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APPLICATION OF MAGNETIC REFRIGERATION AND ITS ASSESSMENT

Annual report 2007

Author und coauthors	A. Kitanovski, D. Vuarnoz, M. Diebold, C. Gonin, P.W. Egolf
Company / Institution	University of Applied Sciences of Western Switzerland
Address	Route de Cheseaux 1
Phone, e-mail, internet	024 557 61 57, Peter.egolf@heig-vd.ch
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SUMMARY

Magnetic refrigeration has the potential to substitute as a future technology conventional refrigeration systems - with often problematic refrigerants - in several niche markets or even some main markets of the refrigeration domain. Based on this insight the Swiss Federal Office of Energy has demanded a division at the University of Applied Sciences of Western Switzerland (HEIG-VD) in Yverdon-les-Bains to list all possible refrigeration technologies and to evaluate the potential of magnetic refrigeration for these specific applications. The HEIG-VD researchers have developed a calculation tool to determine the coefficient of performance (*COP*) values and the exergy efficiency as a function of magnetic field strength and rotation frequency of rotary types of magnetic refrigerators. The considered machine design is based on a patent, which was deposited by these scientists.

Based on this work, it is found that two applications are very interesting for a first possible investigation, namely the household refrigerator without a freezing compartment and the central chilling units, which may be of large size. The *COP* values of such large-scale systems are very high. At present a study, if even superconducting magnets, applying high-temperature superconductivity, could be an economic solution, is performed. The final report of this project will answer this question. It will also present the applied evaluation method in more detail than this brief annual report. Furthermore, the listing of the refrigeration technologies and their evaluation to be suitable for magnetic refrigeration will be outlined in greater detail. The final project report will appear in February 2008.

Objective of the project

Magnetic refrigeration is a technology which applies the magnetocaloric effect (MCE), similar as gas refrigeration is based on the compressibility of a refrigerant. The MCE was first discovered by Warburg [1], who observed in 1881 an increase of temperature when he had brought an iron sample into a magnetic field and a decrease when the sample was removed out of it.

Soon after this discovery approximately in 1890 Tesla [2] and Edison [3] independently and unsuccessfully tried to benefit from this effect by running heat engines for “power production”. In 1918 Weiss and Piccard [4] explained the magnetocaloric effect.

Later Debye [5] and Giauque [6] proposed a method of magnetic refrigeration for low temperature physics in order to obtain sub-Kelvin temperatures. In 1933 Giauque and MacDougall [7] successfully verified the method by experiment. Since the 1930’s magnetic refrigeration is a standard technique in low temperature physics. It has shown to be useful to cool down from a few Kelvin to some hundredths, or in very skilful applications to a few thousandths of a Kelvin.

In 1976 Brown (see Ref. [8] and [9]) designed the first magnetic refrigerator working at room temperature. After that a number of patents were announced, which describe such refrigerators. This may be noted to be the time of the first generation of magnetic refrigerators. The first “room temperature” magnetic refrigerator – containing permanent magnets – was designed and built in 2001 by Astronautics Corporation in the USA [10].

Then the start of the development of a new second generation family of magnetic refrigerators began. The early prototypes did not reach high magnetic flux densities in the magnetocaloric material, if not instead of permanent magnets superconducting magnets were applied. At present one may find numerous prototypes based on permanent magnets operating at magnetic field densities between 1.5 and 2.4 Tesla [11] in the technical and scientific literature. This tendency marks a significant improvement of the magnetic cooling technology. The research in magnetic refrigeration is nowadays focused on improvements on magnetocaloric materials, magnets and their materials, thermodynamics and fluid dynamics and an optimal design and building of devices.

Our team at the HEIG-VD is at present developing the so called third generation magnetic refrigerators (patent files have just recently been sent for protection). This new machines hopefully will bring the Swiss developments a step closer to some suitable market applications.

The interest of the conventional industries in the magnetic refrigeration technology is at present very high. This interest occurs especially in the domain of household appliances, hermetic compressor production and domains related to air-conditioning systems, e.g. in land vehicles. One may recognize that numerous companies working in these areas started with some actions in magnetic cooling research and development. On the other hand, the research activities of industries active in the domain of conventional refrigerators (chillers) are surprisingly small. These companies have also not yet become active in the domain of magnetic cooling. This is surprising, because their domain shows a large potential for this “new” raising technology. Beside industry also venture capital holders are developing some interest in magnetic refrigeration. In Europe at least two spin-off companies, Cooltech in France and Camfridge in England, are supported by high-risk capital investors. The second is a spin-off company of Cambridge University in the UK. The Swiss HEIG-VD team, as numerous other research teams, is now starting some actions with European industries.

