2. Freezing Equipment

2.1 Introduction
The development of the freezing industry is very closely related with the technical ability to create low temperature independent of the environmental conditions. At the beginning of the 18th century the slowly growing food industry developed an increasing demand for ice to control and improve various processing steps (beer brewing, shelf life extension etc.). These demands were at first covered through the use of natural ice which was produced in the cold regions of Europe and North America, from there it was exported to warmer areas, e.g. from Norway to Mexico. When temperatures below 0°C were required “cold mixtures” i.e. mixtures of ice and salts were prepared. The first ideas and technical concepts for the construction of refrigeration equipment with which it was possible to create low temperature independent of the environmental conditions were discussed almost 250 years ago.

According to the available records the first industrial unit for freezing food (meat) was opened 1861 in Darling Harbor/Sydney. The first documented long distance transport of a frozen product (again meat) was carried out by the steamer “Le Frigorifique” from Argentine to France in 1876. The further development of the refrigeration equipment to the present high standards was supported to a large extend by the needs of the brewing industry and the meat industry in the Southern Hemisphere and the United States.

2.2 The Freezer Family

2.2.1 Common features of freezers
Stand alone freezers and to some extent also freezer rooms share some common features.
To assure minimum heat losses all freezer units are highly insulated, in most cases the insulation consist of surfaces treated laminated (aluminum-)panels with cores of expanded polystyrene- or polyurethane foams. The panels are sealed together to form airtight walls.
In order to avoid floor freezing with all unpleasant consequences for the building, the floors on which freezers are placed have to be specially enforced and insulated, in certain cases under-floor heating is applied.
Refrigeration units and fans (in case of air blast freezers) in modern equipment should be generously designed in order to meet all possible product and economical requirements. In case of air blast systems it is important for achieving optimal heat transfer conditions that the fans (usually axial-flow propellers or centrifugal fans) have to be designed and placed in the freezing unit with great care.
In order to control the operation of the freezing units most freezers are equipped with control units which allow for a display of all pertinent freezer parameters and conditions (air/product-temperatures, operation times etc.) and data-logging.
The freezing units (container, mechanical devices, refrigeration unit and fans etc) should all be designed to assure handling safety, allow for an easy maintenance and routine unit cleaning. Most freezer systems can be designed in a large variety of sizes (through put, product dimensions, product structure) in order to meet customer requirements.

Table 2.1 The Freezer Family

2.2.2 Cold Room Freezers

At the beginning of the technical development of freezers the food to be frozen was simply exposed to low temperatures in still air, in such Cold Room Freezers the Heat transfer Coefficients are maximally around 10 W/m² K.
2.2.3 Brine Freezers
At the beginning of the 20th century so called Brine Freezers (Ottensen Freezer) were introduced for freezing of larger pieces of materials mainly fish. In these units (Heat transfer Coefficients: $\alpha \sim 300$ to 500 W/m$^2$K) the products were directly submerged into refrigerated brines, which resulted in high freezing rates, however also in a loss of water and an uptake of salt.
2.2.4 Push Through Freezers /Trolley Blast Freezer

With the progress in fluid mechanics, refrigeration engineering, mechanical engineering and material science, in the middle of the 20th century, new and very effective freezer units were developed.

At the beginning of these developments Push Through Freezers /Trolley Blast Freezer (Heat transfer Coefficients: $\alpha \sim 30$ to 50 W/m²K) were and still are used for freezing all types of packaged and unpacked materials. The freezers are very simple in design and easy to operated. The material to be frozen is manually loaded on trays and then stacked onto the trolleys which are manually pushed-through/placed-in insulated tunnels equipped with axial fans. More sophisticated units are equipped with automatic hydraulic pushing systems.

The units are usually used for freezing smaller quantities/productions of products, they are easy to maintain and easy to clean. The disadvantages of those units were that they worked batch wise and in most cases the steel made rack-trolleys had to be cooled down again after loading the unfrozen material. Typical products to be frozen on push through freezers are: Seafood, Meat & Poultry, Vegetables, Bakery (pre-) products, Ready Meals.

