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TRENDS IN REFRIGERATION TECHNOLOGIES USED FOR FOOD PRESERVATION – A REVIEW

Elisabeta Elena POPA, Amalia Carmen MITELUȚ, Mona Elena POPA

University of Agronomic Sciences and Veterinary Medicine of Bucharest,
Faculty of Biotechnologies, 59 Mărăşti Blvd., Bucharest, Romania

Corresponding author email: amaliamitelut@yahoo.com

Abstract

Food is a perishable commodity. The primary objective of food preservation is to prevent or slow down the growth of microorganisms including moulds, yeasts and bacteria as their growth causes spoilage of food but also to reduce the speed of enzymatic reactions which take place during postharvest or post-slaughter life of raw material or during food product shelf-life. Refrigeration has become an essential part of the food chain. It is used in all stages of the value chain, from farm, food processing, to distribution, retail and final consumption at home. The food industry employs both chilling and freezing processes where the food is cooled from ambient to temperatures above 0°C in chilling and between -18°C and -35°C in freezing to slow the physical, microbiological and chemical activities that may cause deterioration in foods. The use of refrigeration for food production and its preservation is undoubtedly the most extensive technique. The aim of this study is to present the latest trends in refrigeration techniques used for food preservation.

Key words*: refrigeration technologies, food preservation, chilling, freezing.*

INTRODUCTION

Food spoilage represent a continuous threat along the entire food chain, consequently suitable and efficient conservation methods are needed. For food products that cannot be deposited at room temperature, the technologies currently applied are in general represented by chilling and freezing which, while effective, are energy consuming (Santos et al., 2015). New technologies have been presented lately to improve food quality during storage along the cold chain. Despite their advantages, there is still needed the improvement of some factors that may compromise food product's thermal stability and distribution and furthermore causing direct impact on food quality and energy efficiency (Tsang et al., 2017).

Refrigeration is omnipresent in daily life, for example in homes, and vehicles, as well as in less obvious applications, such as cryogenic cooling. The large need for refrigeration on multiple levels of different temperatures has created a vast variety of refrigeration and freezing techniques. For most applications, vapor compression cycles and absorption cycles are used. The latter are used for large scale applications, while the former is used widely in applications encountered on a daily basis (Zink et al., 2010). In terms of food industry, refrigeration represents an essential part of the food chain, being used in all stages from processing to distribution, retail and final consumption at consumer's home (Tassou et al., 2009).

The aim of this study was to provide a brief review of some refrigeration techniques that are or could be used in food industry.

Air cycle refrigeration

The advantages of air as a refrigerant are obvious: it is free, safe for environment and operators and, above all, available everywhere (Shengjun et al., 2011; Giannetti & Milazzo, 2014). Using air as refrigerant has great advantages over conventional refrigerants, many of which have negative environmental effects, are toxic or flammable (Shengjun et al., 2011). This technique allows continuous charge/discharge to the ambient, a unique feature among refrigerant fluids, eliminating the need for a sealed circuit. The circuit can be open to the ambient or to the refrigerated space. In both cases, irreversibility related to heat transfer and flow friction, as well as cost, weight and volume, are avoided. Regarding the second case, elimination of the evaporator has many advantages in terms of frost avoidance on cold surfaces. If the cold air is introduced at an acceptable speed in the cold space, the electric fan integrated on the evaporator can be eliminated as well (Giannetti & Milazzo, 2014).

An air circulation system is mostly composed of a compressor, expander, indoor and outdoor heat exchanger. In an ideal condition, this refrigeration cycle includes two isobaric and two isentropic processes. The circulating air gets into the compressor and becomes compressed (isentropic process) and the temperature and pressure rise; the compressed air of high temperature and high pressure gets into the outdoor heat exchanger and lets out heat (isobaric process) and the temperature falls; the air flow then gets into the expander and expands to the demanded temperature and pressure; the air flow of low temperature and low pressure gets into the indoor heat exchanger and absorbs the indoor heat (isobaric process), then the air flow gets into the compressor and the new refrigeration circulation begins (Xing et al., 2016).

Foster et al. (2011) build and tested a closed air cycle cooling and heating equipment to be used in the food industry. The equipment used a bootstrap unit developed for aircraft air conditioning in a system that has been modified to run at low temperature necessary for food freezing, by using a parallel compressor. This approach allowed temperatures as low as -140°C leaving the turbine and as high as 234°C leaving the bootstrap compressor. The system has been shown to produce cooling at cryogenic temperatures, with waste heat capable of cooking and boiling water, being a good alternative to current systems used in food industry (Foster et al., 2011). Air cycle technology could be used in food industry in processes like fast chilling and/or freezing, cold storage, refrigerated transport or refrigerated storage cabinets (Tassou et al., 2009).

Ejector refrigeration system

The ejector, as a key device in the ejector refrigeration system, is used to create a region with low pressure in the evaporator (Liu et al., 2018).