The objective of this project is a broad overview study of the potential of feasible applications of the magnetic cooling and refrigeration technology. It should result in the evaluation or even selection of some domains, where magnetic refrigeration could be competitive compared to conventional cooling technologies. In most cases, as a basis for comparisons, the vapour-compression based refrigerators are taken to define the standard. Therefore, the project will comprise different tasks as listed in the following section below:

1. Overview of the magnetic refrigeration technology
2. Advantages and drawbacks of magnetic refrigeration
3. Comparison with existing refrigeration technologies
4. A list and short descriptions of possible applications of magnetic cooling or refrigeration
5. Model, analysis and presentation of results on key technical characteristics for selected applications, e.g. coefficient of performance, exergy efficiency, etc.
6. Cost estimations
7. World market potential for selected applications
8. Comparison of selected applications with the conventional ones
9. Proposal for further work.

Accomplished work and achieved results

Introduction

A comprehensive study on all refrigeration technologies, which was only very briefly presented in the annual report 2006 of this project [12], led to an evaluation and selection of best possible applications for the magnetic refrigeration technology. In general, at the present stage of the development of magnetic refrigerators with permanent magnets, hardly any freezing applications are feasible. These results, because large temperature spans occur between the heat source and the heat sink.

An option to realize magnetic freezing applications could be the use of superconducting magnets. However, this may only be economic in the case of rather large refrigeration units. Such are used for freezing, e.g. in cooling plants in the food industry or in large marine freezing applications. Another possibility is the application of a hybrid system, resulting in a combination of magnetic cooling with another kind of cooling technology, which even could be the conventional one. The chapter on industrial refrigeration was mainly focused on food industry, because it presents the largest domain of industrial refrigeration. Furthermore, refrigeration in polygeneration (e.g. trigeneration) systems was not separately studied, because it is related to centralized or district cooling systems. In the final report of the project a comprehensive overview on almost all refrigeration technologies will be presented. With a detailed analysis - supported by a sophisticated model and simple excel calculations - a large amount of different systems were evaluated. Most of them are only briefly presented in the following section:

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, cromatography 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:
    - Hydrocooling 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 feasibile 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 cruiser 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 superconducting magnets, especially because the total cooling power of such systems is usually higher than 10 MW.

h) Supermarket applications

- Living comfort (see e.g. b) and c))
- Food storage (see e.g. e))
- 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).

j) 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.

Selected examples

Detailed evaluation by an analysis, shown in succeeding sections on the listed technologies above, led to a choice of two examples of preferable technologies for an application of magnetic cooling, namely the:

1) ***Household refrigerator without a freezer compartment and the***
2) ***Central chiller.***

Central magnetic chiller units are applied in a large number of different domains. This may be also recognized in the above presented list of possible applications.

Another very important application is the household refrigerator without freezer. It is clear that this product also has a very large market. Magnetic household freezers are at the present stage of the development of the magnetic refrigeration technology hardly feasible.

The assumed characteristic cooling powers of the two selected cases are for the household refrigerator without a freezing compartment 50 W and for the central chiller 1 MW.

In the following sections often coefficents of performance (*COP*) and exergy efficiencies are listed. For readers, who are not aquainted with these quantities, we refer to the final project report.

Household refrigerators without freezing compartment

The world production of compressors for household refrigerators and household freezers presented in 2003 was approximately 100 million units [13]. The estimated world market is approximately 4 billion US $ per year. The ambient room temperature for household refrigerators varies between 16 to 32°C. The lowest temperature in the cooling compartment is usually around 4°C, depending a bit on the specific application. One should note that the operating conditions strongly depend on the outer or/and inner temperature level. Usually a free convection heat transfer occurs in the inner compartment as well as on the condenser side out in the room. Because these heat transfers are low, the evaporation of the refrigerant in conventional household refrigerators occurs approximately 10 K below the required temperature in the internal space of the refrigerator. The same is true for the condensing temperature; it is usually at least 10 K higher than the temperature of the ambient room air. These two temperature differences lead to high irreversibilities, and they influence negatively on the efficiency of the cooling machine. Now it is not surprising anymore to understand that usually *COP* values lower than 2 occur. Household refrigerators without a freezing compartment do not require a very high cooling power. Maximal values are around 200 W. In the case of an application of the magnetic refrigeration technology, water or a brine should be taken as heat transfer fluid. It has to be emphasized that this has to be related to the design of the condenser as well as to the "cold" heat exchanger, which replaces the evaporator. Therefore, one may assume that the development of magnetic household refrigerators will lead to slightly different internal designs of refrigerator containers. Figure 1 shows an example of a conventional refrigerator without a freezing compartment and figure 2 a schematic drawing of a magnetic household refrigerator.

