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MODULE I

Sterilization and Sterilizer

Sterilization (or **sterilisation**) refers to any process that eliminates, removes, kills, or deactivates all forms of life and other biological agents (such as fungi, bacteria, viruses, spore forms, prions, unicellular eukaryotic organisms such as Plasmodium, etc.) present in a specified region, such as a surface, a volume of fluid, medication, or in a compound such as biological culture media.[1][2] Sterilization can be achieved through various means, including: heat, chemicals, irradiation, high pressure, and filtration. Sterilization is distinct from disinfection, sanitization, and pasteurization, in that sterilization kills, deactivates, or eliminates all forms of life and other biological agents which are present.

A widely used method for heat sterilization is the autoclave, sometimes called a converter or steam sterilizer. Autoclaves use steam heated to 121-134 °C under pressure. To achieve sterility, the article is placed in a chamber and heated by injected steam until the article reaches a time and temperature setpoint. Almost all the air is removed from the chamber, because air is undesired in the moist heat sterilization process (this is one trait that differ from a typical pressure cooker used for food cooking). The article is held at the temperature setpoint for a period of time which varies depending on what bioburden is present on the article being sterilized and its resistance (D-value) to steam sterilization. A general cycle would be anywhere between 3 and 15 minutes, (depending on the generated heat)[10] at 121 °C at 100 kPa, which is sufficient to provide a sterility assurance level of 10^{-4} for a product with a bioburden of 10^6 and a D-value of 2.0 minutes.[11] Following sterilization, liquids in a pressurized autoclave must be cooled slowly to avoid boiling over when the pressure is released. This may be achieved by gradually depressurizing the sterilization chamber and allowing liquids to evaporate under a negative pressure, while cooling the contents.

Proper autoclave treatment will inactivate all resistant bacterial spores in addition to fungi, bacteria, and viruses, but is not expected to eliminate all prions, which vary in their resistance. For prion elimination, various recommendations state 121-132 °C for 60 minutes or 134 °C for at least 18 minutes.[*citation needed*] The 263K scrapie prion is inactivated relatively quickly by such sterilization procedures; however, other strains of scrapie, and strains of CJD and BSE are more resistant. Using mice as test animals, one experiment showed that heating BSE positive brain tissue at 134-138 °C for 18 minutes resulted in only a 2.5 log decrease in prion infectivity.[12]

Most autoclaves have meters and charts that record or display information, particularly temperature and pressure as a function of time. The information is checked to ensure that the conditions required for sterilization have been met. Indicator tape is often placed on packages of products prior to autoclaving, and some packaging incorporates indicators. The indicator changes color when exposed to steam, providing a visual confirmation[*citation needed*].

Dry heat was the first method of sterilization and is a longer process than moist heat sterilization. The destruction of microorganisms through the use of dry heat is a gradual phenomenon. With longer exposure to lethal temperatures, the number of killed microorganisms increases. Forced ventilation of hot air can be used to increase the rate at which heat is transferred to an organism and reduce the temperature and amount of time needed to achieve sterility. At higher temperatures, shorter exposure times are required to kill organisms. This can reduce heat-induced damage to food products.[14]

The standard setting for a hot air oven is at least two hours at 160 °C. A rapid method heats air to 190 °C for 6 minutes for unwrapped objects and 12 minutes for wrapped objects.[15][16] Dry heat has the advantage that it can be used on powders and other heat-stable items that are adversely affected by steam (e.g. it does not cause rusting of steel objects).

Batch sterilization is the reduction of contaminant organisms through the heating of a vessel. The entire volume of media is sterilized at once through the use of thermal or radiation techniques. When running a thermal batch sterilization, a system goes through 3 steps: heating, holding, and cooling. Heating requires the addition of energy throughout the entire medium volume. This can be done by adding heat through a jacket on the vessel. The temperature is increased until it reaches the sterilization temperature where it is held for a set period of time. During this phase, most of the unwanted microorganisms are destroyed. Finally, the system is cooled to bring the sterile media back to the desired temperature. For radiation sterilization, the process is similar to above, although it uses radiation intensity instead of heat.

Advantages:

- Most widely used technique
- Simple operation
- No additional materials are added to the media itself

Disadvantages:

- More expensive heat requirements than continuous sterilization

Best results occur in well-mixed closed vessels.

Continuous sterilization is the rapid transfer of heat to medium through steam condensate without the use of a heat exchanger. Once the media is in a holding loop, steam is injected to the system via a nozzle. The medium stays in this loop for a predetermined holding time until the entire medium is sterile. This is more efficient than batch sterilization because instead of expending energy to heat, hold, and cool the entire system, small portions of the inlet streams are heated at a time. By looping sterile media tubes (which are at higher temperatures) past inlet tubes, the difference in temperature is used to help heat the unsterile medium. So instead of having a cold-water stream cool the sterile media, the lower temperature unsterile media stream absorbs heat from the warm stream, cooling the sterile media. Finally, the sterile media is flash cooled through an expansion valve to adjust the temperature to meet process parameters.

Advantages:

- Uniform steam requirements throughout the duration of the sterilization
- Simplified process control
- Shorter sterilization time means less thermal degradation of medium

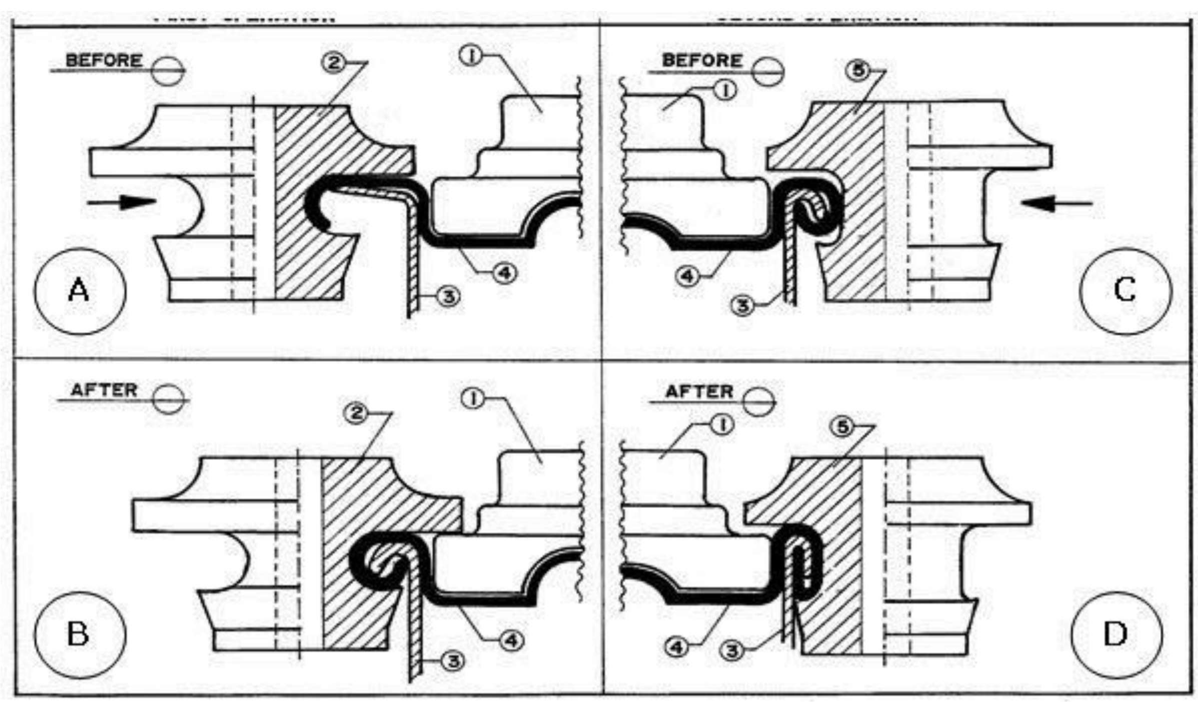
Disadvantages:

- High demand for steam in a shorter period of time than batch
- Concentration of media becomes dilute due to steam condensation
- Since steam is actually dispersed in media, steam must be clean to avoid contamination

Comparison between Batch and Continuous Sterilisation

1. Batch sterilization uses steam or direct heat to elevate the temperature. Both the heat and the cooling water are spent with no opportunity for energy recovery.
2. Temperature in batch sterilization can not increased beyond 121°c as if the temperature is increased, the heating & cooling period increases
3. Batch sterilization wastes energy and can overcook the medium
4. hence during sterilization the nutrient media will be degraded

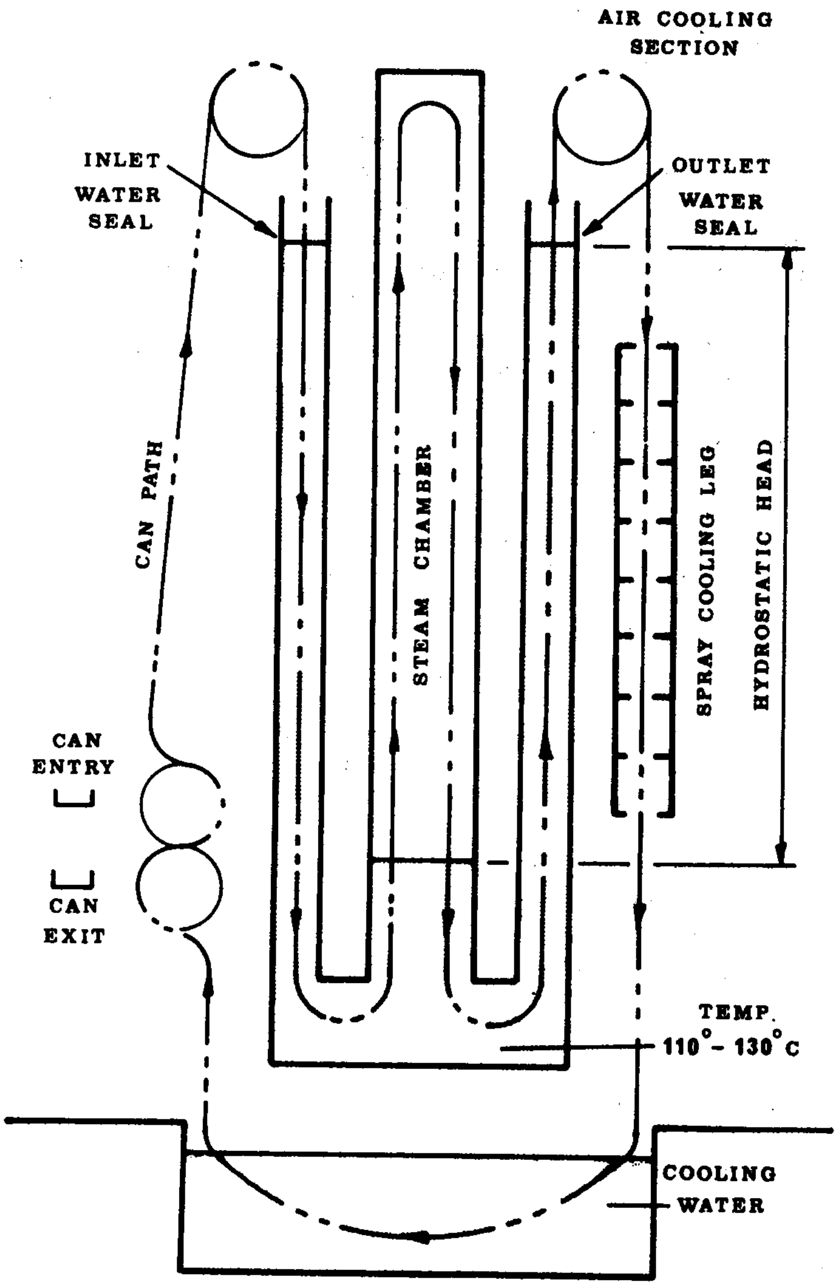
SEAMING MACHINE:



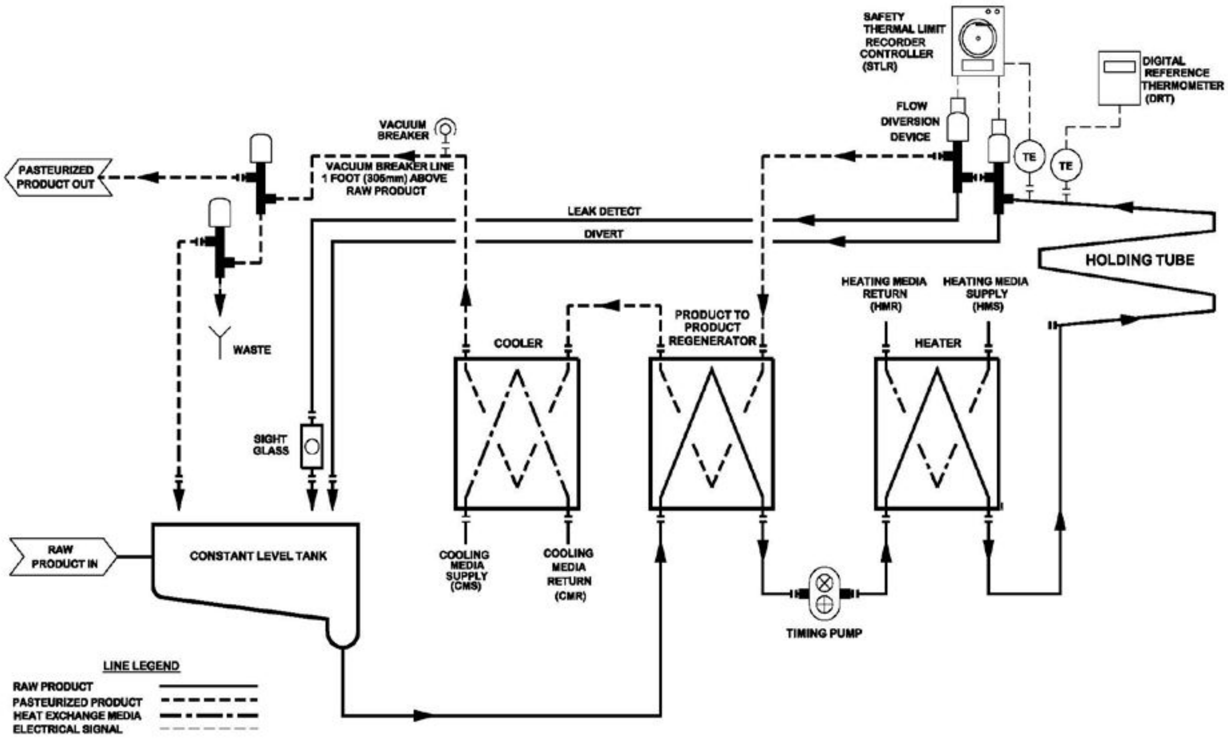
After the can is filled with the product mix the can is sealed with a tight mechanical structure - the double seam. The double seam, in its final form and shape, consists of three layers of lid (4) and two

layers of body material (3). The layers must overlap significantly and all curves must be of rounded shape to avoid small cracks. Each double seam is achieved in two unit operations referred to as "first operation" (A, B) and "second operation" (C, D).The can covered with the lid is placed on the base plate of the can seaming machine. The can is moved upwards while the seaming chuck (1) keeps the lid fixed in position. In the first operation the lid hook and body hook are interlocked by rolling the two into each other using the seaming roll with the deep and narrow groove (A,B). The body hook is now almost parallel to the lid hook and the curl of the lid adjacent to or touching the body wall of the can. In the second operation, the interlocked hooks are pressed together by a seaming roll with a flat and wide groove (C/D). Wrinkles are ironed out and the rubber-based material is equally distributed in the seam, filling all existing gaps thus resulting in a hermetically sealed container.

STERILIZER IN CANNING INDUSTRY:



HYDROSTATIC STERILIZER



Pasteurization

Pasteurization is a process that kills microbes (mainly bacteria) in food and drink, such as milk, juice, canned food, and others.

It was invented by French scientist Louis Pasteur during the nineteenth century. In 1864 Pasteur discovered that heating beer and wine was enough to kill most of the bacteria that caused spoilage, preventing these beverages from turning sour. The process achieves this by eliminating pathogenicmicrobes and lowering microbial numbers to prolong the quality of the beverage. Today, pasteurization is used widely in the dairy industry and other food processing industries to achieve food preservationand food safety.

Unlike sterilization, pasteurization is not intended to kill all microorganisms in the food. Instead, it aims to reduce the number of viable pathogens so they are unlikely to cause disease (assuming the pasteurized product is stored as indicated and is consumed before its expiration date). Commercial-scale sterilization of food is not common because it adversely affects the taste and quality of the product. Certain foods, such as dairy products, may be superheated to ensure pathogenic microbes are destroyed.

Various methods of heat treatment, like short time heating – high temperature (HTST), high temperature - short time (HTST), or ultra high temperature process (UHT) by means of indirect or direct heating are employed depending on food materials.

Homogenizer

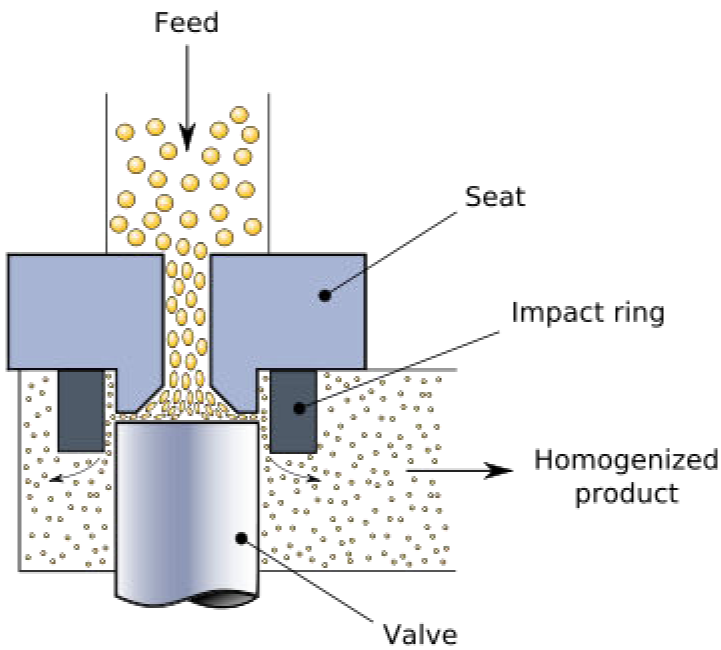
Homogenization or **homogenisation** is any of several processes used to make a mixture of two mutually non-soluble liquids the same throughout. This is achieved by turning one of the liquids into a state consisting of extremely small particles distributed uniformly throughout the other liquid. A typical example is the homogenization of milk, where the milk fat globules are reduced in size and dispersed uniformly through the rest of the milk.

Sometimes two types of homogenization are distinguished: primary homogenization, when the emulsion is created directly from separate liquids; and secondary homogenization, when the emulsion is created by the reduction in size of droplets in an existing emulsion.[3] Homogenization is achieved by a mechanical device called a *homogenizer*.

One of the oldest applications of homogenization is in milk processing. It is normally preceded by "standardization" (the mixing of several different milking herds and/or dairies to produce a more consistent raw milk prior to processing and to prevent, reduce and delay natural separation of cream from the rest of the emulsion). The fat in milk normally separates from the water and collects at the top. Homogenization breaks the fat into smaller sizes so it no longer separates, allowing the sale of non-separating milk at any fat specification.

Milk homogenization is accomplished by mixing massive amounts of harvested milk to create a constant, then forcing the milk at high pressure through small holes. Yet another method of homogenization uses extruders, hammermills, or colloid mills to mill (grind) solids. Milk homogenization is an essential tool of the milk food industry to prevent creating various levels of flavor and fat concentration.

Another application of homogenization is in soft drinks like cola products. The reactant mixture is rendered to intense homogenization, to as much as 35,000 psi, so that various constituents do not separate out during storage or distribution.