Ejectors are widely used in the refrigeration system, fuel cell system, vacuum equipment and desalination plant due to its simple structure, long service life and low maintenance cost. The ejector refrigeration system was studied in recent years due to its promising ability to use the low-grade thermal energy such as solar energy. Nevertheless, compared with the traditional vapor compression refrigeration system, the ejector refrigeration system has relative lower efficiency and presents a complex thermodynamic behaviour due to the supersonic flow phenomenon inside the ejector chamber (Liu et al., 2017).

Ejector refrigeration system has many advantages over traditional compressor-based systems, such as simplicity, the ability to work with different types of refrigerants, low installation and low operating costs. Furthermore, the direct correlation between the peak cooling load and peak solar radiation makes solar ejector cooling systems more advantageous. However, low coefficient of performance (COP) and dependency on the environmental conditions are the main drawbacks of this type of systems (Aligolzadeh & Hakkaki-Fard, 2019). One way to improve COP is to include a booster refrigeration system with ejector which modifies the conventional booster refrigeration system by adding an ejector between evaporator and compressor, which can effectively enhance the system COP when the ambient temperature is high according to Huang et al. (2018).

Ahammed et al. (2018) conducted a thermodynamic analysis of transcritical CO_2 systems that use ejector instead of throttle valve for chilling and heating of milk in the process of pasteurization in a dairy plant. The analysis showed that for pasteurization process, energy savings of about 10% can be reached by replacing the conventional throttle valve with an ejector. Compared to the conventional pasteurization process that use separate heating disposition, use of ejector based transcritical CO_2 system yields a primary energy savings of about 29% even under conservative values of energy conversion (Ahammed et al., 2018).

Applications in the food sector could be for example in areas where waste heat is available to drive the ejector system. Such applications can be found in food processing factories where the ejector refrigeration system can be used for product and process cooling and refrigerated transport (Tassou et al., 2009).

Sorption-adsorption refrigeration

Sorption technology is used in thermal cooling methods. An absorption machine consists of four main components: a desorber, an absorber, a condenser and an evaporator (N'Tsoukpoe et al., 2014).

Sorption technology can be classified as either open sorption system or closed sorption system. Open systems refer to solid or liquid desiccant systems that are used for either dehumidification or humidification.

Principally, desiccant systems transfer moisture from one airstream to another by using sorption and desorption processes. In closed sorption technology, there are two primary methods: absorption refrigeration and adsorption refrigeration (Sarbu & Sebarchievici, 2015).

Solid sorption refrigeration cycle, which is driven by low-grade heat, is extensively used for air-conditioning, freezing, sub-cooling for vapor compression systems to get for example extreme low temperature energy. It shows promising alternatives for application due to its properties for saving energy, decreasing pollution, and beneficial to sustainable development. For solid-gas sorption refrigeration, chemical working pairs generally have the advantage of high sorption capacity and volume cooling density over physical sorbents (Li et al., 2012). Because the sorbents generally have extremely low thermal conductivity, the conventional solid sorption refrigeration systems were mostly driven by hot water or oil, which present much higher heat transfer coefficient than gas. This way the system will be compact, but having the drawbacks of complicated structure for the heat recovery in exhaust gas due to additional heat transfer process between the gas and the liquid, which is required (Gao et al., 2018).

The existing systems for producing cold using solar thermal energy are mainly based on sorption technology: the process by absorption liquid–gas and the process by adsorption solid–gas (Fan et al., 2007). Solar sorption refrigeration technologies are considered as a promising way to meet the growing refrigeration needs for thermal comfort, food products preservation, and vaccines and medicines conservation (Fan et al., 2007; N'Tsoukpoe et al., 2014). These technologies are attractive for refrigeration applications in remote or rural areas of developing countries where the access to electricity is impossible (Fan et al., 2007).

For freezing application that needs temperature below 0°C, like icemaking or frozen storage; an absorption chiller, an adsorption chiller, or a chemical reaction chiller can also be used. Overall, the lower cooling temperatures demanded, the higher generation temperatures are needed for driving a sorption refrigeration system (Fan et al., 2007).

Stirling refrigeration cycle

The Stirling refrigeration cycle is one of the major cycle models in cryogenics. It consists of two reversible isothermal processes and two reversible constant co-ordinate processes such as constant volume or isomagnetic processes. The working matter of a Stirling refrigeration cycle can be a gas, a magnetic material etc. For different working substances, the Stirling refrigeration cycle will have different regenerative properties such as its coefficient of performance is not only dependent on the temperatures of the two heat reservoirs but also, in general, on the specific properties of the working substance (Chen & Yan, 1993).

The duplex Stirling refrigerator is an integrated refrigerator consisting of a Stirling cycle engine and a Stirling cycle refrigerator used for cooling. The equitability of the work generation of the heat engine to the work consumption of the refrigerator is the main limitation of the duplex Stirling (Erbay et al., 2017).