Figure 1: Example of a conventional household refrigerator (www.liebherr.com). The condensing tubes are mounted to the back side of the refrigerator. It is highly insulated and has low power consumption. The minimal temperature is usually 4°C, depending on the specific application. Such types of refrigerators have a low cooling power, e.g. less than 100 W.

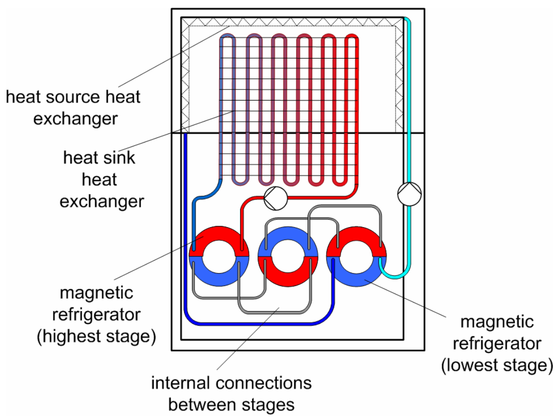

Figure 2: A schematic sketch, shows how a three-stage magnetic household refrigerator could be designed, if it is based on a patent, which was deposited by HEIG-VD/SIT. The three red/blue rotor wheels are connected to perform regeneration cycles. Notify that the design may permit to only have two pumps in such a multi-stage machine.

A small analysis was performed to investigate household refrigerators with a cooling power of 50 W. The comparison was made between a magnetic refrigerator and a compressor of usual size as applied in a typical household appliance. According to the operating characteristics one also expects that in compression/expansion refrigerators the temperature difference between the refrigerant and the internal, respectively external temperature level, is higher than in a magnetic refrigerator. Figure 3 shows the comparison of *COP's* of a rotary magnetic household refrigerator (magnetic flux density 2.5 Tesla) with a hermetic compressor.

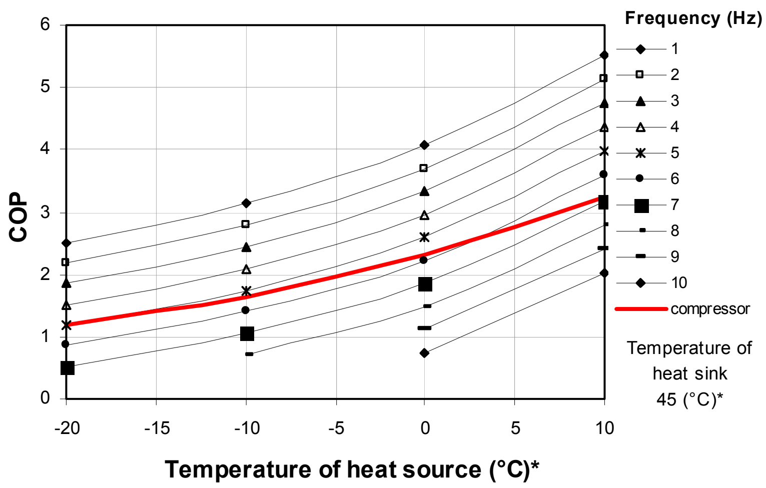

Figure 3: The *COP* of a magnetic household refrigerator as a function of the heat source temperature and the frequency of operation for a magnetic flux density change of 2.5 Tesla is shown. The red colored thicker line corresponds to the *COP* of an Embraco hermetic compressor (M/ HBP, R134a, 50 Hz, type EM20 HBR, condensing temperature 45 °C and L/M/HBP type EM20 HHR). A star (*) denotes that the temperatures are identical to the condensing, respectively to the evaporation temperature of the refrigerant.

Figure 3 shows that the frequency of operation strongly influences the characteristics of a magnetic refrigerator. The reason for that is that a higher velocity of the working fluid leads to a higher pressure drop and therefore also to more irreversibilities. Also figure 4, which presents the exergy efficiency, shows that a magnetic household refrigerator is competitive to one containing a compressor. This is specially the case when the frequency is low, e.g. below 5 Hz. In order to be competitive to compressor refrigerators, for higher magnetic flux density changes the frequency may be higher and vice-versa, for lower magnetic flux density changes the frequency should be lower.

