Air Conditioning of Light Weight Vehicles Using Magnetic Refrigeration System

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Abstract

Paris Agreement on Climate Change, at the 2015 United Nations Climate Change Conference, aimed to keep global temperature increment restricted to 2 °C more than pre-industrial levels by 2100 and called for attempts to restrict the temperature increment even further to 1.5 degrees Celsius to avoid serious climate catastrophes around the world. The participants also aimed to lower the emission of the greenhouse gases by promoting the use of zero carbon technologies. The air conditioning system is one of the basic sub-system in automobiles. Conventional vehicles use vapour compression refrigeration technology for air conditioning purpose, but this technology is energy inefficient and the refrigerants that are used in this system are undesirable for environmental reasons. Researchers are constantly attempting to develop a more efficient alternative refrigeration system to prevent environmental pollution. Magnetic refrigeration is one of the emerging technology that has the potential to lower the carbon emissions. Magnetic refrigeration can reduce the energy consumption for refrigeration by 30% without the use of refrigerant. The magnetic refrigeration working principle is based upon the phenomenon commonly known as magneto-caloric effect (MCE). According to magneto-caloric effect (MCE), some exotic materials such as gadolinium and dysprosium, heat up when subjected to a magnetic field and cool down when the magnetic field is disconnected. The prime purpose of this paper is to design an efficient air conditioning technology for light weight automobiles which can operate on magneto-caloric effect and thus helps in reducing carbon footprints.

Keywords: *Air conditioning system, Magnetic refrigeration, Magneto-caloric effect*

1. Introduction

The process of removal of heat from matter which may be a solid, liquid, or gas, which results in lowering of its temperature is called refrigeration. There are mainly two kinds of refrigeration systems i.e. vapour compression & vapour absorption refrigeration system. Generally, in automobiles, vapour compression refrigeration technologies are used. In this system, heat is absorbed by refrigerant at low temperatures and pressures and this heat is rejected to a condensing medium which is at higher temperatures and pressures by means of expansion and compression of the refrigerant [1].

But the vapour compression refrigeration system is energy inefficient. It utilizes a compressor to compress a huge amount of refrigerant vapour. Due to this, energy consumption for the operation is high and thus COP is low. Also, the refrigerant used in vapour compression refrigeration systems is a serious concern for the environment. These refrigerant leakages have a harmful effects on environment [2, 3]. Therefore, it is required to develop other substitute cooling technologies in vehicles.

ISSN: 2005-4297 IJCA

Magnetic refrigeration is a recent energy efficient and clean refrigeration technique having capabilities to be the replacement of conventional vapour compression refrigeration system. It depends on the principle of magneto-caloric effect which can be applied to various magnetic materials & new alloys called magneto-caloric materials (MCM). Magneto-caloric effect (MCE) is the heating of the magnetic materials or magneto-caloric materials when these are subjected to magnetic field and cooling of these materials when magnetic field is disconnected[4, 5]. Presently, this technology is in pre-industrialization phase, but in few years it will definitely substitute the conventional refrigeration methods. Magnetic refrigeration system has various advantages over conventional vapour compression system in terms of efficiency, cost, noise free operation, compactness, low working pressure and environmental friendliness.

Taking into focus these considerations, this paper aims to seek a more energy efficient and eco-friendly replacement of conventional air conditioning system in light weight vehicles. In this study, the concept of magnetic refrigeration which is based on the principle of magneto-caloric effect is explained along with a proposed air conditioning design of light weight vehicles [6].

2. Magneto-Caloric Effect

The magnetic refrigeration depends on the fundamental principle of magneto-caloric effect (MCE). According to magneto-caloric effect, few magnetic materials get heated up when subjected to magnetic field and cool down when the magnetic field is removed. In 1881, A German Physicist E. Warburg first discovered the magneto-caloric effect in metal iron subjected to varying magnetic field. The MCE is described as a characteristic of magnetic substances resulting in a variation of temperature of the substance when it is exposed to an alternating magnetic current. This circumstance is highest in the proximity of the ordering temp. of the magnetic substance (known as the Curie or the Néel temp.) [5]. Every magnetic material exposed to desired high magnetic currents, exhibits the magneto-caloric effect however the amount of the effect is dependent on the properties of each substance. Researchers continuously attempted to discover materials & alloys having strong MCE at normal temperature. Gadolinium (Gd) acts as the best magneto-caloric material discovered so far.