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**Fig. 2.3 Push Through Freezers /Trolley Blast Freezer**
2.2.5 Belt / Chain Belt / Tunnel Freezers

Belt Conveyer and Chain Belt Conveyer Tunnel Freezers (Heat transfer Coefficients: \(\alpha\ \sim 30\) to 60 W/m\(^2\)K) are designed as very simple one stage units and rather sophisticated helical belt systems. Belts (plastic/metal) as well as chain belts are used for simple stage units of varying width and different speeds of the belts. Helical belt units are mainly equipped with chain belts because of the flexibility of the belt. Both types are frequently build in modular form as a stand-alone unit together with the refrigeration units as clip-on units. The units can however also be part of larger processing lines. *Belt freezers* are in general of rather uncomplicated design, basically the products to be frozen are moved on a conveyer-belt through the refrigerated section of an insulated containment. The belts are made of plastic material or stainless steel. Inside the containment the air is circulated by axial fans.

Belt Freezers can be used for a large variety of products, for packaged materials, materials in trays, as well as small individual items such as shrimp, shellfish, fish bakery products etc. Stainless steel belts are mainly used for freezing marine products and chicken parts or blanched vegetable where as plastic belts are mainly used for products with dry surfaces, packaged materials and trays. Special designs can be operated as double belt units where the material is surface frozen on the first, faster running belt and then finished on the slower moving second belt.

Stainless Steel Belt Freezers can be designed as Pellet Freezer and Scratch Freezer. Pellet Freezers are designed in away that moulds of various shape are integrated in steel belts or chain belts, once liquids or pastes are filled at the beginning of the belt in the pre-cooled cavities the material freezes adapting the form of the cavity. At the end of the belt the material is released and finally frozen in a connecting Tunnel Freezer or Freeze Storage Facility. Pellet Freezers are used to freeze fruit and vegetable pastes, surimi (e.g. to mimic shrimp), starch preparations, sauces, etc. The advantage of the pellets is that the frozen products are free flowing and easy to dose.

Scratch Freezer are Steel Belt Freezers were liquid/semi liquid substrate is applied on the surface of the belt at the entrance of the Freezer Tunnel and removed by a scratch blade in the form of flakes at the end of the tunnel.

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![Fig. 2.4 Belt Conveyer and Chain Belt Conveyer Tunnel Freezers](image-url)
Helical Belt Freezers are designed as non-self-stacking and self-stacking units. This systems are very versatile and allow the processing of a large variety of products. Basically all products which can be placed on a belt can be processed in a helical belt freezer as long as the product cannot be blown off by the circulating air, e.g. cuts of meat and fish, chicken parts, larger vegetable parts, prepared foods, bakery products etc.

Non-Self-Stacking units consist basically of continuous loops of stainless steel mesh conveyor belts that are arranged in a helical spiral onto which the products are placed. The refrigerated air is blown over the product. The conveyor belt is driven by a center-rotating cage.

Self-Stacking units consist of conveyor belts with side links to allow the belt to stack upon it as a spiral is formed which winds up around an insulated inner core. In the course of the spiral formation layer upon layer is stacked, the self supporting side links of the belt elements together with the belt elements are forming a channel in which the refrigerated air moves over the product. This design eliminates the need for a supporting structure. It allows also for smaller and lighter products particles to be processed because the material can not be blown out of the product bed.
2.2.6 Fluidized Bed Freezers

Fluidized Bed Freezers (Heat transfer Coefficients: \( \alpha \sim 30 \) to \( 60 \) W/m\(^2\)K) are designed in a way that a fluidized bed support, mostly a perforated sheet metal, is installed in an refrigerated containment. In most constructions the support system is vibrating in order to move the product, in other systems the support is designed as inclined plane so that the fluidized material flows freely through the unit. In all constructions the material bed is fluidized by a high velocity airflow. Because each individual particle is exposed to the refrigerated air the products do not stick to each other and are all quick and homogeneous frozen (freezing in fluidized beds was therefore also called “Individual Quick Freezing”, “IQF”).