Gadelkareem et al. (2019) performed a study regarding the optimization of different parameters of the Stirling refrigerator/heat pump cycle for a drinking water cooler/heater. In this sense, a mathematical model was developed, based on Schmidt analysis, to evaluate the equipment performance taking into account the flow losses and the regenerator efficacy. Some of the main conclusion of the authors are: (i) the Stirling refrigerator/ heat pump has a great potential to be used for drinking water cooler/heater; (ii) the presented Stirling cycle for water dispensers consumes the minimum electric power compared to the

other commercially available technologies; (iii) the presented Stirling cycle can produce hot water at 95°C without using heating elements, which consumes high electric energy (Gadelkareem et al., 2019).
A study performed by Sun et al. (2008) investigated the reverse Stirling cycle for use in refrigeration processes. This type of cycle is referred to as Stirling cooling or Stirling cooler. An experimental free-piston Stirling cooler (FPSC) was developed and the effects of the device parameters in relation to the performance of the cooler were studied; the equipment was then experimentally applied to churning butter. The results indicated that by churning butter using the Stirling cooler, coagulation of the butter occurred more rapidly compared to when the control was used in the process; the water content of the obtained butter was lower, having a higher fat content when the Stirling cooler was used, showing that the feasibility of using the Stirling cooler for churning butter is high (Sun et al., 2008). The Stirling cycle equipment can have many applications in food industry due to the fact that can it work down to cryogenic temperatures.

Thermoacoustic refrigeration

Thermoacoustic technology received a great attention due to the fact that it uses simple devices without mobile mechanical parts compared with conventional technologies (Belaid and Hireche, 2018). Thermoacoustics is a domain that focuses on the interaction between thermodynamics and acoustics. The thermoacoustic effect represents the energy transformation of acoustic work absorbed to transport heat (thermoacoustic refrigerator TAR) or the energy conversion of the heat supplied to produce acoustic work (thermoacoustic Stirling heat engine TAE) (Alcock et al., 2018), resulting in a system that can operate on waste heat and does not contain refrigerants or moving parts (Zink et al., 2010).
Heat-driven thermoacoustic refrigeration presents great advantages of high reliability and external heat-driven mechanism. In a system like this, heat can be first of all converted into acoustic power and then the acoustical power operates a refrigerator to generate cooling effect without any moving mechanical components (Wang et al., 2019).

Thermoelectric refrigeration

Thermoelectric machines are composed of semiconductor materials that can directly convert heat into electricity. Thermoelectric machines which convert a temperature difference into electrical power are called thermoelectric generators (TEGs). This form of energy conversion is called the See beck effect. The conversion of current to temperature that occurs when an electric current flow through a thermoelectric device (Enescu, 2018) called thermoelectric coolers (TECs) is called the Peltier effect. Although the efficiency of TEC is not very high when compared with conventional refrigeration equipment, it is irreplaceable. TEC is portable, quiet, environmentally friendly and it has high temperature-controlling capacity (He et al., 2017). Recently, thermoelectric devices are taken into consideration in a practical power generation, refrigeration and energy recovery applications. This fact is thanks to remarkable features and properties of these devices, including simplicity, small size and weight, lack of moving parts, ability to heat and cool with the same module, precise temperature control, absence of working fluid and solid-state operation, high reliability and environmentally friendly operation (Hadidi, 2017).

Trigeneration

Polygeneration energy systems are shown to be a reliable, competitive and efficient solution for energy production. The recovery of otherwise wasted energy is the first reason for the high efficiency of polygeneration systems (Urbanucci et al., 2019). Polygeneration can be defined as the combined production of two or more energy services from a common resource. cogeneration, or combined heat and power, is the simplest form of polygeneration, and generally refers to the joint production of electricity (and/or mechanical energy) and heat from a common resource. A typical extension of cogeneration is trigeneration, also known as combined cooling, heating and power, which usually refers to the combined production of electricity, heat, and cooling (Pina et al., 2018).
The principle of operation for a trigeneration system is the conversion of the heat taken from a high temperature process by the heat engine into mechanical work achieving a maximum

efficiency equal to the Carnot cycle. Mainly, trigeneration systems integrate various devices such as refrigeration units, heat engines, heat pumps, hydrogen production units and desalination units (Leonzio, 2018).

Depending on the user's refrigeration needs, direct or indirect activation can be used between the cogeneration and the absorption chiller in food applications, having good results. Direct activation consists of the direct use of exhaust gases to drive the absorption chiller.

Indirect activation uses the exhaust gases to produce hot water or steam in a heat exchanger that is afterwards used as a heating environment for the chiller (Marimón et al., 2011).

CONCLUSIONS

The food industry relies mainly on the vapor compression refrigeration cycle for food preservation and processing (Tassou et al., 2009). To reduce environmental impact, there were developed and tested many technologies based on air cycle refrigeration, ejector refrigeration system, sorption-adsorption refrigeration, Stirling refrigeration cycle, thermoacoustic refrigeration, thermoelectric refrigeration or trigeneration, technologies that can reduce the quantity of used energy, that can use solar energy instead of conventional ones or that can use refrigerants which are environmentally friendly.

In the food industry, refrigeration technologies are applied in all stages from raw materials storage and food processing to distribution, retail and final consumption at consumer's home and from hundreds of years now compression refrigeration cycle is used everywhere.

However, the potential to save energy, resources and significant amounts of money requires more than simply using new technologies.

It requires an entirely new approach to engineering the whole system with which a facility operates, not just the refrigeration system and components themselves. More research and developments are needed to replace the old techniques at industrial level.

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