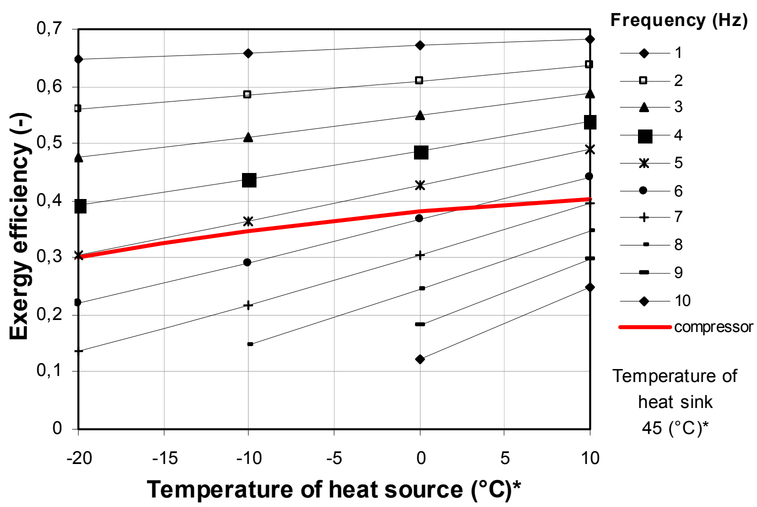

Figure 4: The exergy efficiency as a function of the heat source temperature when a magnetic flux density change of 2.5 Tesla is applied. The data are shown for numerous rotation frequencies of operation. The red thick line shows the exergy efficiency of an Embraco hermetic compressor (M/HBP, R134a, 50 Hz, type EM20 HBR, condensing temperature 45°C and L/M/HBP type EM20 HHR). Please notify that this comparison is favorable for the conventional technology, because a complete magnetic refrigerator (with all its losses) is just compared with the main component "compressor" of a conventional machine.

Central cooling systems

The world production in 2003 of compressors for air conditioning and refrigeration (centrifugal, screw, scroll, reciprocating and the rotary type with two cylinders) was around 22 millions and 18 millions, respectively [13]. The world market estimated for both is approximately 3 billion US$ per year. Conventional central cooling systems, vapor compression and sorptive chillers (usually hot water and gas absorption chillers, rarely adsorption and steam driven absorption chillers) are found in practical applications. In the case of water/water (brine/brine) chillers the temperature level on the cooling side of the water cooling loop usually varies from 5 to 10°C in the supply tubes. On the other hand the temperature is 10 to 18°C in return tubes with fluid arriving from the heat source. The temperature level of the heat rejection loop usually varies between 18 to 35°C. Figure 5 shows an example of the central chiller unit.

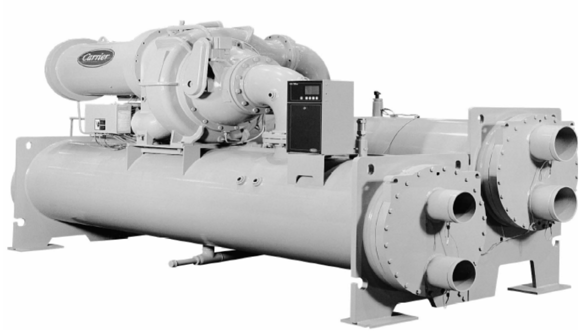

Figure 5: A typical centrifugal chiller (www.carrier.com) of large size. These chillers are usually used for large cooling powers (large refrigerant volume flow and low pressure ratio). The nominal cooling capacity may be kept in a wide range of operating characteristics. Beside electric energy, also other kinds of sources may be used, e.g. direct, gas turbine (or other combustion engine) driven compressor chillers or even a steam turbine.

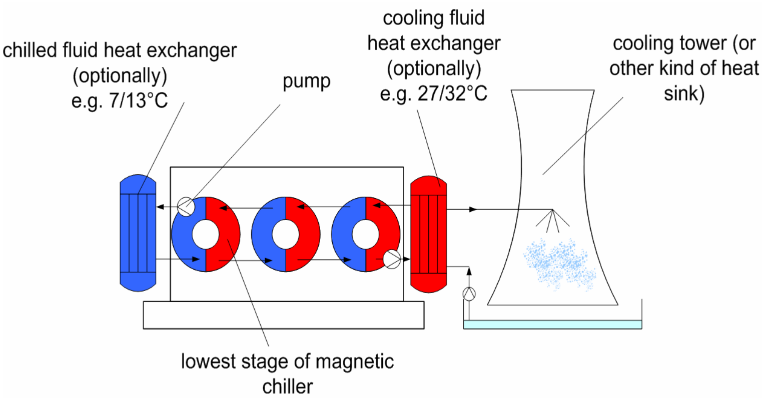

Figure 6: An example of the three-stage magnetic chiller unit is shown. For a typical water/water or brine/brine conventional compressor chiller the cooling water temperatures for the supply and return circuits are usually 27/32°C and the chilled water temperatures of the supply and return circuits are 7/13°C. This technology may present a serious alternative to central cooling systems, especially in larger systems. Such are e.g. district cooling systems.

