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Thermoelectric and Thermoacoustic Technologies for Food Refrigeration

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Abstract: Refrigeration has become an important part of the food industry. It is used in all stages of the chain, from food processing, to distribution, retail and final consumption in the home. The food industry employs both chilling and freezing processes where the food is cooled from ambient to temperatures above 0 °C in the former and between −18 °C and −35 °C in the latter to slow the physical, microbiological and chemical activities that cause deterioration in foods. In these processes mechanical refrigeration technologies are invariably employed that contribute significantly to the environmental impacts of the food sector both through direct and indirect greenhouse gas emissions. To reduce these emissions, research and development worldwide is aimed at both improving the performance of conventional systems and the development of new refrigeration technologies of potentially much lower environmental impacts. This paper provides a brief review of both current state of the art technologies and emerging thermoelectric and Thermoacoustic refrigeration technologies that have the potential to reduce the environmental impacts of refrigeration in the food industry.

Keywords: Thermoelectric, Thermoacoustic, Peltier effect, Food refrigeration.

Introduction

Thermoelectric cooling devices utilize the Peltier effect, which causes the junction of two dissimilar conducting materials to either cool down or warm up when a direct electric current passes through the junction, depending on the direction of the current. In this system,a pair of adjacent thermoelement legs are joined at one end by a conducting metal strip to form a junction. Thus, the legs are connected in series electrically but act in parallel thermally. This unit is referred to as a thermoelectric couple and is the basic building block of a thermoelectric (or Peltier) cooling module. The thermoelement materials are doped semiconductors, one n-type with a majority of negative charge carriers (electrons) and the other p-type with a majority of positive charge carriers (holes). When a DC voltage is applied, the junction experiences a temperature decrease, to T_c, accompanied by absorption of thermal energy from the cold side as electrons moving from the p-type material to the n-type material jump to a higher energy level. The majority charge carriers transport the absorbed energy through the thermoelements to the hot side, at T_h, where heat is rejected as the electrons return to a lower energy level(Tassou, et al., 2010).

Thermoelectric cooling modules contain multiple thermoelectric couples connected in series, sandwiched between electrically insulating, but thermally conductive, substrates. As solid state devices they have no moving parts and, consequently, are highly reliable and virtually maintenance free. Further advantages include the absence of noise and vibration, the compactness and low weight construction, and the capacity for precise temperature control(Tassou, et al., 2010).

Thermoacoustic refrigeration systems operate by using sound waves and a non-flammable mixture of inert gas (helium, argon, air) or a mixture of gases in a resonator to produce cooling. Thermoacoustic devices are typically characterized as either ‘standing- wave’ or ‘travelling-wave’ (Bammann, et al., 2005). The main components of a standing-wave device are a closed cylinder, an acoustic driver, a porous component called a ‘‘stack”, and two heat-exchanger systems. Application of acoustic waves through a driver such as a loud speaker, makes the gas resonant. As the gas oscillates back and forth, it creates a temperature difference along the length of the stack. This temperature change comes from compression and expansion of the gas by the sound pressure and the rest is a consequence of heat transfer between the gas and the stack. The temperature difference is used to remove heat from the cold side and reject it at the hot side of the system. As the gas oscillates back and forth because of the standing sound wave, it changes in temperature. Much of the temperature change comes from compression and expansion of the gas by the sound pressure (as always in a sound wave), and the rest is a consequence of heat transfer between the gas and the stack (Gardner, et al., 2003). In the travelling-wave device, the pressure is created with a moving piston and the conversion of acoustic power to heat occurs in a regenerator rather than a stack. The regenerator contains a matrix of channels which are much smaller than those in a stack and relies on good thermal contact between the gas and the matrix. The design is such that the gas moves towards the hot heat exchanger when the pressure is high and towards the cold heat exchanger when the pressure is low, transferring heat between the two sides.

State of Development

Thermoelectric modules are available to suit a wide range of small and medium cooling duties. Manufacturers’ lists, for example Kryotherm, include single-stage modules with maximum cooling capacities from less than one watt up to 310 W. Module sizes range from a few millimetres square up to 62 mm ×62 mm and number of thermoelectric couples per module from less than 10 to 241. Modulethicknesses are normally between 2 and 5 mm (Tassou, et al., 2010).

Almost all commercially produced modules use n-type and p-type thermoelements cut from bismuth telluride (Bi_2Te_3) based bulkmaterials, which are presently the best available for near room temperatureoperation and give a dimensionless figure of merit close tounity (ZT approximates to 1). The maximumCOP for a single-stage module is, however,limited to approximately 10% of the corresponding reversedCarnot cycle efficiency and a maximum temperature difference ofaround 70 K can be obtained. To achieve efficiencies comparablewith vapour compression systems would require a material with aZT of about 4. Research on ZT enhancement is directed towardsreducing lattice thermal conductivity and includes preparation ofnew bulk materials with more favourable properties and fabricationof quantum thermoelectric structures (Goldsmid, 2006).In thermoelectric refrigeration applications the cooling module (or modules) must be interfaced with cold side and hot side heat exchange systems. The associated thermal resistances and power consumption can significantly influence the overall system coefficient of performance. A variety of heat transfer technologies, including air-cooled heat sinks, liquid-cooled microchannel heat sinks and systems involving heat pipes or two-phase thermosyphons, covering a wide range of heat flux capability, have been developed that help minimize the temperature difference across the thermoelectric module, and hence maintain efficiency (Riffatt, et al., 2004 and Davis, et al., 2006).