The advantages of the Fluidized Bed Freezers are:

- Can be build as compact units in modular form;
- High capacity;
- Low maintenance costs;
- Very high freezing rates

The disadvantages are:

- High investment and maintenance/cleaning costs,
- Suited only for particulate products of various nature.
- Typical products suited for fluidized Bed Freezers are:

All type of particulate vegetables/fruits e.g. beans, cauliflower/broccoli buds, corn, peas, potato cuts, strawberries, shrimps, etc.

In order to obtain optimal heat transfer conditions a homogenous fluidisation conditions have to be maintained.
2.7 Plate freezers

![Plate Freezer Diagram]

**Figure 2.8 Plate Freezer; Design Basics**

<table>
<thead>
<tr>
<th>A Inlet</th>
<th>B Refrigerant Outlet</th>
<th>C Product</th>
<th>D Hydraulic Press</th>
</tr>
</thead>
</table>

**Figure 2.7 Different states of Fluidisation in a fluidised Bed**

\[ w = \text{Air-velocity in the fluidised Bed} \]
\[ w_L < w_1 < w_2 < w_3 < w_S \]
Plate freezers (Heat transfer Coefficients: $\alpha \sim 3000 \text{ W/m}^2\text{K}$) are designed as horizontal and vertical units, they are especially suited for freezing of materials in a block form e.g. filleted fish, cut meat parts and packaged materials. The units consist of the framework, the freezer plates, flexible refrigerant hoses and a hydraulic system. All units are designed for easy cleaning. Frequently plate freezers are placed in insulated containments.

The framework is made of heavy duty galvanized steel. The freezer plates, usually extruded aluminum alloy plates with internal passages for refrigerant, are fitted into the frame either in a horizontal or a vertical mode, they are movable so that the material to be frozen can be placed between two plates. The refrigerant hoses are connecting the freezer plates with the refrigerant container, they consist in modern units of cold resistant plastic materials enclosed in flexible metal tubes. The hydraulic cylinders are opening and closing the freezer plates.

The advantages of the plate freezers are:
- Short freezing cycles,
- Good quality retention,
- Minimal energy losses
- Easy installation and low capital/maintenance/cleaning costs,
- The frozen material forms flat and uniform blocks, which are easily stacked and stored.

The disadvantages of the plate freezers are:
- Only materials which can be shaped in block can be frozen,
- Relatively small freezing capacity,
- Only batch-wise and semi-continuous operations are possible.

![Plate Freezer, Industrial Models](image)

Fig. 2.9 Plate Freezer, Industrial Models
(Left: Horizontal Design; Right: Vertical Design)

2.2.8 Drum/Cylinder Freezer

Drum/Cylinder Freezer (Heat transfer Coefficients: $\alpha \sim 500 \text{ to } 2000 \text{ W/m}^2\text{K}$) consists of a rotating, mostly stainless steel drum/cylinder which is placed in an insulated containment. The drum is cooled from the inside either by direct evaporation or by refrigerated brine ($\text{CaCl}_2$). The liquid product is applied by a feeder as a thin film, in certain cases by an application roller. Because of the intensive contact between product
and drum surface the material freezes very fast, it is removed from the cylinder with a doctor blade before the drum section with the frozen film enters the feeder area again. Depending on the structure of the frozen material the product can be removed as frozen film, as flakes or even powder.

The advantages of the Freezers are:

- Extremely short freezing cycles (20 to 50 seconds),
- High quality retention, Minimal energy losses,
- Easy installation and low capital/maintenance/cleaning costs.
- Minimal use of floor/factory space.

The disadvantages of the Drum/Cylinder Freezers are:

- Only liquid/semi-liquid materials can be frozen,
- Relatively small freezing capacity.

Typical products suited for Drum/Cylinder Freezers are:

All type of liquid/semi-liquid materials e.g. vegetables/fruits pastes/juices, mashed potatoes, sauces, beverages etc..