In a magnetic central chiller, especially operating with water/water or brine/brine, the operating conditions are very favorable for an application of the magnetic refrigeration technology. Additionally it has to be emphasized that for large scale units of central cooling systems other machines than magnetic refrigerators based on permanent magnets may also be applied, e.g. such with superconducting magnet coils. The cooling system for the superconducting coils - which preferably should be performed by high temperature superconductors - may be used for several coils. These coils provide the magnetic field sources for a large number of chiller units. The higher the required cooling power is, the lower the relative costs of such a system will be. Such systems, in general, may show also a much better compactness, especially when compared to magnetic refrigerators with permanent magnets. Furthermore, the use of superconducting coils permits to work with only a single stage magnetic chiller. This results because the magnetocaloric effect is much larger when the magnetic field strength is higher. Furthermore, the maximal magnetic field strength of superconducting magnets is much higher than of permanent magnets. Another advantage of large systems is the fact that the magnetic refrigerator may be produced without moving parts (e.g. reciprocate linear or rotational motion of the magnetocaloric material). This is advantageous because high magnetic fields make it rather difficult to have movements in machines with high precision.

Considering the working fluid, a central cooling plant realized with the magnetic cooling technology permits a one-loop or a two-loop system. In a single-loop system of a magnetic refrigerator the working fluid (liquid or another conventional secondary liquid refrigerant) may be directly transferred to the outer system. The disadvantages are the regulation/control of such a system as well as the required pressure. On the other hand an advantage is the possibly higher efficiency, because of a lack of further intermediate heat exchangers, which are necessary in the case of two-loop systems.

There exist many different possibilities to integrate the magnetic refrigeration technology into central unit systems. This includes, for example, also a kind of decentralized cooling system, where a central unit (central cooling system) causes a pre-cooling and then local magnetic cooling devices are responsible for a further cooling. Such a method could be applied if further cooling is required, e.g. for the cooling of ceiling panels or fan coils, etc.

Another solution is a hybrid system where a compressor chiller takes over a central pre-cooling and - depending on the requirements of end-use coolers - magnetic cooling units are mounted and operated for the final conditioning. Such a kind of system is not analyzed here. Figure 7 shows the coefficient of performance (*COP)* and Figure 8 the exergy efficiency of a magnetic central refrigeration system.

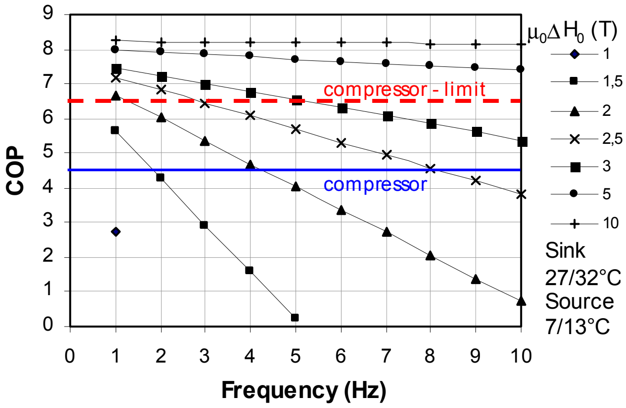

Figure 7: The *COP* of brine/brine central magnetic chiller units is shown. This quantity is presented depending on the frequency of the operation of the machine and the magnetic flux density. Furthermore the graphic contains typical values of *COP*'s of centrifugal compressors operating under the same conditions (taken from Ref [14]) and the upper limit, which for this technology is 60% of the Carnot efficiency. Even the applications of permanent magnets enables competitive efficiencies compared to conventional technologies.