As far as thermoacoustic refrigeration is concerned, a number of design concepts and prototypes are under development in many research establishments. The technology has the potential to offer another refrigeration option but improvements in design are necessary to increase COPs to the level of vapour compression systems. Research effort is currently directed to the development of flow-through designs (open systems) which will reduce or eliminated the use of heat exchangers.

Applications in the Food Sector

Thermoelectric cooling has been extensively applied in numerous fields, handling cooling loads from milliwatts up to tens of kilowatts in systems using multiple modules in parallel, and temperature differences from almost zero to over 100 K with multistage modules (Stockholm, 1997).

Thermoelectric cooling products available for the food sector include compact refrigerators (15–70 l) for hotel rooms (mini bar), mobile homes, trucks, recreational vehicles and cars; wine coolers; portable picnic coolers; beverage can coolers and drinking water coolers (Riffatt, et al, 2003). Prototype domestic refrigerators of larger capacity (115 l and 250 l) have been built and tested, achieving COPs up to 1.2 (Min, et al.,2006). In addition, an overall COP of 0.44 was measured for a prototype 126 l refrigerator–freezer (Davis, et al., 2004).

While, thermoacoustic refrigerators have the potential to cover the whole spectrum of refrigeration down to cryogenic temperatures. It is likely that potential market for food applications will initially be in the low capacity equipment such as domestic and commercial refrigerators, freezers and cabinets.

Barriers to Uptake of the Technology

The main barriers to the uptake of thermoelectric refrigeration are, lower efficiency than vapour compression technology, and thermoelectric cooling modules are widely available but, apart from small capacity items, packaged thermoelectric refrigeration systems are not as yet available(Tassou, et al., 2010).

The main barriers to the uptake of thermoacoustic technology are, in their present state of development the efficiency of prototype thermoacoustic refrigeration systems is lower than that of vapour compression systems, and systems operating on the thermoacoustic principle are not yet commercially available.

Key Drivers to Encourage Uptake

The main drivers to encourage uptake of thermoelectric cooling technology in the food sector are legislation that significantly limits or prohibits the use of HFCs in small capacity, self contained refrigeration equipment, and limits imposed on the amount of flammable refrigerant that can be used in self contained refrigerated cabinets (Tassou, et al., 2010).

The main drivers to encourage uptake of thermoacoustic technology once they become commercially available in the food sector are environmental considerations and legislation that significantly limits or prohibits the use of HFCs in small capacity, self contained refrigeration equipment, limits imposed on the amount of flammable refrigerant that can be used in self contained refrigerated cabinets, development and availability of systems that offer efficiency and cost advantages over vapour compression systems.

Conclusion

Increased application of thermoelectric cooling in the food sector will require a significant improvement of COP to make it competitive with vapour compression technology. Principally, new thermoelectric materials or structures are needed with much higher figures of merit than currently achieved with established Bi_2Te_3 based bulk materials. Further work is also required to improve the performance and integration of heat exchange systems on both the hot and cold sides, to reduce module temperature differentials.

In case of thermoacoustic technology, to improve efficiency and reduce cost, developments are needed in the design of stacks, resonators and compact heat exchangers for oscillating flow. Research is also required in the development of flow-through designs (open systems) which will reduce or eliminated the use of heat exchangers and will reduce complexity and cost.

References

1. Bammann, T.C., Howard, C.Q., Cazzolato, B.S. (2005). Review of flow-through design in thermoacoustic refrigeration, in: Proceedings of ACOUSTICS 2005, 9–11 November 2005, Busselton, Western Australia.
2. Davis, M., Manners, B., and Clarke, P. (2004). Design of a 126 l refrigerator/freezer commercial freezer prototype, in: 23rd International Conference on Thermoelectrics, Adelaide.
3. Davis, M.C., Banney, B.P., Clarke, P.T., Manners, B.R., and Weymouth, R.M. (2006). Thermoelectric refrigeration for mass-market applications, in: D.M. Rowe (Ed.), Thermoelectrics Handbook: Macro to Nano, Section V, CRC Press.
4. Gardner, D.L., Swift, G.W. (2003). A cascade thermoacoustic engine, Journal of the Acoustical Society of America 114 (4): 1905–1919.
5. Goldsmid, H.J. (2006). A new upper limit to the thermoelectric figure-of-merit, in: D.M. Rowe (Ed.), Thermoelectrics Handbook: Macro to Nano, Section I, CRC Press.
6. Kryotherm, Thermoelectric coolers and related subsystems, <http://www.kryotherm.ru/dir2attz/Kryotherm%20catalog.pdf>.
7. Min, G., and Rowe, D.M. (2006). Experimental evaluation of prototype thermoelectric domestic-refrigerators, Applied Energy 83:133–152.
8. Riffatt, S.B., and Ma, X. (2003). Thermoelectrics: a review of present and potential applications, Applied Thermal Engineering 23: 913–935.

9. Riffatt, S.B., and Ma, X. (2004).Improving the coefficient of performance of thermoelectriccooling systems: a review, International Journal of Energy Research 28: 753–768.
10. Stockholm, J.G. (1997). Current state of Peltier cooling, in: Proceedings of 16th International Conference on Thermoelectrics, Dresden, Germany, pp.37–46.
11. Tassou, S.A., Lewis, J.S., Ge, Y.T., Hadawey, A., and Chaer, I. (2010). A review of emerging technologies for food refrigeration applications. Applied Thermal Engineering 30: 263–276