Fostering the Development of Technologies and Practices to Reduce the Energy Inputs into the Refrigeration of Food

Alternative and Emerging Refrigeration Technologies for Food Refrigeration Applications

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1. TRIGENERATION

Description of technology

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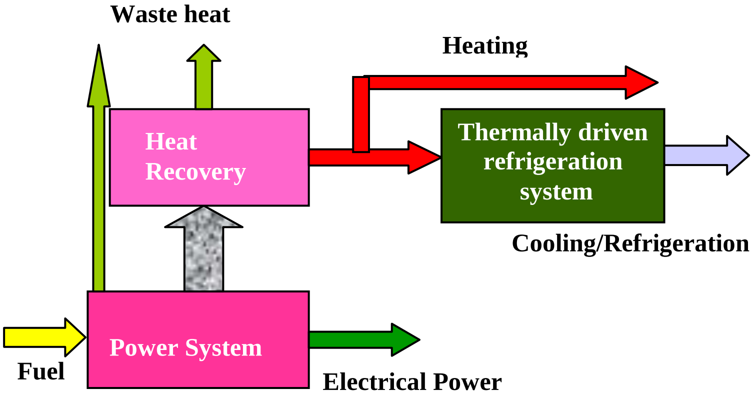

Figure 1. Schematic of a trigeneration system

Barriers to uptake of the technology

2. AIR CYCLE REFRIGERATION

Description of technology

Air cycle systems can produce low temperatures for refrigeration by subjecting the gaseous refrigerant (air) to a sequence of processes comprising compression, followed by constant pressure cooling, and then expansion to the original pressure to achieve a final temperature lower than at the start of compression. Air cycle refrigeration is based on the reversed Joule (or Brayton) cycle illustrated in figure 1.

Air cycles can be classified as closed, open or semi-open/closed. **Closed cycles** are, by definition, sealed systems and consequently there is no direct contact between the working fluid and the product being cooled. Hence, in comparison with open and semi-open/closed cycles an additional heat exchanger (with associated temperature difference) is required for transferring heat from the refrigeration load. **Open cycles** can be open on either the low-pressure side or the high-pressure side of the cycle. Cold air leaving the system passes through the refrigerated space coming in direct contact with the product being cooled. **Semi-Open/Closed cycles** are also open to the refrigerated space, where the cold air comes into direct contact with the product being cooled but the air is then drawn back through the low-pressure side of the regenerator to the compressor.

State of Development

Air cycle is a reasonably well established technology. Plant operating characteristics are understood and issues such as condensation and icing have been addressed and solutions developed. Closed and open air cycle systems have been developed by industrial companies with refrigeration capacities ranging from 11 to 700 kW for closed systems and from 15 to 300 kW for open systems. Information on coefficient of performance for refrigeration is sparse but most values quoted are in the range 0.4 to 0.7. It is also noted that the efficiency of air cycle systems is relatively unaffected under part load conditions.

Applications in the food sector

Air cycle refrigeration can deliver air temperatures down to -100°C, giving it a niche position in the -50°C to -100°C range, beyond the capability of vapour compression plant, and is a cost-effective alternative to the use of cryogenics for low temperature food freezing operations. Air cycles also generate high air temperatures, typically of over 200°C, that can be used in combination with the low temperatures to integrate cooking and refrigeration processes.

In the food sector air cycle technology can be applita631ons iEoIO9fo(ai)-00e313( )-70(t(c)-5(s)-54(og)(i)5(ge)4(r

Barriers to uptake of the technology

The main barriers to uptake of air cycle technology are:

unavailability of packaged equipment off the shelf for application in the food sector

