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Study of a Hybrid Magneto-Caloric Refrigerator and It's Applications in the Industry

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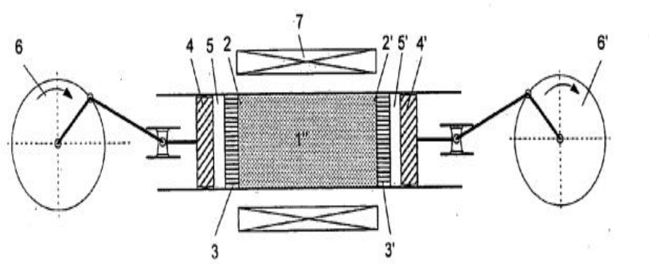
***Abstract*:**

This paper presents a new refrigeration system that does not use any refrigerant gas. The design consists of a device for transporting heat from a cold to a warm reservoir, in which at least two cyclic processes are used for transporting heat, thereby absorbing work, of which at least one's regenerative cyclic process, and at least one is a magneto caloric cyclic process, wherein the regenerative cyclic process has a working fluid and a heat storage medium, is characterized in that the heat storage medium of the regenerative cyclic process comprises a magneto-caloric material for the magneto-caloric cyclic process, wherein the magneto-caloric material is in a regenerator area with a cold end and a warm end, the working fluid of the regenerative cyclic process additionally serving as a heat transfer fluid for the magneto-caloric cyclic process.

Keywords-Magneto-caloric effect, Regenerative cyclic process, Magneto-caloric material, Hybrid Stirling.



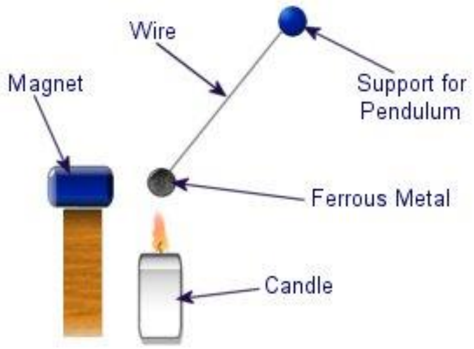
Hybrid Magneto-caloric Refrigerator

Description of the figure

1'' -passive and active regenerators of the innovative device (magneto caloric material)
2 -Warm end of the regenerator
2' - Cold end of the regenerator
3 '- Cold heat exchanger
5- Space for compression
5' -Space for expansion
3 - Warm heat exchanger
4 - Warm piston
4' - Cold piston
6 - Warm driver mechanism
6' - Cold driver mechanism
7 - Permanent magnet

BACKGROUND OF THE DESIGN

One of the main challenges of the industry today is to face its impact on global warming. Magnetic cooling offers an innovative technical solution that will enable to reduce this global warming impact through two ways: first, it will eliminate refrigerant fluids as CFC, HCFCs and other ammonia, thus it will decrease the direct gas emissions. Secondly, the intrinsic better performance of a magneto caloric material (MCM): quanta effect on spin vs. a standard gas compression cycle (mechanical effect) will reduce the electric energy used to run HVAC and refrigeration units.



The Magneto-caloric effect

The Curie point is the temperature at which a material changes from a ferromagnetic to a paramagnetic state; this temperature is significant because a material will exhibit its greatest magneto-caloric effect near the Curie temperature. The curie effect usually refers to a magnetic phenomenon discovered by Pierre Curie. She discovered that ferromagnetic substances exhibited a critical temperature transition, above which the substances lost their ferromagnetic behavior. This is now known as the Curie point. This concept is used in magneto caloric effect.

Magnetic cooling offers a green solution to this emerging challenge and it allows to generate both heating and cooling.

The magneto caloric effect (MCE) can be used to develop air cooling or heat pump systems harmless for the environment because they don't require compression or expansion of gas, such as those currently used in today's systems.

