Technical press

Gently freezing with cryogenic gases

Quick freezing

The main consideration for deep-freezing is the rate at which the temperature of the food is reduced, whether it is meat, vegetables or baked products. There is a good reason for this: the longer the freezing process takes, the more time there is for the water molecules contained in the food to come together to form large ice crystals. These can pierce the cell membranes and damage the tissue, with the result that the frozen food loses its form and structure while vitamins, nutrients and flavours are also lost.

Gently freezing with cryogenic gases

If the freezing process is carried out rapidly, predominantly small ice crystals are formed, which do not put excessive strain on the cellular material (Fig. 1).

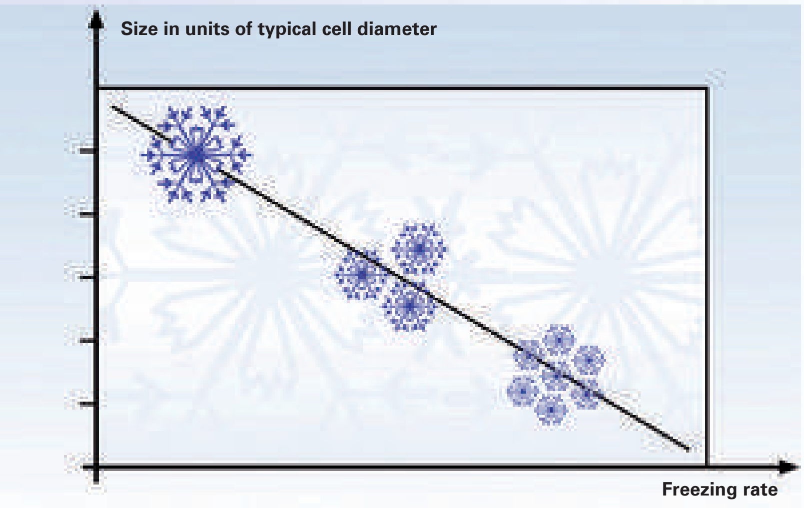

Fig. 1: During cryogenic freezing, the ice crystals remain small, avoiding damage to the cell walls. As a result, the defrosted product is fresh and appetising.

The required freezing rate is at least 5 cm/h and can be achieved by means of cryogenic freezing methods, which use the cold of the cryogenically liquefied gases nitrogen and carbon dioxide. Both gases are natural constituents of air and have been approved as food gases in the EU.

Cryogenic applications work as follows: sprayed directly into a freezer, the nitrogen boils or the carbon dioxide snow sublimes. The food supplies the necessary thermal energy, while it is cooled and frozen in a matter of minutes.

Cryogenic freezing versus conventional freezing methods

Chilling refers to the reduction in temperature of a product until just before it freezes. For most foodstuffs this point is between 0 °C and -2 °C. Freezing refers to the cooling of aqueous foodstuffs from an ambient temperature (e.g. +20 °C) to at least -15 °C. The efficiency of a freezing process is defined via the mean freezing rate (given in cm/h). The physically correct formula is:

$$\overline{w} = d_0 / z_0$$

Where d_0 corresponds to the shortest distance from the core of the product to its surface; z_0 is the time it takes the product core to cool from 0 °C to -10 °C. Freezers can be classified on the basis of this definition: a domestic freezer, for example, has a mean freezing rate of ≤ 0.1 cm/h, which should be interpreted as slow freezing. Freezer chambers offer 0.1 - 0.5 cm/h. Freezing is more rapid in a cold-air fluidised bed (0.5 - 5 cm/h). Rates of 5 cm/h and above can be achieved with cryogenic freezing methods; on which, for example, the Messer Group's Cryogen-Rapid® freezing systems are based. In order to freeze at rates of 5 cm/h or above, however, more than just a high temperature gradient is required (Fig. 2). The nitrogen must boil directly on the surface of the food or sublimate the CO_2 snow. The heat transfer takes place according to the following formula:

$$Q = \alpha \bullet A \bullet \Delta T$$

Expressed in words: the heat quantity Q transferred to the given product surface A (m^2) per unit of time depends on the temperature gradient ΔT (K) and the heat transfer coefficient α (W/m^2K).