Homogenizing valve, a method to homogenize at high pressure

What is homogenization of milk
Homogenized milk is that which has been treated in such a manner as to ensure break up of the fat globules to such an extent that after 48 hours of storage, no visible cream separation occurs on the milk in a quart bottle, or, proportionate volumes in containers of other sizes does not differ by more than 10% from the fat percentage of the remaining milk as determined after through mixing.
To achieve this, we should have the fat globules in small and uniform sizes.The process of breaking up the fat globules to very small sizes in order to prevent cream formation is known as homogenization.
The equipment used for the same is known as
homogeniser.The fat globules present in normal milk vary from 0.1 to 3 or 4 microns depending upon the breed of cows and various other factors. By homogenization, we break up the fat globules to below 2 micron sizes.

Homogenization of milk also serves the following purposes.
• Prevents cream formation.
• Increases milk viscosity, it gives richer appearance to tea or coffee.
• Fat globules do not rise readily and there is no necessity for agitating the milk before serving.
• Prevents churning of fat during rough handling or excessive agitation.
• Reduces curd tension, i.e. forms a soft curd when homogenized milk is coagulated, i.e. Milk becomes more palatable due to brighter appearance, heavier body and richer flavor.
• Milk becomes more digestible partly because of the smaller fat globules and partly because of the lower curd tension.
The homogenized milk can be recommended for infants.

• Reduces the chances of separation of fat during the manufacture of evaporated milk and ice-cream, it gives a smoother texture of the product.
• Homogenizer can be used to prepare reconstituted milk by mixing butter oil or butter with skim milk.
• The milk becomes less susceptible to oxidized flavor development.

However, if we are interested in recovery of fat, then homogenized milk should not be taken. Fat recovery from homogenized milk is difficult.

Main components of a homogenizer are pump, homogenizing valve, breaker ring, tension spring and the valve sheet. Homogenizing valve
• The homogenizing valve is the heart of the homogenizer.
• This may be of different shapes and sizes.
• Most valves are of poppet type, which have a breaker ring so that the fluid strikes the inner surface of the breaker ring perpendicularly as it leaves the orifice formed by the conical shaped valve and seat.
• The valve is held by a heavy spring having adjustable tension. As the fluid pressure comes against it, the valve rises few thousandth of an inch to form a narrow annular opening(orifice).
• The valve parts are subjected to extreme abrasion because of the high velocity and pressure of the fluid as it passes through the valve. So they must be constructed of extremely tough and wear resistant hard metals such as stellite.
• The valve size must be suited to the capacity of the machine. Larger valves cause excessive clustering and too small valves may not give proper break up.
• Any slight grooving due to wear and tear may reduce the effectiveness. Hence, two valves are used in series, which is called a two stage homogeniser.
.
• The principal advantage of the two stage method is that it improves dispersion of fat globules and is useful in controlling viscosity of cream and ice cream mix.

Single Effect Evaporator

Frequently in the food industry a raw material or a potential foodstuff contains more water than is required in the final product. When the foodstuff is a liquid, the easiest method of removing the water, in general, is to apply heat to evaporate it. Evaporation is thus a process that is often used by the food technologist.

The basic factors that affect the rate of evaporation are the:

- rate at which heat can be transferred to the liquid,
- quantity of heat required to evaporate each kg of water,
- maximum allowable temperature of the liquid,
- pressure at which the evaporation takes place,
- changes that may occur in the foodstuff during the course of the evaporation process.

Considered as a piece of process plant, the evaporator has two principal functions, to exchange heat and to separate the vapour that is formed from the liquid.

Important practical considerations in evaporators are the:

- maximum allowable temperature, which may be substantially below 100°C.
- promotion of circulation of the liquid across the heat transfer surfaces, to attain reasonably high heat transfer coefficients and to prevent any local overheating,
- viscosity of the fluid which will often increase substantially as the concentration of the dissolved materials increases,
- tendency to foam which makes separation of liquid and vapour difficult.

THE SINGLE EFFECT EVAPORATOR

The typical evaporator is made up of three functional sections: the heat exchanger, the evaporating section, where the liquid boils and evaporates, and the separator in which the vapour leaves the liquid and passes off to the condenser or to other equipment. In many evaporators, all three sections are contained in a single vertical cylinder. In the centre of the cylinder there is a steam heating section, with pipes passing through it in which the evaporating liquors rise. At the top of the cylinder, there are baffles, which allow the vapours to escape but check liquid droplets that may accompany the vapours from the liquid surface. A diagram of this type of evaporator, which may be called the conventional evaporator, is given in **Fig. 8.1**.

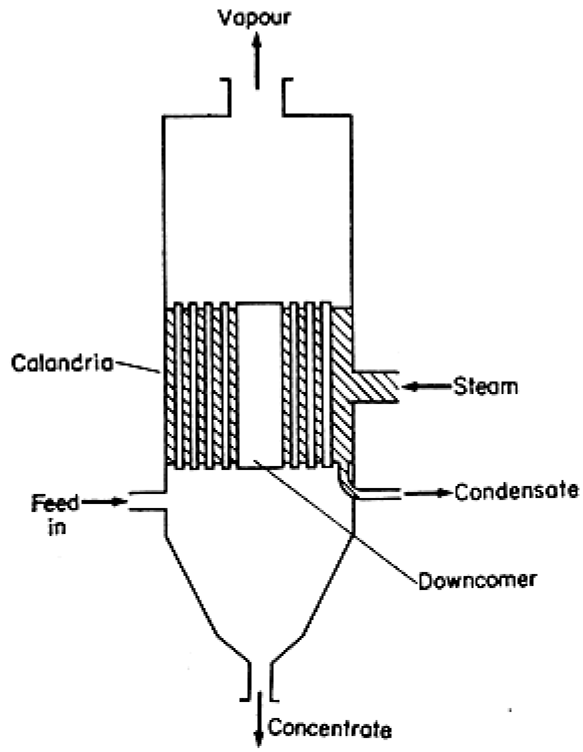


Figure 8.1 Evaporator

In the heat exchanger section, called a calandria in this type of evaporator, steam condenses in the outer jacket and the liquid being evaporated boils on the inside of the tubes and in the space above the upper tube plate. The resistance to heat flow is imposed by the steam and liquid film coefficients and by the material of the tube walls. The circulation of the liquid greatly affects evaporation rates, but circulation rates and patterns are very difficult to predict in any detail. Values of overall heat transfer coefficients that have been reported for evaporators are of the order of 1800-5000 J m^{-2} s^{-1} $°C^{-1}$ for the evaporation of distilled water in a vertical-tube evaporator with heat supplied by condensing steam. However, with dissolved solids in increasing quantities as evaporation proceeds leading to increased viscosity and poorer circulation, heat transfer coefficients in practice may be much lower than this.

As evaporation proceeds, the remaining liquors become more concentrated and because of this the boiling temperatures rise. The rise in the temperature of boiling reduces the available temperature drop, assuming no change in the heat source. And so the total rate of heat transfer will drop accordingly. Also, with increasing solute concentration, the viscosity of the liquid will increase, often quite substantially, and this affects circulation and the heat transfer coefficients leading again to lower rates of boiling. Yet another complication is that measured, overall, heat transfer coefficients have been found to vary with the actual temperature drop, so that the design of an evaporator on theoretical grounds is inevitably subject to wide margins of uncertainty.

Perhaps because of this uncertainty, many evaporator designs have tended to follow traditional patterns of which the calandria type of Fig. 8.1 is a typical example.

Vacuum Evaporation

For the evaporation of liquids that are adversely affected by high temperatures, it may be necessary to reduce the temperature of boiling by operating under reduced pressure. The relationship between vapour pressure and boiling temperature, for water, is shown in Fig. 7.2. When the vapour pressure of the liquid reaches the pressure of its surroundings, the liquid boils. The reduced pressures required to boil the liquor at lower temperatures are obtained by mechanical or steam jet ejector vacuum pumps, combined generally with condensers for the vapours from the evaporator. Mechanical vacuum pumps are generally cheaper in running costs but more expensive in terms of capital than are steam jet ejectors. The condensed liquid can either be pumped from the system or discharged through a tall barometric column in which a static column of liquid balances the atmospheric pressure. Vacuum pumps are then left to deal with the non-condensibles, which of course are much less in volume but still have to be discharged to the atmosphere.

Heat Transfer in Evaporators

Heat transfer in evaporators is governed by the equations for heat transfer to boiling liquids and by the convection and conduction equations. The heat must be provided from a source at a suitable temperature and this is condensing steam in most cases. The steam comes either directly from a boiler or from a previous stage of evaporation in another evaporator. Major objections to other forms of heating, such as direct firing or electric resistance heaters, arise because of the need to avoid local high temperatures and because of the high costs in the case of electricity. In some cases the temperatures of condensing steam may be too high for the product and hot water may be used. Low-pressure steam can also be used but the large volumes create design problems.

Calculations on evaporators can be carried out combining mass and energy balances with the principles of heat transfer.

- **EXAMPLE 8.1. Single effect evaporator: steam usage and heat transfer surface**

A single effect evaporator is required to concentrate a solution from 10% solids to 30% solids at the rate of 250 kg of feed per hour. If the pressure in the evaporator is 77 kPa absolute, and if steam is available at 200 kPa gauge, calculate the quantity of steam required per hour and the area of heat transfer surface if the overall heat transfer coefficient is 1700 J m^{-2} s^{-1} $°C^{-1}$.
Assume that the temperature of the feed is 18°C and that the boiling point of the solution under the pressure of 77 kPa absolute is 91°C. Assume, also, that the specific heat of the solution is the same as for water, that is 4.186 x 10^3 J $kg^{-1}°C^{-1}$, and the latent heat of vaporization of the solution is the same as that for water under the same conditions.

From steam tables (Appendix 8), the condensing temperature of steam at 200 kPa (gauge)[300 kPa absolute] is 134°C and latent heat 2164 kJ kg^{-1}; the condensing temperature at 77 kPa (abs.) is 91°C and latent heat is 2281 kJ kg^{-1}.

Mass balance (kg h^{-1})

	Solids	Liquids	Total
Feed	25	225	250
Product	25	58	83
Evaporation			167

Heat balance

Heat available per kg of steam

= latent heat + sensible heat in cooling to 91°C
$= 2.164 \times 10^6 + 4.186 \times 10^3(134 - 91)$
$= 2.164 \times 10^6 + 1.8 \times 10^5$
$= 2.34 \times 10^6$ J

Heat required by the solution

= latent heat + sensible heat in heating from 18°C to 91°C
$= 2281 \times 10^3 \times 167 + 250 \times 4.186 \times 10^3 \times (91 - 18)$
$= 3.81 \times 10^8 + 7.6 \times 10^7$
$= 4.57 \times 10^8$ J h^{-1}

Now, heat from steam = heat required by the solution,

Therefore quantity of steam required per hour $= (4.57 \times 10^8)/(2.34 \times 10^6)$
= 195 kg h^{-1}

Quantity of steam/kg of water evaporated = 195/167
= <u>1.17 kg steam/kg water</u>.