![Diagram of Drum Freezer, Design Basics](image)

<table>
<thead>
<tr>
<th>A</th>
<th>Refrigerant Inlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Refrigerant Outlet</td>
</tr>
<tr>
<td>C</td>
<td>Freezing Drum</td>
</tr>
<tr>
<td>D</td>
<td>Product Container</td>
</tr>
<tr>
<td>E</td>
<td>Product Film, Freezing</td>
</tr>
<tr>
<td>F</td>
<td>Frozen Product</td>
</tr>
</tbody>
</table>

Fig. 2.10 Drum Freezer, Design Basics
2.2.9 Cryogenic Freezing
Basics and Equipment
In the middle of the last century when the development of the freezing industry took off to its present high standards it was unthinkable that cryogenic gases would ever be available for freezing of foods. Developments in other areas of the industry made it however possible to reduce the price of cryogenic gases to a level which makes it affordable for many applications including freezing of food.

When properly handled freezing with cryogenic gases offer a variety of advantages for special situations.
The major advantage is that the investment costs of a cryogenic freezing unit (freezer and storage tank) are much lower than comparable compression/adsorption units and much more flexible in installation. It has to be noted however that the operating costs of cryogenic freezers are higher than comparable compression/adsorption units. In a time were processing of frozen products has to be organised with great flexibility the low start up costs are rather important in decision making.

Technologically cryogenic freezing offers the advantage of very fast/quick freezing of small and particulate products. The formation of very small ice crystals in the surface layer helps in addition to reduce moisture losses. If the supporting surfaces are pre-cooled to very low temperatures they offer also the advantage that the goods to be frozen do not adhere to the surfaces.

Typical products for cryogenic freezing are bakery products, including roll/pretzel/cookie dough, pizza dough and pastry dough, berries, shrimp and other high priced items. Liquid nitrogen (-195.6°C) and/or carbon dioxide (-67.8°C) are typically used in cryogenic freezing tunnels/units as expendable refrigerant. While differences in the thermodynamic properties of each gas influences the tunnel design, the basic design principle is a simple counter-current or co-current heat exchange. (Heat transfer Coefficients: Boiling Nitrogen (Bulk Boiling, $\Delta T = 8/20$ K) $\sim$1.300 to 8.000 W/m²K, Film Boiling, $\Delta T = 100/300$ K $\sim$500 to700 W/m²K; Carbon Dioxide Snow (Sublimation, $\Delta T = 50/105$ K) $\sim$100 to2.000 W/m²K).

<table>
<thead>
<tr>
<th>Property</th>
<th>Cryogenic Fluid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Liquid Nitrogen (LN)</td>
</tr>
<tr>
<td>Storage Pressure /bar</td>
<td>2</td>
</tr>
<tr>
<td>Boiling Temperature,1bar</td>
<td>77 K (-196 °C)</td>
</tr>
<tr>
<td>Boiling Temperature,2bar</td>
<td>88 K (-185 °C)</td>
</tr>
<tr>
<td>Evaporation/Sublimation Enthalpy</td>
<td>185 kJ / kg (related to 1 kg LN) at 77 K</td>
</tr>
<tr>
<td>Enthalpy (Gas Phase) at 273 K</td>
<td>201 kJ / kg (related to 1 kg LN)</td>
</tr>
<tr>
<td>Total Enthalpy</td>
<td>386 kJ / kg</td>
</tr>
</tbody>
</table>

Table 2.2 Physical/Thermal Properties of Cryogenic Fluids
Specific Consumption of Cryogenic Fluid

\[ m_{H,\text{spez.}} = \frac{\Delta H (\text{Product})[\text{kJ} / \text{kg}]}{\Delta H (\text{LN/LCO}_2)[\text{kJ} / \text{kg}]} \]

\[ m_{W,\text{spez.}} = \frac{\text{Product}[\text{kg}]}{\text{LN/LCO}_2[\text{kg}]} \]

<table>
<thead>
<tr>
<th>Product</th>
<th>LN</th>
<th>LCO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lean Meat /Fish</td>
<td>352/386 = 0,9</td>
<td>352/354 = 1,0</td>
</tr>
<tr>
<td>Eggwhite</td>
<td>430/386 = 1,1</td>
<td>430/354 = 1,2</td>
</tr>
<tr>
<td>Bread dough</td>
<td>210/386 = 0,5</td>
<td>210/354 = 0,6</td>
</tr>
</tbody>
</table>