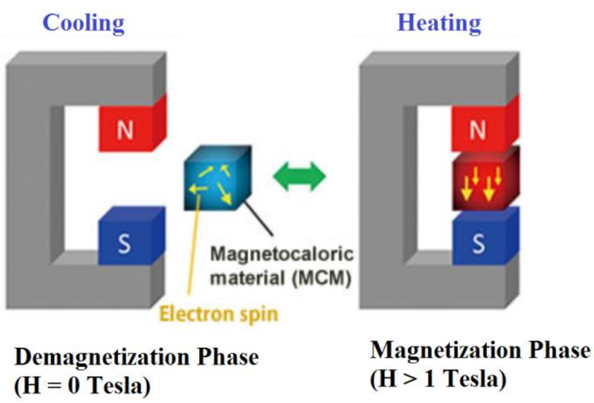

Figure 1. Magneto-Caloric Effect

We have to apply the concepts of thermodynamics in order to understand the cause of the magneto-caloric effect, which establishes a relation between the magnetic variables (magnetization & magnetic field) and thermodynamic variables (entropy and temperature). All magnetic materials exhibit MCE; however the intensity of the effect is dependent on the properties of each material. The physical origin of the MCE is that when magnetic sub-lattice of the magneto-caloric material is subjected to applied magnetic field H, magnetic contribution to the entropy of the material changes. This phenomenon is equivalent to the thermodynamics of a gas. The isothermal compression process of the gas (when pressure increases, the entropy decreases) is analogous to isothermal magnetization of a magnetic material (when magnetic field H is applied, the magnetic entropy decreases), although the adiabatic expansion process of a gas (when pressure is decreased at constant entropy, the temperature decreases) is analogous to adiabatic demagnetization (when magnetic field H is removed, the total entropy of the material remains constant but the magnetic entropy increases, therefore temperature decreases).

When a magnetic field is applied under adiabatic conditions, the decrease of magnetic entropy is remunerated by an increment of entropy of crystal lattice. This transfer of entropy is origin of warming of the material. And when magnetic field is removed, opposite effect is observed which results in cooling of the material [6]. Figure 1 illustrates the operating principle of magneto-caloric effect. A magnetic fi**eld (H**> 1 Tesla) is generated with the composite comprised of two permanent magnets. A magneto-caloric material is exposed to the magnetic field of the permanent magnet and as the magnetic entropy changes, the material heats up. At the moment magnetic field is removed (H = 0 Tesla), the material gets demagnetized and cools down [7]. We can utilize this cooling effect developed by MCE in magneto-caloric materials to develop efficient and clean refrigeration system for light weight vehicles.

3. Magneto-Caloric Refrigeration System

The main objective of this paper is the design of an efficient and clean air conditioning technology for light weight automobiles dependent on magneto-caloric refrigeration. For a better explanation of working principle of the magneto-caloric effect, we have developed a new technology based on this principle as shown in the figure 2. This system consists of two portions of magneto-caloric materials connected in series and mounted on a rigid frame. These portions are called Regenerators. These regenerators are made up of selected MCM depending upon their Curie temperature. Also two permanent magnets of opposite polarity are mounted on actuators which assist in the movement of the magnets over the two portions of MCM. The actuators are powered by the energy supplied from the vehicle engine. When magnets are placed over MCM portion 1, the material gets magnetized which results in the rise of its temperature. This heat generated in the MCM will be rejected in the atmosphere. On the other hand, when the magnets move to the MCM portion 2, the MCM portion 1 gets demagnetized and its temperature decreases. At the moment when MCM portion 1 cools down, a coolant (mixture of water and anti-freeze) is allowed to flow over the demagnetized MCM portion with the help of tubes. Coolant rejects its heat to the demagnetized MCM portion and thus the temperature of the coolant decreases to the desired level. This cooled coolant then flows to the air conditioning cabin of the vehicle with the help of a pump. The pumps are operated from the automobile engine power. In the air conditioning cabin, the coolant absorbs the heat and then flows back to the MCM portions. Again, when MCM potion 2 gets demagnetized, the coolant is allowed to flow over MCM portion 2 and thus, coolant rejects heat to the MCM. The motion of coolant to different portions of the MCM is controlled by a 2-way valve which is guided from the motion of the actuators. The coolant is allowed to flow only in that MCM portion which is demagnetized (i.e. cooled) at that moment.