Heat-transfer area

Temperature of condensing steam = 134°C.

Temperature difference across the evaporator = (134 - 91) = 43°C.

Writing the heat transfer equation for q in joules/sec,

$$q = UA\,\Delta T$$

$$(4.57 \times 10^8)/3600 = 1700 \times A \times 43$$

$$A = 1.74\ m^2$$

Area of heat transfer surface = <u>1.74 m^2</u>

(It has been assumed that the sensible heat in the condensed (cooling from 134°C to 91°C) steam is recovered, and this might in practice be done in a feed heater. If it is not recovered usefully, then the sensible heat component, about 8%, should be omitted from the heat available, and the remainder of the working adjusted accordingly).

Condensers

In evaporators that are working under reduced pressure, a condenser, to remove the bulk of the volume of the vapours by condensing them to a liquid, often precedes the vacuum pump. Condensers for the vapour may be either surface or jet condensers. Surface condensers provide sufficient heat transfer surface, pipes for example, through which the condensing vapour transfers latent heat of vaporization to cooling water circulating through the pipes. In a jet condenser, the vapours are mixed with a stream of condenser water sufficient in quantity to transfer latent heat from the vapours.

EXAMPLE 8.2. Water required in a jet condenser for an evaporator

How much water would be required in a jet condenser to condense the vapours from an evaporator evaporating 5000 kg h^{-1} of water under a pressure of 15 cm of mercury? The condensing water is available at 18°C and the highest allowable temperature for water discharged from the condenser is 35°C.

Heat balance

The pressure in the evaporator is 15 cm mercury = $Z\rho g$ = 0.15 x 13.6 x 1000 x 9.81 = 20 kPa.
From Steam Tables, the condensing temperature of water under pressure of 20 kPa is 60°C and the corresponding latent heat of vaporization is 2358 kJ kg^{-1}.

Heat removed from condensate

$= 2358 \times 10^3 + (60 - 35) \times 4.186 \times 10^3$
$= 2.46 \times 10^6$ J kg^{-1}

Heat taken by cooling water

$= (35 - 18) \times 4.186 \times 10^3$
$= 7.1 \times 10^4$ J kg^{-1}

Quantity of heat removed from condensate per hour

$= 5000 \times 2.46 \times 10^6$ J

Therefore quantity of cooling water per hour

$= (5000 \times 2.46 \times 10^6)/7.1 \times 10^4$
$= \underline{1.7 \times 10^5 \text{ kg}}$

EXAMPLE 8.3. Heat exchange area for a surface condenser for an evaporator

What heat exchange area would be required for a surface condenser working under the same conditions as the jet condenser in Example 8.2, assuming a U value of 2270 J m^{-2} s^{-1} $°C^{-1}$, and disregarding any sub-cooling of the liquid.

The temperature differences are small so that the arithmetic mean temperature can be used for the

heat exchanger (condenser).
Mean temperature difference

$$= (60 - 18)/2 + (60 - 35)/2$$
$$= 33.5°C.$$

The data are available from the previous Example, and remembering to put time in hours.

Quantity of heat required by condensate = $UA\ \Delta T$

$$5000 \times 2.46 \times 10^6 = 2270 \times A \times 33.5 \times 3600$$

and so $A = 45\ m^2$

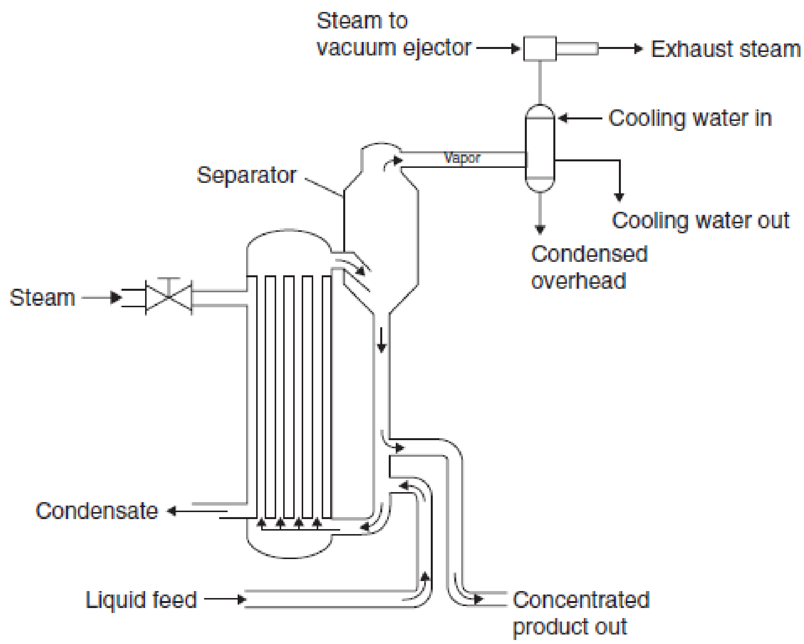
Heat transfer area required $= \underline{45\ m^2}$

This would be a large surface condenser so that a jet condenser is often preferred.

EVAPORATORS AND CONCENTRATOR:

Evaporation is an important unit operation commonly employed to remove water from dilute liquid foods to obtain concentrated liquid products. Removal of water from foods provides microbiological stability and assists in reducing transportation and storage costs. A typical example of the evaporation process is in the manufacture of tomato paste, usually around 35% to 37% total solids, obtained by evaporating water from tomato juice, which has an initial concentration of 5% to 6% total solids. Evaporation differs from dehydration, since the final product of the evaporation process remains in liquid state. It also differs from distillation, since the vapors produced in the evaporator are not further divided into fractions.

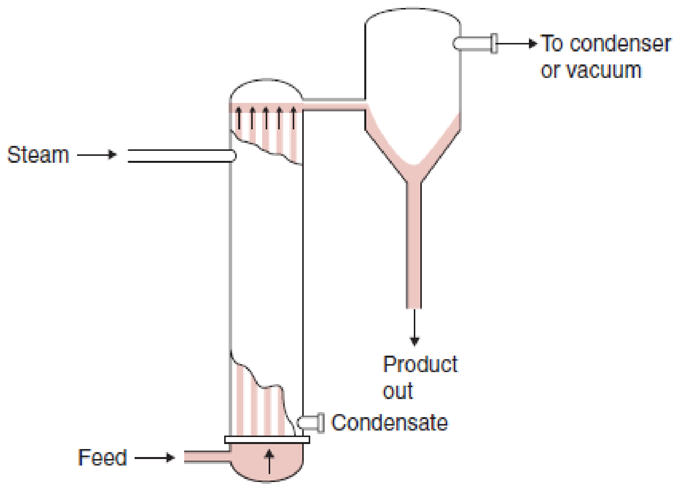
A simplified schematic of an evaporator is shown. Essentially, an evaporator consists of a heat exchanger enclosed in a large chamber; a noncontact heat exchanger provides the means to transfer heat from low-pressure steam to the product. The product inside the evaporation chamber is kept under vacuum. The presence of vacuum causes the temperature difference between steam and the product to increase, and the product boils at relatively low temperatures, thus minimizing heat damage. The vapors produced are conveyed through a condenser to a vacuum system. The steam condenses inside the heat exchanger and the condensate is discarded.



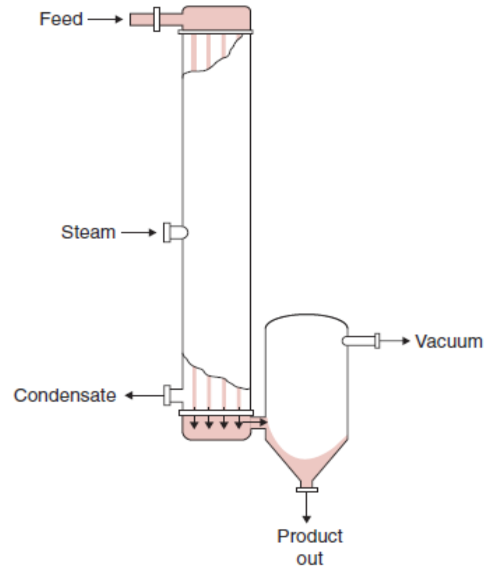
TYPES OF EVAPORATORS: Batch-Type Pan Evaporator, Rising-Film Evaporator, Falling-Film Evaporator, etc.

In a rising-fi lm evaporator, a low-viscosity liquid food is allowed to boil inside 10–15 m-long vertical tubes. The tubes are heated from the outside with steam. The liquid rises inside these tubes by vapors formed near the bottom of the heating tubes. The upward movement of vapors causes a thin liquid film to move rapidly upward. High convective heat-transfer coefficients are achieved in these evaporators.

In contrast to the rising-film evaporator, the falling film evaporator has a thin liquid fi lm moving downward under gravity on the inside ofthe vertical tubes.The design of such evaporators is complicatedby the fact that distribution of liquid in a uniform film flowing downward in a tube is more difficult to obtain than an upward-flow system such as in a rising-fi lm evaporator.



Steam
To condenser
or vacuum
Product
out
Condensate
Feed



Feed
Steam
Vacuum
Condensate
Product
out

MODULE II

Design of cold storage

DESIGN OF COLD STORAGE FOR FRUITS AND VEGETABLES

1. Introduction

Cold storage is the one widely practiced method for bulk handling of the perishables between production and marketing processing. It is one of the methods of reserving perishable commodities in fresh and whole some state for a longer period by controlling temperature and humidity with in the storage system. Maintaining adequately low temperature is critical, as otherwise it will cause chilling injury to the produce. Also, relative humidity of the storeroom should be kept as high as 80-90% for most of the perishables, below (or) above which his detrimental effect on the keeping quality of the produce.

