrounding the planet Earth that is retained by Earth's gravity. The atmosphere protects life on Earth by absorbing ultraviolet solar radiation, warming the surface through heat retention (greenhouse effect), and reducing temperature extremes between day and night (the diurnal temperature variation).[13]

Pressure: Pressure is force per unit area applied in a direction perpendicular to the surface of an object.[14]

Refrigerator: A refrigerator (colloquially fridge) is a common household appliance that consists of a thermally insulated compartment and a heat pump(mechanical, electronic, or chemical) that transfers heat from the inside of the fridge to its external environment so that the inside of the fridge is cooled to a temperature below the ambient temperature of the room.[15]

Vacuum: Vacuum is space that is devoid of matter. The word stems from the Latin adjective vacuus for "vacant" or "void". An approximation to such vacuum is a region with a gaseous pressure much less than atmospheric pressure.[1] Physicists often discuss ideal test results that would occur in a perfect vacuum, which they sometimes simply call "vacuum" or free space, and use the term partial vacuum to refer to an actual imperfect vacuum as one might have in a laboratory or in space. The Latin term in vacuo is used to describe an object as being in what would otherwise be a vacuum.[16]

X. ADVANTAGES

This systems has a few remarkable advantages that are worth and need to be mentioned:

1. The need of a refrigerant is eliminated merely by just replacing it with a plate of gadolinium alloy.
2. Air is sucked in quicker by the vacuum which is much faster than compressing it with a compressor.
3. The mode of heat transfer here is radiation.
4. The air is not re-circulated but fresh air is taken in.
5. There is not much time for any chemical reaction to take place as air is continuously being removed.
6. We know that air that is hot rises up faster hence the hot air sucked first as the pipe is placed on the top portion.

XI. CONCLUSION

Thus we have come across a specialization of the magnetic gadolinium refrigerator that makes use of vacuum to remove the heat from a body through convection. This may provide a breakthrough in the field of thermodynamics and refrigeration.

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