HYBRID REFRIGERATION

In the following magnetic cold stage, the working medium which passes through a thermodynamic process is not gas, but magneto caloric material, a solid. Heat is exchanged between the magneto caloric material and a heat source or heat sink via a thermal connection (in the form of a thermal switch) that can be connected or disconnected, or an additional heat transfer fluid. The temperature in the process is increased and decreased through magnetization or demagnetization of the magneto caloric material e.g. by a permanent magnet. The temperature change is maximum when the average temperature of the material corresponds to its curie temperature. In order to bridge large temperature differences between the heat source and sink, several materials having different curie temperatures may be used, which are disposed in layers next to each other in bulk form. The magneto caloric material provided at each location in the regenerator bed runs through its own cycle between different temperatures using the heat transfer fluid. Coupling to the outside is provided at the ends of the regenerator bed, where the heat transfer fluid flows through heat exchanger. Heat is thus finally transported from a cold heat source to a warm heat sink. The magneto caloric material may introduce into a magnetic field in cycles or a magnetic field may be switched on and off. The heat transfer fluid (a liquid or gas depending on the application) must be supplied at the right moment through the magneto caloric material e.g. using a pump.

The advantage of an innovative device compared to conventional devices consists in that the operative expense is greatly reduced. Moreover the innovative combined process is thermodynamically more efficient than a conventional regenerative gas cycle alone. The cooling or heating performance may be increased without considerably increasing the volume of the machine, thereby increasing the power density. Moreover, an existing external magnetic field is not disturbing, but even advantageous, since it can be utilized for the magneto caloric cycle.

A particularly preferred embodiment of the innovative device for transporting heat from a cold reservoir has a temperature below the ambient temperature, and the warm reservoir has a temperature which is equal to or larger than ambient temperature. Thus, a refrigerator may generate a temperature below the ambient temperature, which provides a plurality of possible applications. It is, however, also feasible to use the principle with a heat pump for heating.

PROCESS:

In a one stage magnetic refrigerator or heat pump, there is an (active) regenerator which consists of a magneto caloric working medium, mostly in the form of bulk particles in a regenerator bed. The regenerator is, in turn, bordered by two heat exchangers, its warm end by the warm end heat exchanger and its cold end by cold heat exchanger. In order to bridge larger temperature differences between the two heat exchangers, several components of magneto caloric active materials having different curie temperatures may be used in the regenerator which are disposed next to each other in layers, such that the component of the magneto-caloric materials with the highest curie temperature comes to rest on the warm heat exchanger and the component with lowest curie temperature comes to rest on the cold heat exchanger. The two pistons transport a heat transfer fluid (liquid or gas) through the (active) regenerator, its motion via the drive mechanism is performed in phase and the heat transfer is neither compressed nor expanded. The working medium (magneto-caloric material) in the regenerator is magnetized via a magnet. The magnet may be designed as a permanent magnet which is cyclically shifted over the regenerator bed, or as a coil of normally and/or superconducting wire. Then the magneto-caloric material in the regenerator is magnetized or demagnetized through charging and discharging of the magnet coil. The motion of the two pistons and the motion of the permanent magnet or charging and discharging of the magnet coil must be matched in time such that the magneto-caloric material runs through a magneto-caloric cycle.

The invention device is based on a Hybrid Stirling refrigerator which comprises the compression space and expansion space with an intermediate regenerator. As in the magnetic machine, it is thereby also possible to switch on or off an external magnetic field B. This results in the following cycle:

1→ 2 Isothermal compressions:

When an external magnetic field B is present, the working fluid in the compression space is isothermally compressed by the piston, thereby releasing heat. The released heat may be absorbed by cooling medium at a constant temperature.

2→3 Demagnetization

The magneto-caloric material in the regenerator is demagnetized i.e. a magnetic field of a strength B which is present in states 1 & 2is reduced (by removing the permanent magnet, discharging the magnet coil or activating the shield etc.). The magneto-caloric material of the regenerator is thereby cooled at any location over its length by a certain temperature difference. The temperature profile in regenerator prior to demagnetization is different to temperature profile after demagnetization.

3→4 Cooling (release of heat)

The warm heat transfer fluid i.e. the working fluid in step 1→2 is transferred with the piston through the magneto-caloric material of the regenerator. It is thereby cooled (i.e. magneto-caloric material absorbs heat). When it leaves the regenerator the heat transfer fluid is initially colder than the environment at that location. The heat transfer fluid may thereby absorb heat from the (cold) environment. During transfer, the temperatures in the regenerator changes and in state 4, the temperature, the temperature profile is restored.