Table 2.3 Specific Consumption of Cryogenic Fluid

<table>
<thead>
<tr>
<th>Product</th>
<th>Temperature Difference/°C</th>
<th>Freezing Time /min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ΔT = T₁ - T₂</td>
<td>Compression Freezer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LN - 100 °C</td>
</tr>
<tr>
<td>Chicken Parts</td>
<td>4,5 to -18</td>
<td>45</td>
</tr>
<tr>
<td>125 g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pizza Dough</td>
<td>20 to -18</td>
<td>30</td>
</tr>
<tr>
<td>200 g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hamburger Patty</td>
<td>70 to -18</td>
<td>38</td>
</tr>
<tr>
<td>85 g / 13 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish, breaded</td>
<td>5 to -18</td>
<td>10</td>
</tr>
<tr>
<td>50 g / 15 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cutlet</td>
<td>10 to -18</td>
<td></td>
</tr>
<tr>
<td>205 g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plaice</td>
<td>15 to -18</td>
<td></td>
</tr>
<tr>
<td>280 g</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.4 Freezing Times of various Food Products in Cryogenic Freezers

Cryogenic Freezing units consist of a Freezing Tunnel and a storage tank for the cryogenic fluid.

For freezing food is in most cases conveyed through the insulated tunnel on a belt, the liquid cryogen is introduced into the tunnel by sprays; in the course of the heat exchange process the liquid evaporates and the product is frozen. The gas is released into the atmosphere. Cryogenic gases are also used in other areas of food processing e.g. sausage making (cutting meat) or freezing and coating of pastes in tumblers.
A Truck  B Storage Tank  C Freezing Tunnel

Fig. 2.11 Cryogenic Freezing System, Delivery Truck, Storage Tank, Freezing Tunnel

A Cryogenic Fluid Inlet  B Gas Outlet  C Product Inlet  D Product Outlet  E Belt (Perforated)  F/G Cryogenic Fluid Re-feed

Fig. 3.12 Cryogenic Freezing Tunnel, Design Basics
2.2.11 Cryogenic Equipment for Special Processing Purposes

Cryogenic Liquids are very versatile to use as cooling agents, examples are:
- Cryogenic Meat Cutter where meat is reduced in size to be processed for sausages etc.
- Freezing Tumbler, where food products can be frozen, structured and shaped in one step

![Cryogenic Freezing Tumbler Diagram]

A Tumbler Vessel, Rotating
B Tumbler Support
C Cryogenic Fluid Inlet Inlet
D Cryogenic Fluid Inlet Outlet
E Product

Fig. 2.13 Cryogenic Freezing Tumbler

2.3 Post freezing operations

Important infrastructural factors are amongst others:
- Skilled personnel
- Safeguarded electricity and water supply
- Production site cold stores
- Appropriate transport connection

The decision to set up a freezing unit as an independent industrial plant or as part of a more complex food processing plant should only be made once the above infrastructural factors are assured.
Extremely important for any successful commercial freezing operation is that the frozen products can be stored during the quality inspection period under the control of producer. That means that the production of 2 to 3 weeks has to be stored under the control of the producer in a production site cold store.

Under optimal conditions the cold store should be situated between production site and truck/rail road loading facilities. Modern cold stores are built with prefabricated panels which are placed on a foundation which can be protected against frost heave. Cold store size, insulation and refrigeration system have to be planned according to local conditions as there are production capacity, local climate, possible secondary uses.

2.4 Final Considerations

In good industrial practice freezers should always be part of a technical set-up comprising

- Produce acceptance
- Produce preparation (e.g. cleaning, trimming, blanching)
- Freezing
- Packaging
- Storing
- Shipping of frozen products

As it should become evident from the preceding considerations, there is a great variety of freezers available for various applications. The correct choice of a freezer depends on the products to be frozen and on infrastructure of the area in which the freezer will be located. In case the technical resources are limited it is advisable to start small scale industrial freezing by using cold room freezers. In case a technically more advanced infrastructure is available the use of containerized plug-in freezer units as well as prefabricated cold stores is advisable.

2.5 Recommended reading

- Recommandations pour la preparation et la distribution des aliments congeles-
- Recommendations for the processing and handling of frozen foods

By

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