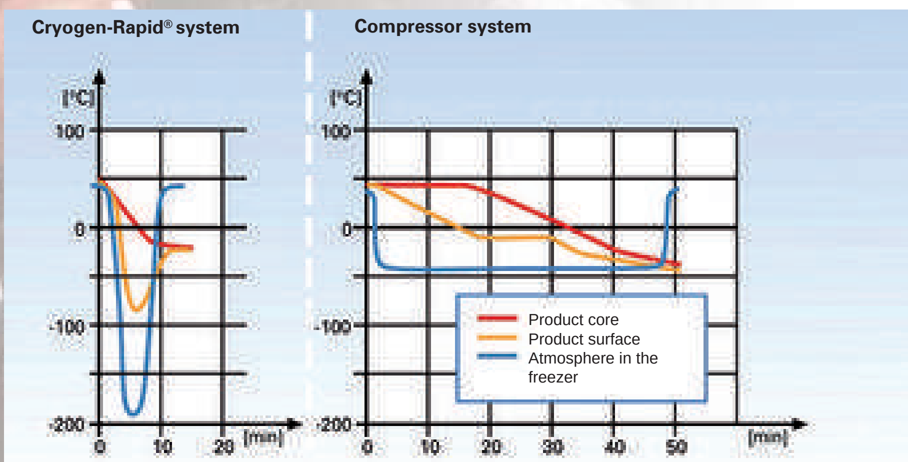

Fig. 2: Typical temperature profile in a Cryogen-Rapid® system and a comparable cold air tunnel freezer (compressor system)

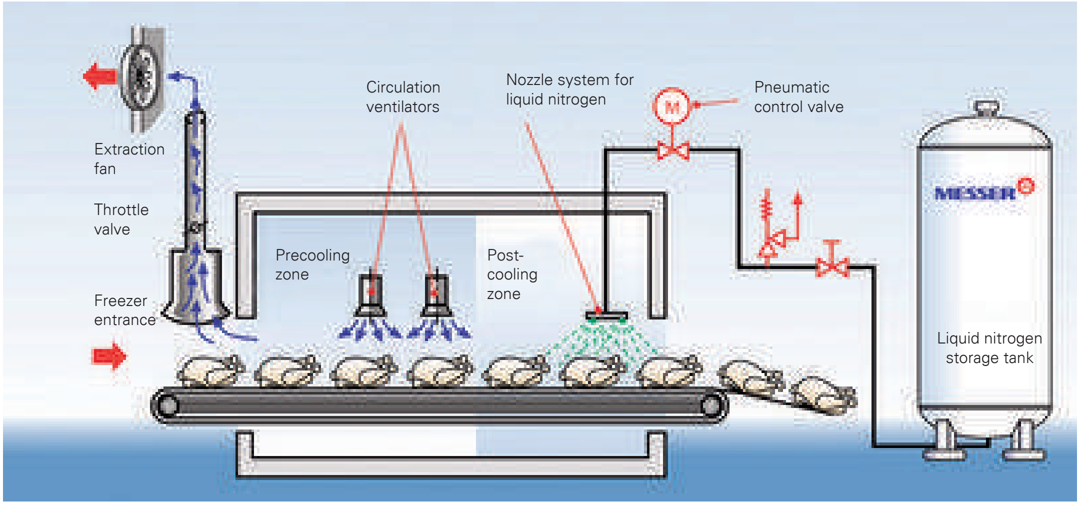

Fig. 3: Process flow of a continuously operating nitrogen tunnel freezer

Only at very high freezing rates (over 5 cm/h) does the cell water crystallise quickly enough to allow predominantly small ice crystals to form (Fig. 4), which do not damage the cellular material:

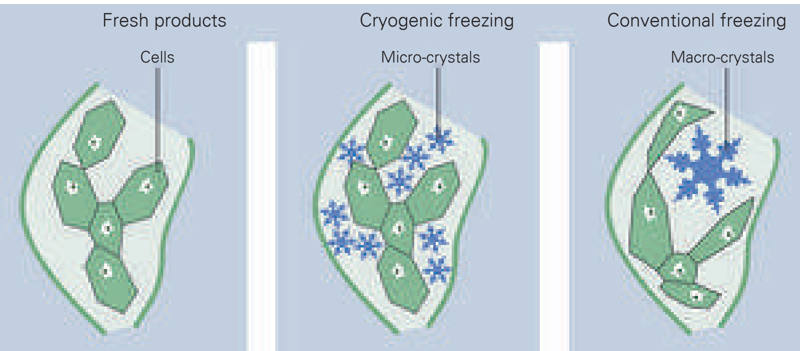

Fig. 4: During cryogenic freezing, the ice crystals remain small, avoiding damage to the cell walls. As a result, the defrosted product is fresh and appetising.

Drip losses, which can be as much as five percent with conventional systems, are less than one per-cent with cryogenic freezing. Products that have been cryogenically frozen are visually appealing and appetising after defrosting. The high freezing rate of cryogenic freezers saves time and space.