Most fruits and vegetables have a very limited life after harvest if held at normal harvesting temperatures. Postharvest cooling rapidly removes field heat, allowing longer storage periods. Proper postharvest cooling can:

- Reduce respiratory activity and degradation by enzymes;
- Reduce internal water loss and wilting;
- Slow or inhibit the growth of decay-producing microorganisms;
- Reduce the production of the natural ripening agent, ethylene.

In addition to helping maintain quality, postharvest cooling also provides marketing flexibility by allowing the grower to sell produce at the most appropriate time. Having cooling and storage facilities makes it unnecessary to market the produce immediately after harvest. This can be an advantage to growers who supply restaurants and grocery stores or to small growers who want to assemble truckload lots for shipment. Postharvest cooling is essential to delivering produce of the highest possible quality to the consumer

Cold storage can be combined with storage in an environment with added of carbon dioxide, sulfur dioxide, etc. according to the nature of product to be preserved. The cold storage of dried/dehydrated vegetables in order to maintain vitamin C, storage temperature can be varied with storage time and can be at 0°-10°C for a storage time of more than one year, with a relative humidity of 80-95 %.

The cold storage of perishables has advanced noticeably in recent years, leading to better maintenance of organoleptic qualities, reduced spoilage, and longer shelf lives. These advances have resulted from joint action by physiologists to determine the requirements of fruit and vegetables, and by refrigerating specialists to design and run refrigerating machines accordingly.

Care should be taken to store only, those kinds, which does not show in compatibility of storage, when storing multi produce in the same room. For example, apple can be stored with grapes, oranges, peaches, and plums and not with banana. However with potato and cabbage slight danger of cross actions can occur. Contrary to this, grape in compatible to all other vegetables except cabbage. To resolve the incompatibility during cold storage, foodstuffs are grouped into three temperature ranges Based on their thermal incompatibility the produce are classified into

1. Most animal products (or) vegetable produce, not sensitive to cold (0-4°C)

E.g. Apple, grape, carrot and onion

2. Vegetable produce moderately sensitive to cold (4-8°C)
E.g. Mango, orange, potato and tomato (ripened)
3. Vegetable produce sensitive to cold (>8°C)
E.g. Pineapple, banana, pumpkin and bhendi
Based on the purpose the present day cold stores are classified into following groups:
1. Bulk cold stores: Generally, for storage of a single commodity which mostly operates on a seasonal basis E.g.: stores for potatoes, chilies, apples etc.
2. Multi purpose cold stores: It is designed for storage of variety of commodities, which operate practically, throughout the year.
3. Small cold stores: It is designed with pre cooling facilities. For fresh fruits and vegetables, mainly for export oriented items like grapes etc.
4. Frozen food stores: It is designed for with (or) without processing and freezing facilities for fish, meat, poultry, dairy products and processed fruits and vegetables.
5. Mini units /walk in cold stores: It is located at distribution center etc.
6. Controlled atmosphere (CA) stores: It is mainly designed for certain fruits and vegetables

2. GENERAL ARRANGEMENTS AND CONSIDERATIONS

If produce is to be stored, it is important to begin with a high quality product. The produce must not contain damaged or diseased units, and containers must be well ventilated and strong enough to withstand stacking. In general proper storage practices include temperature control, relative humidity control, air circulation and maintenance of space between containers for adequate ventilation, and avoiding incompatible product mixes. Commodities stored together should be capable of tolerating the same temperature, relative humidity and level of ethylene in the storage environment. High ethylene producers (such as ripe bananas and apples) can stimulate physiological changes in ethylene sensitive commodities (such as lettuce, cucumbers, carrots, potatoes, sweet potatoes) leading to often undesirable color, flavor and texture changes.
The general features of a cold store operational programme (products, chilling and chilled storage and freezing) include total capacity, number and size of rooms, refrigeration system, storage and handling equipment and access facilities. The relative positioning of the different parts will condition the refrigeration system chosen. The site of the cold chambers should be decided once the sizes are known, but as a general rule they should be in the shade of direct sunlight. The land area must be large enough for the store, its annexes and areas for traffic, parking and possible future enlargement. A land area about six to ten times the area of the covered surface will suffice.
There is a general trend to construct single-storey cold stores, in spite of the relatively high surface: volume ratio influencing heat losses. The single storey has many advantages: lighter construction; span and pillar height can be increased; building on lower resistance soils is possible; internal mechanical transport is easier. Mechanical handling with forklift trucks allows the building of stores of great height, reducing the costs of construction for a given total volume.
The greater the height of the chambers the better, limited only by the mechanical means of stacking and by the mechanical resistance either of the packaging material or of the unpackaged merchandise. The length and width of the chambers are determined by the total amount of merchandise to be handled, how it is handled (rails, forklift trucks), the number of chambers and the dimensions of basic handling elements.

There is no advantage in building many chambers of a small size. Thermal and hygrometric requirements are not so strict as to justify a lot of rooms: the accuracy of the measuring instruments and the regulation of conditions inside the chamber always produce higher deviations than those of ideal storage conditions for different products. This is particularly true for frozen products.

A design that opts for fewer, larger chambers represents in the first place an economy in construction costs as many divisional walls and doors are eliminated. Refrigeration and control equipment is simplified and reduced, affecting investment and running costs. Large chambers allow easier control of temperature and relative humidity and also better use of storage space. Only in very particular situations should the cold store be designed with more than five or six cold chambers. Store capacity is the total amount of produce to be stored. If the total volume of the chambers is filled, the quantity of produce by unit of volume will express storage density.

Several parameters must be defined within a cold store. The total volume is the space comprised within the floor, roof and walls of the building. The gross volume is the total volume in which produce can be stored, that is excluding other spaces not for storage. The net volume represents the space where produce is stacked, excluding those spaces occupied by pillars, coolers, ducts, air circulation and traffic passages inside the chambers that are included in the gross volume. Storage density referred to as net volume is expressed in kg/useful m3, but is most commonly referred to as gross volume.

An index of how reasonably and economically the cold store has been designed is the gross volume divided by the total volume. It must be in the range of 0.50 to 0.80.Similarly gross volume is about 50 percent greater than net volume, and gross area (same concept as volume) is about 25 percent greater than net area. The extent of occupation is the ratio between the actual quantity of produce in storage at a given moment and that which can be stored. Equally the extent of utilization is the average of the extent of occupation during a given period — usually a year, but it can also be per month

Temperature management during storage can be aided by constructing square rather than rectangular buildings. Rectangular buildings have more wall area per square meter of storage space, so more heat is conducted across the walls, making them more expensive to cool. Temperature management can also be aided by shading buildings, painting storehouses white or silver to help reflect the sun's rays, or by using sprinkler systems on the roof of a building for evaporative cooling. The United Nations' Food and Agriculture Organization (FAO) recommends the use of Ferro cement for the construction of storage structures in tropical regions, with thick walls to provide insulation. Facilities located at higher altitudes can be effective, since air temperature decreases as altitude increases. Increased altitude therefore can make evaporative cooling, night cooling and radiant cooling more feasible.

The air composition in the storage environment can be manipulated by increasing or decreasing the rate of ventilation (introduction of fresh air) or by using gas absorbers such as potassium permanganate or activated charcoal. Large-scale controlled or modified atmosphere storage requires complex technology and management skills; however, some simple methods are available for handling small volumes of produce.

3. HEAT LOAD CALCULATION FOR TAMARIND STORAGE

The optimal storage temperature must be continuously maintained to obtain the full benefit of cold storage. To make sure the storage room can be kept at the desired temperature, calculation of the required refrigeration capacity should be done using the most severe conditions expected during operation. These conditions include the mean maximum outside temperature, the maximum amount of produce cooled each day, and the maximum temperature of the produce to be cooled. The total amount of heat that the refrigeration system must remove from the cooling room is called the heat load. If the refrigeration system can be thought of as a heat pump, the refrigerated room can be thought of as a boat leaking in several places with an occasional wave splashing over the side. The leaks and splashes of heat entering a cooling room come from several sources:

- Heat Conduction - Heat entering through the insulated walls, ceiling, and floor;
- Field Heat - Heat extracted from the produce as it cools to the storage temperature;
- Heat of Respiration - Heat generated by the produce as a natural by-product of its respiration;
- Service Load - Heat from lights, equipment, people, and warm, moist air entering through cracks or through the door when opened

4.0. MODEL CALCULATION FOR STORAGE OF TAMARIND OF 100 TONNES CAPACITY

Calculation of the heat load involves considerations of various parameters and some of them are presented below:

Harvesting season : April-June
Optimal storage temperature : 7°C
Optimal relative humidity (%) : 90-95%
Approximate cold storage : 3-4weeks
Quantity to be stored : 100 tonnes
Ambient conditions : 30°C and 70 % RH
Latitude : North 11.00°
Altitude : 409 MSL

TAMARIND PROPERTIES:
Bulk density : 850 kgm-3
Heat of respiration : 700 Kcal/ton/24 h
Specific heat (20%M.C) : 0.524 Kcal/Kg°C

4.1. DESIGN OF BOX FOR STORAGE OF THE PRODUCE:

Volume of the product = Total Weight of the Produce / Bulk Density of Produce
= 1, 00,000 kg /850 kgm-3
= 117.64 m3
Assumed size of each box = 0.554 x 0.304 x 0.228m
Therefore volume of each box = 0.0383 m3
*Bulk density of the hard wood used for the storing the tamarind = 850 kgm-3
Weight of produce in each box = (Volume of each box) (B.D of Hard wood)
= 0.0363 m3 x 850 kgm-3
= 30 kg/box
Total number of boxes = Total weight of the Produce
Weight of the produce in each box
= 100,000 kg / 30 kg
= 3226 boxes
Thickness of each box = 0.004 x 0.004 x 0.008m