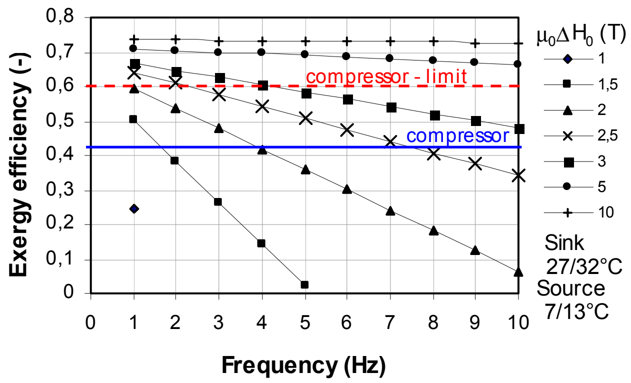

Figure 8: Exergy efficiency of brine/brine central magnetic chiller units. Furthermore, the graphic contains typical values of the exergy efficiency for centrifugal compressors operating under the same conditions (taken from Ref [14]) and the upper limit, which corresponds to 60% of the Carnot efficiency for this technology. Magnetic refrigeration presents the most efficient solution of cold production, especially in large scale systems where also superconducting magnets become feasible.

As may be seen in Figure 7, magnetic refrigerators based on permanent magnet's assemblies are not competitive to compressor cooling technologies for magnetic flux densities lower than e.g. 1.5 Tesla. The *COP* as well as the exergy efficiency also strongly depend on the frequency of the operation, because this is related to higher velocities of the working fluid and thus leads to higher pressure drops. Research in magnetic refrigeration has shown that permanent magnet assemblies with higher than 2 Tesla magnetic inductions in the magnetocaloric material are feasible. Based on that, one may see that with, e.g. a magnetic flux density of 2.5 Tesla, one is capable to perform a very efficient cooling device, competitive with compressor containing refrigerator units. Furthermore, the use of superconducting magnets (e.g. 5 Tesla and above) beats the efficiency of conventional compressor technologies. However, as already mentioned before, this technology should rather be used for very large central units.

Other very important information is the total mass of a device (see Figure 9), as well as the volume that such a device occupies (Figure 10). A comparison between magnetic refrigerators with permanent magnets and different conventional chillers was made (e.g. compressor chiller, hot water absorption chiller, gas or steam driven absorption chiller). All the data for conventional machines were taken from Ref. [14].

The *COP* values and the exergy efficiency have been calculated by a modified method outlined in Ref. [15]. There it was applied for magnetic heat pumps; but the difference to magnetic refrigerators is small. The analysis of the *COP* and exergy efficiency comprises losses occurring due to the motor and pump efficiency, hysteresis of the magnetocaloric material, eddy currents, irreversible heat transfer, heat losses (or gains) and losses related to the frictional flows. A major part of the calculations was based on methods presented in Ref. [15] with certain modifications, which will be presented in the final report and scientific publications. The required total mass and volume of the device are taking into account the magnetocaloric material, the magnet assemblies, pipes, valves and motors. The mass and volume of the permanent magnets were defined with some experience resulting from a very large amount of numerical simulation results of magnetic field line distributions of magnetic assemblies.

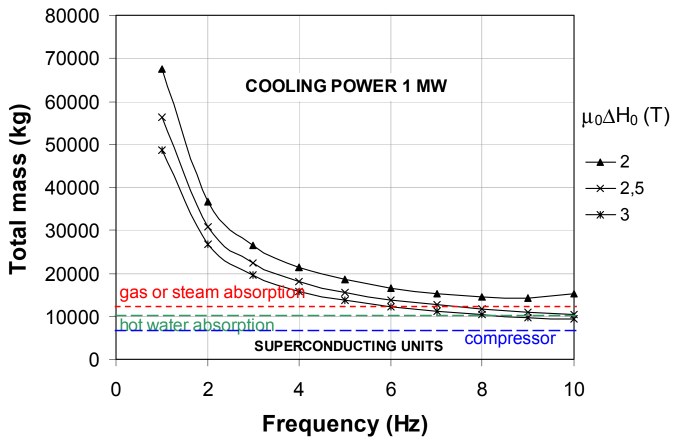

Figure 9: Total mass estimation of magnetic chillers with a cooling power of 1 MW and a comparison with conventional chillers (taken from the Ref. [14]) are shown. The operating conditions are the same as assumed in Figure 7. The central magnetic cooling units in general show a larger total mass as conventional machines, especially when permanent magnets are applied. Note that the mass is high, because of a rather high mass of the permanent magnet assemblies and not because of the mass of the magnetocaloric fillings.