In most cases, the freezing capacity of conventional freezer systems is only designed for a specific function. Freezer systems operated with liquid nitrogen or liquid carbon dioxide, on the other hand, offer a wide range of functions.They are comparatively inexpensive to buy and offer flexibility in their use, including integration into existing production lines. Moreover, they are smaller than comparable conventional systems. Special structural measures (e.g. a power house with a correspondingly high electrical power output) are not required.

Cryogen-Rapid® systems are not fixed in one place and are easy to transport. The necessary storage tanks for the refrigerant are installed outside. An additional benefit is that Cryogen-Rapid® systems do not require a heat exchanger, which can ice up. The low temperatures inside the freezer mean that only the slightest traces of moisture are required for the atmosphere to become saturated. There is hardly any drying out of the food during freezing, so it retains its weight and appetising appearance.

Freezer systems for every requirement

In order to be able to make optimum use of the strengths of the cryogenic gases – nitrogen and carbon dioxide – Messer uses the appropriate freezer systems for a wide range of requirements. These are briefly described below.

The cold-gas control mechanism of the **Cryogen-Rapid® Tunnel Freezer**, for example, is particularly suitable for dealing with large quantities of food. Liquid nitrogen or liquid carbon dioxide is sprayed into the tunnel freezer via a nozzle system in a temperature-controlled process. In the tunnel freezer, the resulting cold gas is swirled around the product surfaces by circulating fans (Fig. 3). The gas is extracted once it has completed its cooling work. The temperature rapidly drops to well below zero. Even the slightest traces of moisture are sufficient for the atmosphere to become saturated. The products do not dry out and retain their weight. The unit is particularly suitable for high-quality fish, meat and baked products as well as convenience products. Pastry cooks also use it to stabilise decorations before freezing gateaux in a conventional way. Conveyor belts and product contact parts can be easily cleaned.

N_2 and CO_2 – the ideal refrigerants

Liquid nitrogen

Nitrogen (N_2) is an inert, reaction-inhibiting gas which is produced in its liquid form through cryogenic air separation; N_2 is the main component of air with 78 volume percent. Cryogenic liquid nitrogen (LIN) boils at –196 °C under atmospheric pressure. At 3 bar in a storage tank, liquid nitrogen has a boiling temperature of –185 °C. When applied to the product surface, LIN evaporates and absorbs around 183 kJ/kg of heat (enthalpy of evaporation). The heat absorption is doubled if the cold nitrogen gas is heated to –20 °C in the course of the deep-freezing process. This means that a theoretical energy content of around 363 kJ/kg is available for cooling.

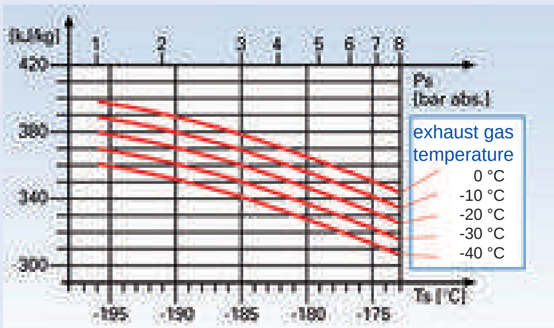

Fig. 5: Heat absorption capacity of liquid nitrogen in relation to the boiling state and temperature of the nitrogen exhaust gas

Liquid carbon dioxide

Carbon dioxide (CO_2), also known as carbonic acid in the trade, is an inert, odourless, tasteless, colourless and non-flammable gas under normal conditions (0 °C, 1 bar). It is obtained from natural sources or produced industrially. CO_2 can only be liquefied at a pressure of 5.18 bar.
Liquid carbon dioxide is stored in thermally insulated tanks. If a kilogramme of liquid carbon dioxide, which was stored at 17 bar and –25 °C, expands to atmospheric pressure, this produces around 0.5 kg of dry ice snow and 0.5 kg of gas with a cold content of around 285 kJ. Both CO_2 phases reach a temperature of –78.8 °C as a result of the expansion. When brought into contact with the comparatively warm product surface, the CO_2 snow sublimes, in other words it goes straight to the vapour phase. If the gas is heated to –20 °C, its total energy content is around 330 kJ/kg.
Through "subcooling" of the CO_2 with the Thermocool process developed by Messer, the cold content can be increased by a further 15 percent. Another significant factor as far as food is concerned is the fact that CO_2 has a bacteria-inhibiting effect. (All pressures are given as absolute pressures).