Actual volume of wood used per box = 0.0020 m3/box
Total volume of boxes = (volume of each box) (total number of boxes)
= 0.002 x 3226
= 6.452 m3
Total volume of boxes and produce = (Total volume of tamarind +box volume)
= 117.64 + 6.452
= 124.092 m3
DIMENSIONS OF THE WOODEN BOX (m)
4.2. INTERNAL DIMENSIONS OF THE COLD STORAGE:
The efficiency of the cold storage as well as for easy handling and movement of the produce during loading and unloading of the tamarind can be improved by stacking the boxes or containers in proper way. The boxes can be stacked in row and columns on the Standard pallets as given in the general considerations. Proper stacking helps in uniform
0.228
0.554
0.304
4
cooling of the produce, also spacing should be considered for the movement of air and handling equipments. Assumed dimensions based on the total capacity of the tamarind to be stored, are given below:
Length = 13.972 m
Breadth = 7.648 m
Height = 4.42 m
Total internal volume = (13.972 x 7.648 x 4.42) m
= 472.3 m3
Free volume available inside the Cold storage = (Product volume – Internal volume)
= 472.3 m3 -124.4 m3
= 348.3 m3
Inner dimensions = 13.972 x 7.648 x 4.42
EXTERNAL DIMENSIONS OF THE COLD STORAGE (m)
4.3. EXTERNAL DIMENSIONS OF THE COLD STORAGE:
1. Length = 13.972 m + (0.5 x2)m (walls) = 14.972 m
2. Breadth = 7.648 m + (0.5 x2)m (walls) = 8.648 m
VOLUME =472.3 m3
14.972
8.648
5.0
3. Height = 4.42 m + 0.6m (floor & ceiling) = 5.0 m
4. Total external volume = 647.38 m3
5. Outer dimensions = 14.972 x 8.648 x 5.0 m3
6. Total building volume = (External volume – Internal volume)
= 647.38 – 472.3
= 175 m3
4.4. HEAT TRANSFER THROUGH THE BUILDING:
The R (for resistance) number, is always associated with a thickness; the higher the R-value, the higher the resistance and the better the insulating properties of the material.

There are three alternatives for insulating the facility. Alternative A uses 10-20-30 R-values for the floor, walls and ceiling respectively. Alternative B uses 0.4-20-30 R-values, which are equivalent to no insulation in the floor and only a concrete slab 4 inches thick. Alternatives A and B correspond to grower self-built units. Alternative C corresponds to a new prefabricated walk-in cooler with an insulation of 30-30-30 R-values for the walls, ceiling, and floor.
This calculation is based on the first option i.e. R-value 10-20-30 as this would be suitable for most of the tropical countries, where the losses through the buildings is higher.
4.4.1. HEAT TRANSFER THROUGH THE WALLS:
If the steady state flow is considered than, the heat flow is
Q = UA (To – Ti) Kcal / hr
Where,
U --- Over all heat transfer coefficient (Kcal/m2 hr° C)
A --- Surface area through which heat is transferred (m2)
To --- Temperature of outside air (°C)
Ti --- Temperature of inside storage space(° C)
The overall heat transfer coefficient is given by

$$u = \frac{1}{\frac{1}{h_o} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \ldots \frac{1}{hi}}$$

Where,
ho ---- heat transfer coefficient on the out or surface
hi ---- heat transfer coefficient on the inner surface
X1, X2 --- Thickness of wall and insulating material respectively (cm).
K1, K2 --- Thermal conductivity of wall and insulating materials (Kcal/m.hr. °C)
With thick wall and low conductivity, the resistance X/K makes U so small that 1/hi and 1/ho have little effect and can be omitted from the calculation. The values of U for different types of walls and ceilings various from 1.00 to 4 Kcal /m2.hr. °C.
*Surface area = A = [2 x 13.972] x 4.42 = 123.5 m2 (Length)
[2 x 7.648] x 14.972 = 229.0 m2 (Breath)
*Total surface area = (length x Breadth) = 352.5 m2
*Ambient temperature (To) = 30oc
*Cold storage temperature (Ti) = 7oc
* Insulations resistance to the movement of heat (R) = 20
* Thickness of the brick = 0.44m
* Thermal conductivity of the brick = 0.62 kcal/m/hoc

* Thickness of the cement plaster = 0.10m
* Thermal conductivity of the cement plaster = 1.488 kcal/m/hoc

Overall heat transfer coefficient

1/u = 0.44/0.62 + 0.01/1.48

u = 1.398 kcal/m2/hoc

Therefore heat transfer through building material

Q = 1.398 x 352.5 x (30-7) x 24

= 272139.81 Kcal/24h

Heat transfer through insulation material

Q = [A (To – Ti) x 24]/R

= [352.5 x (30-7) x 24]/20

= 9729 Kcal/24h

Total heat transfer through walls = 272139.81 + 9729

= 281868.81 Kcal/24h

4.4.2. HEAT TRANSFER THROUGH CEILING:

* Surface area = A = 13.972 x 7.648 = 106.85 m2
* Insulations resistance to the movement of heat (R) =30
* Thickness of the cement concrete = 0.20m
* Thermal conductivity of the cement concrete = 1.488 kcal/m/hoc

Therefore heat transfer through ceiling material, can be generally taken as 20% more than wall overall coefficient

i.e. Q = (1.398 x1.2) x 106.85 x (30-7) x 24

= 98946.859 Kcal/24h

Heat transfer through insulation material

Q = [A (To – Ti) x 24] /R

= [106.85 x [30-7] x 24]/30

= 1966.04 Kcal / 24 h

Total heat transfer through walls = 98946.859 + 1966.04

= 100912.89 Kcal/24h

4.4.3. HEAT TRANSFER THROUGH FLOOR:

* Surface area = A = 13.972 x 7.648 = 106.85 m2
* Insulations resistance to the movement of heat (R) =10
* Thickness of the cement concrete = 0.15m
* Thermal conductivity of the cement concrete = 1.488 kcal/m/hoc

Heat transfer through insulation material

Q = A (To – Ti) x 24 /R

= 106.85 x [30-7] x 24/10

= 5898.12 Kcal / 24 h

Total heat transfer = Heat transfer through walls +ceiling + floor

= (281868.81 + 100912.89 + 5898.12) Kcal / 24 h

= 388679.00 Kcal /24 h

Based on the above R-value the most appropriate insulation material can be selected considering various parameters like Availability of the material, Cost on insulating material, conductivity, Quality and life of the material. The most commonly used building and the insulating materials with their properties are presented in the appendix.

4.5. PRODUCT LOAD:

Product cooling = (Weight of the fruit) (Specific heat of fruit) (Temperature difference)
= (100000) x (0.524) x (30-7)
= 1205200 Kcal / 24 h
Box heat load (Hard wood) = (weight of the box) (sp heat of box) (temp. difference)
= (0.002 m3 x 3226 boxes x 720 kg/m3) (0.571) (30 – 7)
= 4645.4 x 0.571 x 23
= 61008.562 Kcal / 24 h
Total product load = 1205200 +61008.562
= 1266208.5 Kcal/ 24 h

4.6. RESPIRATION LOAD DURING COLD STORAGE:

Average temperature = (30 + 7) / 2 = 18.5 C
Respiration heat load = wt. of the fruit x heat of respiration
= 100 tonnes x 700 Kcal/ton/24 h
= 70000 Kcal / 24 h
Total heat load = Heat transfer through surface + Product cooling + Respiration load
= 388679.00 + 1266208.5 + 70000
= 1724887.5 Kcal/ 24 h

VII. Miscellaneous load calculation

*Service load can be taken as 10 per cent of the total load i.e., lights, fans, forklift and working men. Therefore, total heat load during cooling = 1897376.2 Kcal/ 24 h
*Including 10 % of the total heat load as a safety factor, the overall heat load 2087113.8 Kcal/ 24h

TOTAL HEAT LOAD CALCULATION

*Assuming refrigeration operates for about 16 hours/ day, the refrigeration capacity requirement = 2087113.8 / 16
= 130444.61 kcal/ h =546041.13kJ/h
*One ton of refrigeration = 12660 kJ / h
Therefore, refrigeration required = 546041.13/ 12660
= 43.0 tons of refrigeration
So based on this cooling load calculation we can select the refrigeration unit capacity for particular product to be stored.

5. FUNDAMENTALS FOR IMPLEMENTING A COLD STORAGE PROJECT

The design of cold storage facilities is usually directed to provide for the storage of perishable commodities at selected temperature with consideration being given to a proper balance between initial, operating, maintenance, and depreciation costs. The basic procedures for constructing (or) implementing the cold store units are should have the following requirements:

a) Process Layout

The most important requirement for any food project using insulated envelopes is to determine the process layout of the operation which is to be housed by the envelope. In the case of a meat plant, this can be a carcass dressing line or a boning room, or for a cold store, the pallet layout and mode of operation must be established. It is simply no good building an envelope and then attempting to place the processing machinery inside it.

b) Planning Drawings and Application

It is only after concluding the process layout that a planning application can be made when the dimensions of the envelope and supporting buildings can be frozen.

c) Design Drawings and Specifications

Once planning approval has been obtained then the preparation of design drawings and specifications can proceed. For a competitive design and construct tender, it is essential to prepare some 15 - 20 detailed drawings covering, at the minimum, the process layout, elevations and sections, the refrigeration system layout, mechanical and electrical systems reticulation and the lighting layout.

In addition to make up package at least six separate detailed specifications are required covering the project's requirements on:

1. Contractual requirements
2. Building specification
3. Refrigeration specification
4. Insulation panel supply and erection
5. Electrical requirements
6. Mechanical services.

6. LOCATION CONSIDERATIONS IN DESIGN OF COLD STORAGE

Location

Environment

Local Factors

Altitude

Latitude

(For calculating solar loads)

Place

Water

Atmosphere

Labor

Materials Transportation

Elevation above sea level

1) North or south of equator

2) Degree Line

1) Outside design conditions

2) Unusual surroundings

1) Corrosion and scaling properties of local water

Outdoor contaminants which could affect outdoor equipment, air handling equipment filtration

1) Availability, skill and costs

2) Design should be based on use of local labor

Availability and costs Shipping, receiving and storage availability of equipment

6.1. LOCATION AND LAYOUT

The location chosen for the cooling facility should reflect its primary function. If the plan is to conduct retail sales of fresh produce from the facility, it should be located with easy access to public roads. A retail sales operation located away from the road, particularly behind dwellings or other buildings, discourages many customers. Adequate parking for customers and employees, if any, must be provided.