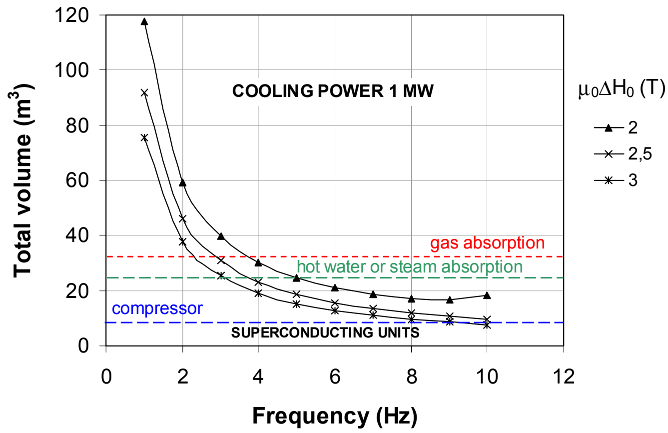

Figure 10: Total volume estimation of magnetic chillers with a cooling power of 1 MW and a comparison with conventional chillers (taken from the Ref. [14]) are shown. The operating conditions are the same as assumed in Figure 7. The total volume was defined to be ten times that of the sum of the magnet's assembly and the magnetocaloric porous structure. Therefore, it is possible to expect that real industrial applications will lead to a lower total volume as it is predicted in this analysis and consequently lead to compacter magnetic chiller applications, which are based on permanent magnets.

Both quantities, the mass and volume strongly depend on the frequency of operation. Superconducting magnets in contrary lead to a much compacter solution, especially if a magnetic refrigerator with no moving parts is taken into consideration. One should note that the volume fraction of the magnetocaloric material in the porous structure was taken to be only 10 vol.-%. This is rather small, but it enables a high rate of heat transfer. If the volume fraction is increased, this leads to a more compact device, but on the other hand reduces the efficiency due to the higher pressure losses.

Conclusions and Outlook

This annual report contains a list of refrigeration systems in practice, which may be successfully replaced by the magnetic cooling technology. By adapting and applying a method developed for heat pumps and financed in another project of the BFE the coefficent of performance values *COP's* and exergy efficiencies of all these systems were calculated. This evaluation shows that some systems are more ideal for an application of magnetic refrigerators than others. Two good examples - the household refrigerator without a freezing compartment and the central refrigeration unit/system - were chosen for a more detailed presentation.

Briefly one can say that applications with smaller temperature differences are much more favourable. This results from the limited adiabatic temperature difference of the magnetocaloric materials. The result then is that numerous cascading or regeneration stages have to be taken into consideration. These lead to additional heat transfer losses, so that the coefficient of performance is lower. Furthermore, the restriction of an operation to a domain around the Curie temperature of the magnetocaloric material makes systems with steady operation conditions more favourable. If for example the temperature of the heat source and sinks are wildly fluctuating, a well determined operation of a machine is not guaranteed. Please notify that these two restrictions are valid for all kind of magnetic machines, namely magnetic heat pumps, magnetic refrigerators and magnetic “power conversion” machines.

Furthermore the study reveals that for smaller magnetic fields high *COP* values are only possible, if the rotation frequency is low. That is a result of the connection of the rotation frequency and the fluid velocity, given by a criterion to keep the carry-over leakages small. And only small fluid velocities lead to small pressure losses in the porous structures of the rotary wheels. But, if these velocities must be small, also the angular velocity and the frequency must be low.

At higher magnetic fields the dependence on the rotational frequency is smaller. This is because a second loss, the irreversibilites between stages, is also important. If the magnetic field strength is high, a lower number of stages must be foreseen, and these irreversibilities are lower. And even more, because of fewer stages, fewer rotors in series occur, and also the pressure drop loss is smaller. That explains why high fields are very interesting for the magnetic/magnetocaloric machine design. Therefore, we propose to study machines with superconducting magnets with large cooling powers. The economy of such systems will be determined by the installation costs of superconducting magnets. A further study at the beginning of next year of all these aspects will lead to more information.

National collaboration

A project of the Gebert Rüf foundation with the title: “Magnetic cold production at room temperature” had the objective to open us the chance to immediately start with some work on the field. In this project a first “demonstrator”, a radial magnetic refrigerator, was designed and built. This machine was not optimized by numerical simulations, that’s why we call it “demonstrator” instead of “prototype”. HEIG-VD/TIS (TIS denotes the division Thermal Industrial Systems) obtained an additional financial support from the Swiss Federal Office of Energy for developing the demonstrator.

The Swiss Federal Office of Energy also finances a further study, in which potential applications of a magnetic “power production” system (inverse process), by applying magnetocaloric material, will be listed. A corresponding annual report, showing the results of that study, is also available.