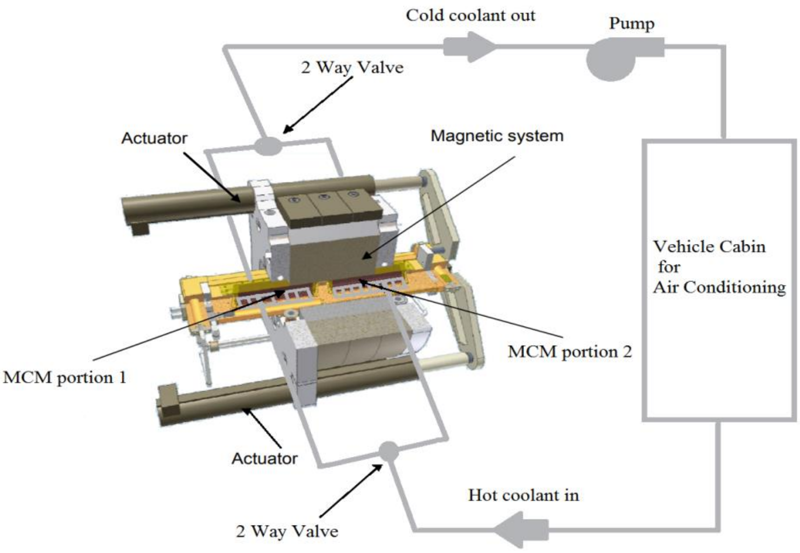

Figure 2. Magneto-caloric air conditioning design

The cooling potential of this air conditioning system based on the properties and on the quantity of the MCM regenerators used. There are some points to be considered to ensure optimum efficiency for this air conditioning technology, i.e.

- MCM regenerators must be divided into thin sheets to increase the surface area for heat transfer.
- The magnets used should have high intensity (H > 1 Tesla), and an air gap > 10 mm.
- The flow of coolant must be laminar to reduce the pressure loss.
- Convective heat transfer coeff. 'h' of the coolant should be high to ensure maximum heat transfer in limited time and surface area.
- The MCM must have high values of specific heat capacity.
- The actuator design must not be complex to ensure smooth operation at higher frequencies.

4. Conclusion

There are various potential advantages of air conditioning based on magneto-caloric effect as compared with the conventional air conditioning technology in the light weight vehicles. The proposed air conditioning system for the vehicles discussed in this paper can be the future of air conditioning in automobiles because of the following reasons:

- Efficiency of this system is higher than the conventional air conditioning system of the vehicles.

- Higher efficiency ensures no need of conventional refrigerants which are noxious for the environment.

- Since no compressor is used in this system, the whole operation in noiseless & vibration free.

- Working pressure is lower (atmospheric pressure) than the conventional vapour compression system.

- Compact and simple design.

- Overall maintenance cost for this system is quite low.

However, there are some fields for further research in order to optimize the efficiency of this system, i.e.

- Magnetic field strength of permanent magnets are limited. While, electro magnets & superconducting magnets have high cost. Therefore, further research is needed to obtain a cheaper magnet of high magnetic field strength.

- Electronic components of the vehicle must be protected from the magnetic field of the magnets.

- The availability of magneto-caloric materials are scarce. Therefore, there is a requirement for identification of new materials.

- There exist some thermal and hysteresis problems in materials exhibiting magneto-caloric effect that is required to be solved in order to achieve smooth operation.

Some polymers can enhance nucleate boiling while others cannot on other hand there is not much study of flow boiling with polymeric additive so a conclusion cannot be reached in flow boiling .Some of the parameters affecting boiling by polymeric additive

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