If, however, the primary function of the cooling facility is to cool and assemble wholesale lots, ease of public access is less important. In this case, the best location may be adjacent to the packing or grading room. In addition to housing grading and packing equipment, the space could be used to store empty containers and other equipment and supplies when it is not needed for cooling. All cooling and packing facilities should have convenient access to fields or orchards to reduce the time from harvest to the start of cooling.

Regardless of how it is used, the facility will need access to electrical power and water. For larger cooling rooms requiring more than about 10 tons of refrigeration in a single unit, access to three-phase power will be necessary. The location of existing utility lines should be carefully considered, as connection costs can be prohibitive in some rural areas. Consult your local power company for details.

In addition, it is a good idea to anticipate any future growth when locating and designing your facility. The cold storage unit should be built on a site, a where the ground in clean, well drained and preferably leveled and near to supplies of energy and water. If possible, it should be in the shade of prevailing wind and direct sunlight. A refrigerated store, with one (or) more thermally insulated places, and refrigerating machines can be planned with the aim of assuring certain services. The details about:-

1. Nature of the products
2. Frequency of loading and unloading
3. Calendar for harvest and dispatch
4. Field heat of the produce
5. Daily tonnage of produce to be handled
6. Daily tonnage of ice to be manufactured
7. Nature and dimension of packages

The above particulars are to be collected before initiating the cold storage unit work. The conditions to be considered for planning, a cold storage are temperature and duration of storage, handling and stacking method, type of; commodities to be stored together, prevailing climatic factors like temperature, relative humidity, rainfall, wind and water. Availability of skilled and unskilled labor from the local area is the major factor to be considered for the successful operation.

7. CONSTRUCTONAL DETAILS REQUIRED FOR COLD STORAGE DEISGN

Category

Factor

Specific information required

Architectural Design

Structural Design

Type of Construction

Surrounding

Condition

Access

Scale Drawings

Type of Structure:

Columns, Beams Bracing

Seismic Effects Expansion
and Settlement
Joint
Walls, Roof, Floors
Insulation
Outside
Adjacent Spaces
Adjacent Buildings
Doors
Stairways and Elevators
Plans, elevations, sections
Orientation
Size, depth, location
Record and Pattern
Location and expected movement of
joints
Materials, thickness
Type, thickness, "k" or "C" value,
"R" factor
Design conditions, summer and
winter
Conditioned or Unconditioned
temperature
Shading
1) Location, type, size and usage
2) Doors for access to and removal
of conditioning equipment
3) Access of lift trucks
1) Location and size
2) Temperature of connecting spaces
3) Equipment horsepower
4) Ventilation requirements

CALCULATION OF THE COLD STORAGE DIMENSIONS

The useful volume of a chamber is calculated as a function of the maximum mass of produce, in store at the same time, taking account of the useful densities of storage, expressed respectively as net mass of goods, per useable m3 (or) in kg of carcasses suspended per linear in of rail.

The gross volume of a cold room is equal to the useful volume, increased by the volumes necessary to allow for circulation of air and for handling. For a preliminary, assume that the gross internal volume is twice the useful volume, (or) alternatively for rooms to be used for miscellaneous products that it is of the order of 160kg/m3 gross for chilling (or) 300 kg/m3 for freezing. The internal height depends on the means of handling and stacking in very large stores, (or) where stacking is done by lift trucks, the internal height is of the order of 8.5 cm for 4 super imposed pallets. If stacking is manual, the maximum height of stacks does not exceed 3 m, which gives an internal height of 3.50 to 4 m.

7.1. FOUNDATION AND FLOOR

Almost all postharvest cooling facilities built nowadays are constructed on an insulated concrete slab with a reinforced, load-bearing perimeter foundation wall. The slab should be built sufficiently above grade to ensure good drainage away from the building, particularly around doors. The floor should also be equipped with a suitable inside drain to dispose of wastewater from cleaning and condensation.

The ground loads from a cold store are in the order of 5500-8000 kg/m2. This consists of static loads due to merchandise, structure and concentrated rolling loads transmitted by e.g., forklift trucks and other handling equipment. It is of importance that those loads are investigated in detail for each special project.

STANDARD FLOORS

Standard floors shall be a minimum 125mm concrete. A 150mm hardcore base shall be provided, compacted with vibrating or heavy roller, and topped with fine sand. All floors shall incorporate 1000 gauge polythene D.P.C. membrane with 600mm overlaps laid on the sand under concrete, and taken up along walls to meet D.P.C., where this has been installed. In stores for certain forms of produce, or with floors subject to heavy mechanized traffic, reinforced floors shall be installed. The design shall meet the requirements of the specific loading. In the absence of specific design data an A393 mesh to BS4482/BS 4483 [10mm @ 200mm c/c : 6.16 kg/m2] shall be placed 40mm below the finished floor surface. Depending on specific requirements the top surfaces of floors may require proprietary hardeners and/or sealing agents.

MOBILE RACKING FLOOR & TYPICAL FLOOR AND DOOR DETAILS

UNDER FLOOR DUCTING

Stores for certain forms of produce may require underfloor ducting. Design of ducting (size, spacing, and construction) is specific to the type of produce stored and the mechanical plant installed. Lay-out and design details shall be provided by the mechanical plant supplier or consultant.

LAYING OF CONCRETE FLOORS

Laying of concrete floors shall be done in alternate bays measuring not more than 4.5m wide by 6m long where there is no fiber additive, and not more than 4.5m wide by 8m long with fiber additive. In the case of mesh reinforced floors joint spacing can be extended to 12m by 8m. Concrete shall be placed about 20mm proud of the shuttering and tamped to the correct level using a tamper or vibrating screed. Concrete may also be laid in one operation as above and bays to the dimensions specified shall be cut by concrete saw 25mm deep x 12mm wide in the hardened concrete within 24 hours of pouring. All joints shall be brushed out and filled with mastic as per manufacturers' instructions.

CURING OF CONCRETE FLOORS

As soon as concrete surface is firm enough (within about 1 hour) the slab shall be sprayed lightly with water and maintained in a damp condition for seven days. This is best achieved by covering the wetted slab with a polythene sheet. Care should be taken to ensure that polythene firmly fixed at the edges of the slab to avoid wind draught between the polythene and the concrete surface.

In the case of a single-storey building, a reinforced raft is usual, including ground beams at the edges or bases for the structural frame. This can rest directly on the existing ground or a supported slab. The floor wearing surface requires particular care. In addition to the wear other industrial floors have to stand, it is exposed to low temperature. All other parts of the cold store can be repaired whilst most of the space is still used for storage, but not the floor. Most commonly the floor wearing surface is a concrete slab cast on the floor insulation with a thickness of 100-150mm. In cases where intensive traffic is foreseen a special hard wearing top-finish is recommended. Before casting the wearing surface, the floor insulation should be protected by bituminous paper or plastic sheeting, the function of which is twofold. Firstly, to prevent the water from the fresh concrete penetrating into the floor insulation and secondly, to provide a slip-sheet, which will reduce the friction when the concrete when contracts. It is of great importance that the floor wearing surface be level to enable high stacking and easy traffic. The top-finish should provide a reasonable anti-slip surface.

Special attention must be given to floor joints. It is recommended that a device which allows horizontal displacement, but not vertical movement, is used between the joints. If the joints open too much after lowering of the temperature, they must be filled with a suitable jointing compound. If the pallet layout is painted on the floor (the conventional way for easy location) a special hard-wearing, alcohol-based paint should be used.

The floor of a refrigerated room must support heavy loads and withstand hard use in a wet environment but still provide an acceptable measure of insulation. The slab floor should be at least 4 inches of wire-mesh-reinforced concrete over 2 inches of waterproof plastic foam insulation board such as DOW Styrofoam or equivalent. Five or even 6 inches of concrete may be necessary for situations where loads are expected to be unusually heavy. The need for floor insulation is often poorly understood and therefore neglected to cut cost. This is false economy, however, since the insulation will pay for itself in a few seasons of use. If the room is to be used for long-term subfreezing storage, it is essential that the floor be well insulated with at least 4 inches of foam insulation board (having a rating of R-20 or greater) to prevent ground heave.

Any framing lumber in contact with the concrete floor must be pressure treated to prevent decay, especially the sill plates and lower door frames, which may be in long-term contact with water. Although no produce would normally come into contact with it, the lumber must be treated with an approved nontoxic material. Information on the toxicity of treated lumber should be obtained from the building materials supplier.

During construction, the interface between the underside of the sill plate and the floor must be sealed to prevent the movement of water. This is easily done by completely coating the underside of the sill plate with a heavy layer of suitable sealant before securing it to the foundation pad with anchor bolts. The sill plate must be adequately secured to the floor to prevent the building from moving off the foundation in a high wind.

Different types of freezers

There are now many different types of freezer available for freezing fish, and freezer operators are often uncertain about which type is best suited to their needs. Three factors may be initially considered when selecting a freezer; financial, functional and feasibility.

Financial considerations will take into account both the capital and running cost of the equipment and also projected losses such as product damage and dehydration. Expensive freezers should therefore justify their purchase by giving special benefits and if these benefits are not worthwhile, they need not be considered.

Functional considerations will take into account such things as whether the freezer is required for continuous or batch operation and also whether the freezer is physically able to freeze the product. For instance, a horizontal plate freezer would be inappropriate for freezing large whole tuna.

Feasibility will take into account whether it is possible to operate the freezer in tile plant location. A liquid nitrogen freezer (LNF), for instance, may be suitable in every respect for freezing the product and the high costs of using this method of freezing may be justified. However, if the location of the plant is such that there can be no guaranteed supply of liquid nitrogen, the freezer should not be considered.

Initial considerations such as those mentioned above will eliminate many freezers from the final choice but still leave many options open to the freezer operator. In order to give the reader some guidance in both selection and use of freezers, descriptions of the various types now available for freezing fish are described. The types of freezer likely to be used in developing countries, especially where freezing is a relatively new process, are those that have already been widely used for freezing fish and have therefore been well tried and tested. Freezers in this category are described more fully than others.

4.1 Types of freezer

The three basic methods of freezing fish are:

1. Blowing a continuous stream of cold air over the fish - air blast freezers.
2. Direct contact between the fish and a refrigerated surface - contact or plate freezers.
3. Immersion in or spraying with a refrigerated liquid - immersion or spray freezers.