3. SORPTION REFRIGERATION - ADSORPTION SYSTEMS

Description of technology

Sorption refrigeration technologies such as absorption and/or adsorption are thermally driven systems, in which the conventional mechanical compressor of the common vapour compression cycle is replaced by a ‘thermal compressor’ and a sorbent. The sorbent can be either solid in the case of adsorption systems or liquid for absorption systems. When the sorbent is heated, it desorbs the refrigerant vapour at the condenser pressure. The vapour is then liquefied in the condenser, flows through an expansion valve and enters the evaporator. When the sorbent is cooled, it reabsorbs vapour and thus maintains low pressure in the evaporator. The liquefied refrigerant in the evaporator absorbs heat from the refrigerated space and only two manufacturers of commercial products and distribution channels are not well established

4. THERMOELECTRIC REFRIGERATION

Description of technology

Thermoelectric cooling devices utilise the Peltier effect, whereby the passage of a direct electric current through the junction of two dissimilar conducting materials causes the junction to either cool down (absorbing heat) or warm up (rejecting heat), depending on the direction of the current.

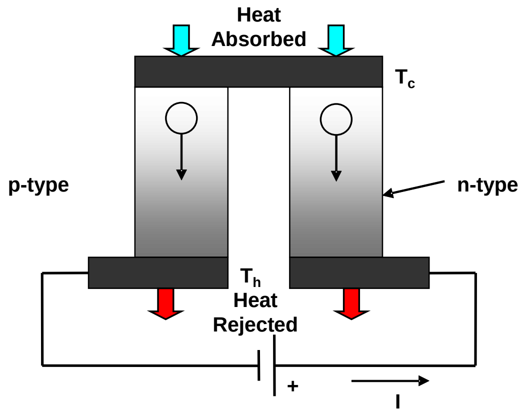

Figure 1, shows a pair of adjacent thermo-element legs joined at one end by a conducting metal strip forming a junction between the legs. Thus, the legs are connected in series electrically but act in parallel thermally. This unit is referred to as a thermoelectric couple and is the basic building block of a thermoelectric (or Peltier) cooling module. The thermo-

thermoelectric cooling modules are commercially available but packaged thermoelectric refrigeration systems are not as yet 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.
- limits imposed on the amount of flammable refrigerant that can be used in self contained refrigerated cabinets.
- increased efficiency of thermoelectric modules.

Research and development needs

Application of thermoelectric cooling technology to the food sector will require improvement of th

5. STIRLING CYCLE REFRIGERATION

Description of Technology

The Stirling cycle cooler is a member of a family of closed-cycle regenerative thermal machines, including prime movers as well as heat pumps and refrigerators, known collectively as Stirling cycle machines. In any refrigeration cycle, including the reversed Stirling cycle, net work input is necessary in-line with the second law of thermodynamics. This is achieved by shuttling the gas in the system backwards and forwards between the hot end and cold end spaces so that the temperature of the system during compression is, on average, higher than during expansion. As a result the work done on the gas during compression is greater than the work done by the gas during expansion, Figure 1. Accordingly, the hot end and cold end gas spaces are also referred to as the compression space and the expansion space respectively. Furthermore, for operation as a refrigerator, heat must be rejected via a heat exchanger at the hot end, and heat must be absorbed from the space to be cooled via a heat exchanger at the cold end.

State of Development

Free-piston machines (FPSC)

Barriers to uptake of the technology

The main barriers to uptake of Sterling cycle refrigeration technology are:

- currently only small capacity units are available which in their present state of development cannot compete on price and efficiency with vapour compression systems.
- application of FPSC machines is tightly controlled by Global Cooling which determine the areas of application through licensing of the technology.

Key drivers to encourage uptake

The main drivers to encourage uptake of the technology in the food sector are:

- 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

Research and development needs

Wider application of FPSCs to the food sector will require higher cooling capacities and higher system COPs. Important areas of research are:

- development of higher efficiency linear motors and design to increase cooling capacity,
- improved heat exchange on the cold and hot sides and better component integration.

6. THERMOACOUSTIC REFRIGERATION

Description of technology

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 characterised as either ‘standing-wave’ or ‘travelling-wave’. A schematic diagram of a standing wave device is shown in figure 1. The main components 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

7. MAGNETIC REFRIGERATION

Description of Technology