The County of Vaud intends to support the division HEIG-VD/SIT (Simulations of Thermal Systems) with priority. Therefore, the Swiss Federal Office of Energy (R&D program heat pumping technologies, cogeneration, refrigeration of SFOE) together with the County of Vaud finances a project to build a magnetic heat pump prototype. Also for this activity an annual report 2007 is available.

A meeting to present magnetic refrigeration to experts from a Swiss company led to a collaboration to develop some other technology. At present HEIG-VD researchers are discussing research and development projects with different European companies, which are building refrigeration machines.

International collaboration

Two main authors of this work are the President and the Vice-president of the Magnetic Cooling Working Party of the International Institute of Refrigeration (IIF/IIR) in Paris. Up-to-present this group has organized two “International Conferences on Magnetic Refrigeration at Room Temperature”, a first one in 2005 in Montreaux, Switzerland, and a second one in 2007 in Portoroz, Slovenia (see figure 11 and Ref. [16]). Both conferences were very successful and a large number of participants from Universities and different companies worldwide participated. The next - the “Third International Conference on Magnetic Refrigeration at Room Temperature” - will be organized by V.K. Pecharsky in Spring 2009 in the USA. V.K. Pecharsky is professor at the IOWA State University (AMES Laboratory). The HEIG-VD/SIT group has created the web-site of the working party, which may be found under the address given in Ref. [17].

After the conference the two pioneers on materials for room-temperature magnetic refrigeration, K A. Gschneidner Jr. [18] und Vitalij K. Pecharsky [19], travelled with the group from Yverdon to Switzerland. Karl Gschneidner held a well-visited invited presentation at the University of Applied Sciences of Western Switzerland with the title: „Thirty years of near room temperature magnetic cooling“. Furthermore, successful discussions on future collaboration were performed. The two experts explained that they are open to discuss a delivery of high-quality magnetocaloric material for magneto-thermodynamic testing in prototypes to the HEIG-VD group.

Figure 11: The participants of the above mentioned conference in 2007, briefly named THERMAG II (THERMAG is an abbreviation for thermodynamics and magnetism), in front of the famous Postojnska caves. We experience that these conferences are visited by approximately 150 interested scientists and industrial representatives from all over the world. These conferences are also the official meeting occasions of the working party. During the conference always a larger meeting is organized to discuss with the members of the IIR working party the next two-years activities.

A result of the preceeding conference Thermag I, which took place in the year 2005 in Montreux, is a Special Issue of the International Journal of Refrigeration on Magnetic Cooling (see Ref. [20]). It contains selected and improved conference articles.

The division HEIG-VD/SIT in summer 2006 had the excellent opportunity to benefit from a guest professor visit of R. Rosensweig, who is a pioneer of the domain Ferrohydrodynamics. The collaboration with R. Rosensweig focuses mainly on the domain of the theory of magneto-thermodynamics and magnetic refrigeration as well as on the field of magnetocaloric slurries. In October 2007 P.W. Egolf produced together with him the 20th Informatory Note of the International Institute of Refrigeration (see Ref. [21]). R. Rosensweig is the well-known author of the standard text book „Ferrohydrodynamics“ [22]).

Our work on magnetic heating and cooling as well as a first “demonstrator“ were presented as results of a model project of a Swiss University of Applied Sciences in Switzerland at Swissnex in San Francisco [23].

In 2007 HEIG-VD - with the initiative of the division SIT - has signed a collaboration agreement with the deputy rector of Lomonosov State University in Moscow. A strong collaboration is under development with the well known specialist for magnetism, Prof. Alexander M. Tishin [24], who is also the author of a wide-spread standard text book on magnetocaloric materials and systems (see Ref. [25]).

The group SIT also collaborates with the University of Ljubljana. Two authors of this report are members of the commission for the Slovenian thesis of PhD student Alen Sarlah.

A further collaboration agreement is now under discussion with BASF (Future Technologies). This large German chemical company intends to start to produce magnetocaloric materials in large quantities. Such an action would tremendously support the production of magnetocaloric machines.

Evaluation of 2007 and view of 2008

The project could be performed as planned and led to a large insight into the different refrigeration technologies and their suitability to apply successfully the magnetic refrigeration technology. All these systems are briefly listed in this annual report. More detailed results shall be presented in the final report of the project in form of a more comprehensive overview with a large table.

The final report will comprise the analysis of all the listed refrigeration technologies, which are only briefly presented in this report as possible applications. The evaluation method will be presented in detail. A selection of the most feasible magnetic refrigeration technologies will be made based on market requirements and environmental aspects. A main driving force to support magnetic refrigeration is the environmental begnin behaviour of this technology.

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