4→5 isothermal expansion

The heat transfer fluid in the expansion space is isothermally expanded by the piston, thereby absorbing heat. The absorb heat is thereby supplied from the outside of the object/space to be cooled.

5→6 magnetization

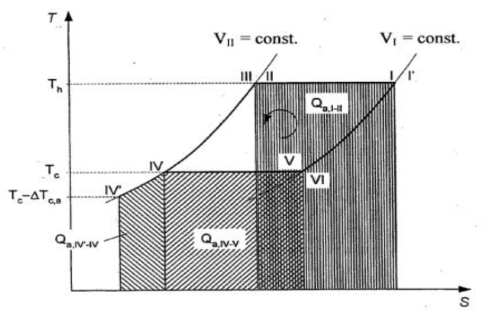
The magnetization material of the regenerator is magnetized by applying a magnetic field with a field strength B. the magneto-caloric material of the regenerator is heated at any location over its length by a certain temperature to yield the temperature profile.

6→1 heating (absorption of heat)

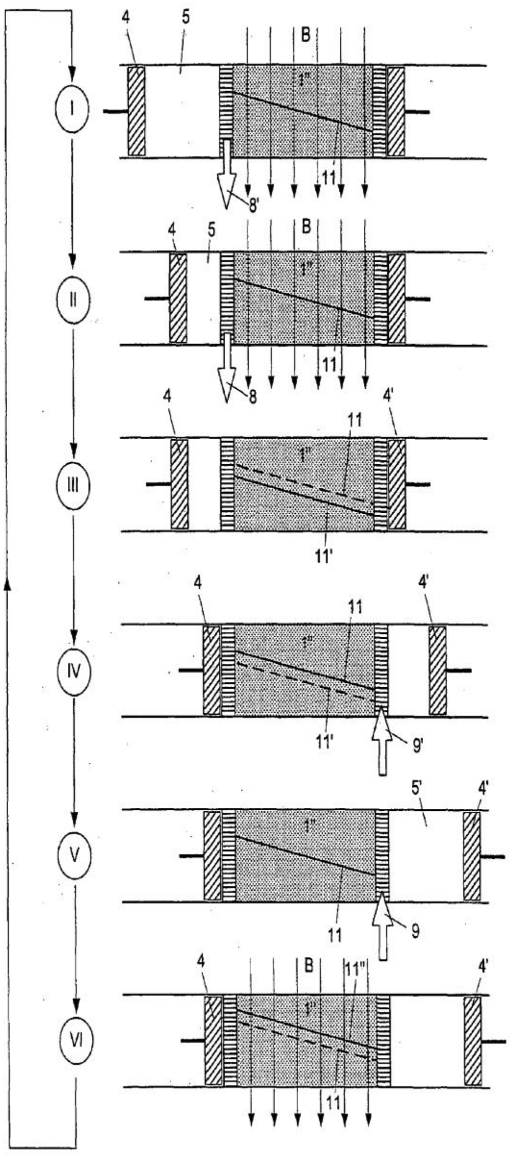
The cold heat transfer fluid (working fluid in the process step 4→5) is passed back by the pistons through the magneto-caloric material of the regenerator. It is thereby heated (i.e. the magneto-caloric material releases heat). When it leaves the regenerator, the heat transfer fluid is initially warmer than the environment at that location. The heat transfer fluid releases heat to the (warm) environment. During passage, the temperature in the regenerator changes and in state 1, the original temperature profile has been restored.

The heat is thereby supplied from the space to be cooled (useful cold) during two process steps (3→4 & 4→5). The heat is released to the warm environment during the process steps 6→1 & 1→2. The required work increases correspondingly. The coefficient of performance (COP) and the efficiency of the device are, however, high.

One of the main challenges of the industry today is to face its impact on global warming. Magnetic cooling offers an innovative technical solution that will enable to reduce this global warming impact through two ways: first, it will eliminate refrigerant fluids as CFC,HCFCs and other ammonia, thus it will decrease the direct gas emissions. Secondly, the intrinsic better performance of a magneto-caloric material (MCM):quanta effect on spin vs .a standard gas compression cycle will reduce the electric energy used to run HVAC and refrigeration units .Magnetic cooling offers a green solution to this emerging challenge and it allows to generate both heating and cooling. The magneto-caloric effect(MCE)can be used to develop air cooling or heat pump system for the environment because they don't require compression or expansion of gas, such as those currently used in today's systems.