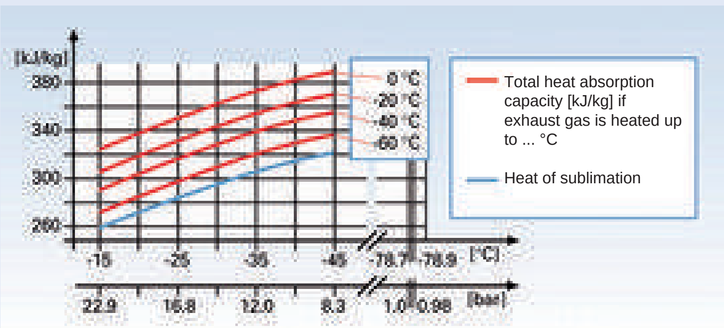

Fig. 6: Heat absorption capacity of liquid carbon dioxide in relation to the tank pressure and temperature of the CO_2 exhaust gas

High freezing capacity in a minimum of space can be achieved with the **Cryogen-Rapid® Spiral Freezer** (Fig. 7). The freezer delivers 1,000 kg/h, with an edge length of only 5 m. The conveyor belt runs over several levels like a spiral staircase. Product input and output can be tailored to the space and production conditions.

For small production quantities or where batch refrigeration or freezing with liquid nitrogen or carbon dioxide is required, the **Cryogen-Rapid® Cabinet Freezer** is the method of choice. Food is placed on the different tiers of a tray trolley, which is then pushed into the cabinet freezer. Ventilators push the cold gas between the tiers, ensuring optimum heat transfer and even refrigeration or freezing results (Fig. 8). The freezer can be set up as a walk-in freezer, allowing the tray trolley to be moved in and out effortlessly. Users who operate the freezer as a double cabinet can make optimum use of the cold energy by using the waste gas from one freezer to precool the other one. The cabinet freezer can be described as an all-rounder that can be used for all quality products; in particular for sausage, meat and baked products.

Cryogen-Rapid® Rotary Freezer freezes individual pieces of fish and meat, pasta, vegetables and precooked dishes to IQF quality, either with CO_2 snow or with liquid nitrogen.
A conveyor belt transports the products to the drum at high speed. The drum in question is an elongated, insulated, rotary drum which rotates continuously. This prevents products from clumping together or freezing to it.

Fig. 7: High freezing capacity in a small area – that's the advantage of the spiral freezer.

Fig. 8: For batch operation and freezing jobs ranging from 100 to 1,000 kg/h: the Cryogen-Rapid® Cabinet Freezer

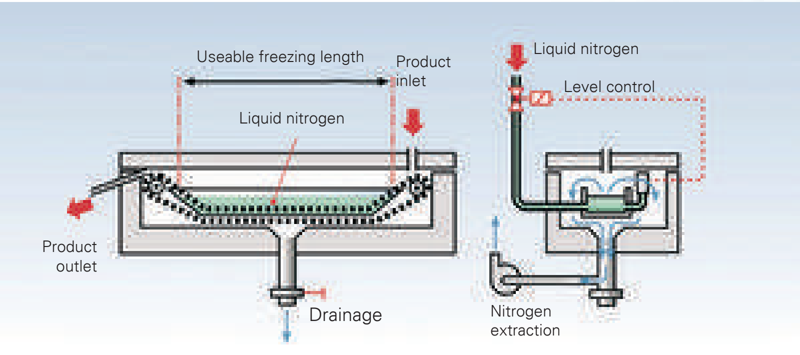

Fig. 9: Operational principle of an immersion freezer

The rotary freezer ensures even, reproducible freezing results; individual components for complete menus can be carefully frozen.

Freezing times of just a few seconds can be achieved with the **Cryogen-Rapid® Immersion Freezer** (Fig. 9). The system utilises the high heat transfer coefficient (2,300 W/m²K) of the boiling nitrogen with which the product comes into contact. A conveyor belt transports the food through the level-controlled nitrogen bath. The immersion freezer is mainly used in combination with other freezers in order to boost their effectiveness. Direct contact with the coolant causes the surface of the product to become fixed. Depending on the freezer being used, efficiency can be improved by up to 300 percent. The immersion freezer also allows products with a low thermal conductivity or a high input temperature to be chilled to low temperatures. Hot products discharged from extruders are reliably and quickly frozen without any adverse effects such as discolouring.

The Cryogen-Rapid® Pelletizer is predestined for the freezing of liquid and paste-like products in the form of easily dosable pellets: liquid nitrogen is pumped onto a pelletising trough, forming an even flow of nitrogen. The liquid product drips into the nitrogen, fixing the product surface and forming a pellet. A close-meshed conveyor belt transports the frozen pellet on to the next stage while the unused liquid nitrogen seeps down and back to the cooling cycle. This method can be used, for example, for flash freezing of enzymes, sorbet, dessert additives, fruit juices, dairy products and sauces.

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