Working fluid in T-S diagram.



The process cycle of hybrid refrigeration

APPLICATIONS

a) Magnetic household refrigeration appliances

- Household refrigerator without freezer
- Wine/beverage refrigerator.

b) Magnetic cooling and air conditioning in buildings and houses

- Magnetic RAC (RAC – Room Air conditioning unit), window, wall or ceiling mounted
- Magnetic split system (e.g. single outside heat rejection unit, multiple inner cooling units).

c) Central cooling system

- Magnetic water cooled water or brine chiller (water/water, brine/brine)
- Magnetic air cooled water or brine chiller (water/air, brine/air).

Both units may be used for fan coils, ceiling cooling or in the air-conditioning system.

d) Refrigeration in medicine

- Blood plasma storage refrigerators, chromatography and other laboratory refrigerators
- Walk in rooms (refrigeration, not freezing).

e) Cooling in food industry and storage

- Food production:
• Refrigerated silos, vessels or blenders, e.g. in diary industry
• Wine and beer fermenters
• Beverage carbonation.

- Food processing for storage:
• Hydro cooling of vegetables and fruits (by immersing)
• Forced air cooling of vegetables and flowers
• Spray chilling or brine cooling of meat
• Dry air coolers for meat.

- Food storage:
• Cold storage of fruits, vegetables and flowers
• Short term storage of meat products
• Refrigerated walk in rooms
• Cold storage rooms with temperatures above freezing.

f) Cooling in transportation

- Air conditioning in land transport

Too large temperature spans avoid that the magnetic refrigeration technology can occur for such applications. On the other hand an application of a hybrid system, namely magnetic refrigeration combined with another cooling technology, may be a feasible solution. Another option is an off-board cooling of PCM's (phase change material) and their introduction to vehicles as a passive non- mechanical cooling method (at present mostly applied in trains).

- Marine air conditioning

Sea water cooled magnetic refrigerators serving as central cooling units in e.g. yachts and ships (e.g. ship carriers, ship cruisers). In large ships the possibility of introducing a superconducting-magnet-based magnetic refrigerator seems feasible. This method also could enable freezing.

- Refrigeration of food or other goods in transportation

• Refrigeration of vegetables or cut flowers in truck trailers, refrigerated mechanical rail cars, ship containers
• Centralized or decentralized magnetic refrigeration units in ships (use of sea water for heat rejection) for food storage (e.g. walk in rooms, compartments in ships, cold rooms, etc.). Large carrier or cruise ships enable use of refrigerators (or even freezers) based on superconducting magnets.

g) District cooling systems

These systems could enable the application of permanent magnets as well as refrigerators with super- conducting magnets, especially because the total cooling power of such systems is usually higher than 10 MW.

h) Supermarket applications

- Living comfort
- Food storage
- Display cabinets (refrigerators only) and the glass-door and chest-types of refrigerators (all such applications may be centralized or decentralized by the application of magnetic refrigeration).

i) Cooling of electronics

Cooling of electronics by the magnetic refrigeration technology may be provided by e.g. central cooling systems and not by local devices. The main reason for this is that in the second a strong shielding of the magnetic fields is demanded. Local devices may be applied, e.g. in the surroundings of certain units (e.g. mobile telephone, etc.) which require cooling.

CONCLUSION

The innovating problem of the magnetic cooling at room temperature is definitely an interdisciplinary subject that requires the knowledge of the magneto caloric material behavior of the mechanical configuration and of the design of the permanent magnetic flux source. We have outlined the basics of magnetic refrigeration the relation between the magneto caloric materials with an important variation of entropy and the temperature variation. The results and the performance of our magneto caloric system were exposed. Today due to the performance obtained and the developments which have been made, it is possible to design magneto caloric systems which meet up the product specifications.
Desired commercialize properties of magneto-caloric

materials:

•Significant MCE at reasonable fields (H < 2 Tesla)
• Tunable transition temperatures—tailored effective ranges.
• Environmentally friendly materials
• Affordable, abundant, and easily synthesized materials.

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