4.1.1 Air blast freezers

The advantage of the blast freezer is its versatility. It can cope with a variety of irregularly shaped products and whenever there is a wide range of shapes and sizes to be frozen, the blast freezer is the best choice. However, because of this versatility it is often difficult for the buyer to specify precisely what he expects it to achieve and, once it is installed, it is all too easy to use it incorrectly and inefficiently.

Before going on to describe the various types of air blast freezer, it is necessary to deal with some of the basic principles of air blast freezer design and operation.

Designing air blast freezers

The use of air to transfer heat from the product being frozen to the refrigeration system is probably the most common method used in commercial refrigeration. The natural convection of the air alone would not give a good heat transfer rate, therefore, forced convection by means of fans has to be introduced. To enable the product to be frozen in a reasonable time the air flow rate should be fairly high. Also, in order to obtain uniform freezing rates throughout the freezer, the air flow requires to be consistent over each fish or package.

Examination of Figure 5 shows that at very low air flow rates the freezing time is long. A single fillet for instance will take 4 times as long to freeze in the relatively still air in a cold store as it would in a properly designed air blast freezer. Figure 5 also shows that a high air speed, which also means high fan power, freezing times will change very little with further increases in air speed. A design air speed of 5 m/s has been found to be a good compromise between slow freezing rates and high fan costs and this air speed is recommended for most air blast freezers.

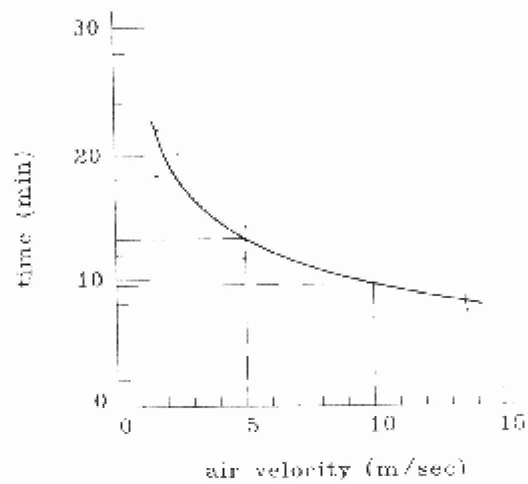


Figure 5 Variation of freezing time with air velocity for 14 mm thick fillets

Continuous air blast freezers may economically justify air speeds in excess of the above-recommended value. Continuous freezers are expensive and require a good deal of floor space. If the air speed is increased and the freezing time reduced, a smaller freezer will be required for a given freezing capacity. The savings in freezer costs may therefore justify the use of higher air speeds. Air speeds as high at 10 to 15 m/s may therefore be economically justifiable for continuous freezers. Higher airspeeds can also be justified when products have freezing times of less than about 30 mins.

The air flow over the surface of a product being frozen cannot be measured simply. In reality the air immediately adjacent to the surface of the product is stagnant due to the friction between the air and the surface of the product. This stagnant air forms a boundary layer which acts as a resistance to heat transfer. The layer thickness depends on air velocity, degree of turbulence and other factors. The air speeds quoted for air blast freezers are therefore only average speeds for the spaces between the fish or packages of product being frozen. A simple calculation which shows how this average air speed is derived is shown diagrammatically in Figure 6.

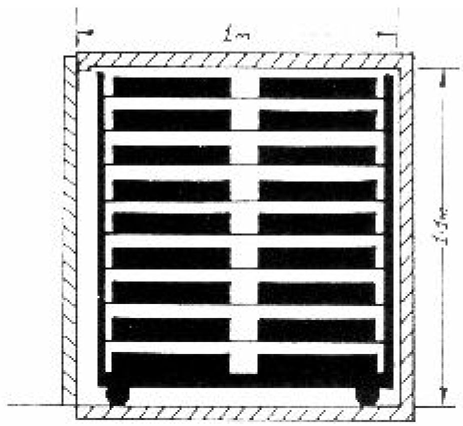


Figure 6 Calculation of average air speed in an air blast freezer

Calculated cross sectional area of tunnel,1.1m x 1.0m = 1.1 m2

Calculated cross sectional area of produce and trolley (shaded areas) = 0.7 m2

Air flow (obtained from fan rating or measured in open part of tunnel) = 2.0 m3/S

Calculated average air velocity, 2.0 ÷ (1.1-0.7) = 5 m/s

Another aspect of air flow rate that has to be considered in the design of a freezer the permitted temperature rise over the product. If the temperature rise is too great, the will be differences between the freezing times of products placed upstream and downstream in the freezer space. The differences in freezing time can be calculated by the method shown in Chapter 5. If the air temperature rise in the freezer is too small then it is possible that t freezer design is poor, the quantity of air being circulated is too high and more powerful fans than necessary are being used to maintain the recommended air speed.

Table 3 Fan power requirement for a continuous air blast freezer

Air velocity over product (M/S)	Freezing section pressure drop (mm water gauge)	Fan static pressure (mm water gauge)	Fan power (kW)
5.5	1.8	17.3	6.26

11.0	9.5	25.0	7.16

However, from Table 3 it can be seen that (in a well designed blast freezer) the increase in fan power required to double the air velocity over the product is no more than 15%.

Even in a good air blast freezer, the fan load can account for 25 to 30 percent of the refrigeration requirement and in a poor design it has even been known for the fan load to exceed the product load. No firm recommendation can be made about the permissible rise in temperature but an average air temperature rise of 1 to 3 degC is reasonable and may be used as a guide. This temperature rise will depend on the heat load; therefore it will be higher at the start of a freeze than at the end. The average temperature rise is therefore calculated from the total heat extracted from the fish and the weight of air circulated during the freezing period. The following sample calculation is used by way of illustration:

Weight of fish frozen	100 kg
Heat content of 1 kg of fish (+ 8°C to -30°C)	80 kcal/kg
Total heat to be extracted 90 x 100 =	8000 kcal
Freezing time	2 h
Fan circulation rate	2.5 m3/s
Density of air	1.45 kg/m3
Weight of air circulated during freezing	
2.5 x 3600 x 2 x 1.45 =	26 100 kg
Specific heat of air	0.24 cal/kg °C
Average rise in air temperature 8000 ÷ (26100 x 0.24) =	1.28°C

Many of the faults of air blast freezers can be attributed to insufficient or non-uniform air flow over the product. Air must be directed to flow uniformly over the product and not merely be blow into the freezer space to find its own way to where it is required. Air will normally take the path of least resistance. Many of the faults of air blast freezers are due to the low resistance paths which allow air to be diverted from its main work - transfer of heat from the surface of the product.

Given a free choice, the designer should position the fan before the cooler. The cooler provides a relatively high resistance to air flow and this helps to even out the flow. Air leaving an axial fan is also imparted with a whirling motion and the fins of the cooler act as a flow- straightener.

However, if proprietary unit coolers are used the designer may have no choice. Unit coolers generally have lower capital costs then separate fans and coolers.

When air changes direction in the freezer, there are difficulties in maintaining uniform distribution, and air flow over the product may be variable (Figure 7). There are a number of ways of solving this problem by using vanes, baffles and plenum chambers. In Figure 7 the air is shown to be correctly distributed by using suitably designed and properly spaced turning vanes. The air may also be redistributed by means of baffles which are spaced so that the pressure resistance across the section results in an even flow. It is difficult to predict the exact pattern required for correct redistribution of the air, and to compensate for this the baffles are often made adjustable. This method adds to the total resistance of the system and may mean higher fan power and additional costs. The method however is very simple, allows for readjustment on site and therefore is well worth considering.

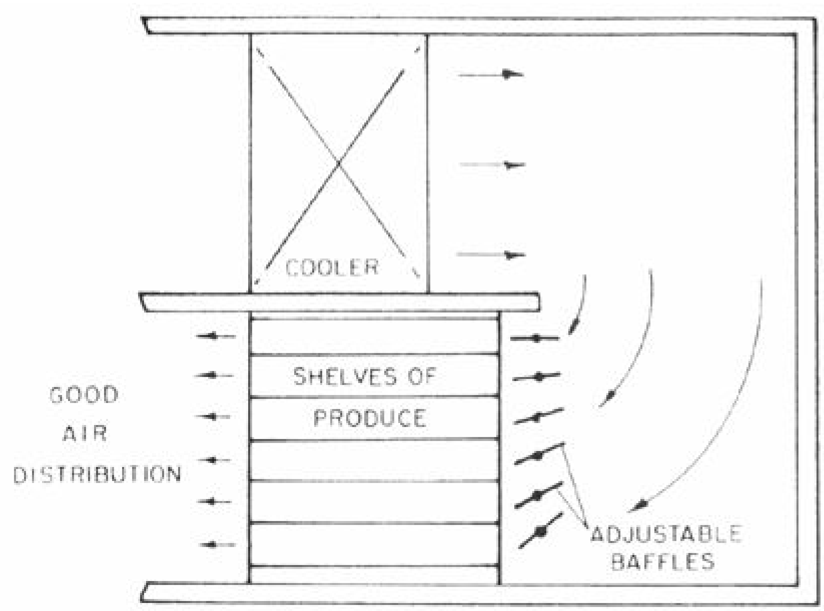


Figure 7 Good air distribution in a tunnel air blast freezer using adjustable baffles.

Nearly all air blast freezers operate with finned tube coolers. The fins greatly extend the surface for heat exchange, and the closer the fins the greater will be the surface area and the smaller the cooler unit. Moisture lost from fish during freezing and from air infiltrating into the cooler will eventually be deposited as frost on the cooler surface. If this frost eventually bridges the space between the fins, the effective cooler surface is then reduced, the rate of heat transfer will be reduced and the freezer temperature will rise. There will also be a greater resistance to air flow through the cooler and the air flow rate may be reduced.

Most of the water lost from the fish is lost during the early stages of freezing and in some freezer designs, this will mean a higher degree of frosting on some parts of the cooler than on others. This will effectively reduce the period of operation before a defrost is necessary. Frost build-up on the cooler is also more prolific on the front, upstream coils; therefore a cooler with a large frontal area will be able to operate longer before a defrost is necessary. The specified fin spacing may also be increased where there is likely to be a quick build-up of frost. A good freezer design should be able to operate for at least 8h before a defrost is required but a poor design may require defrosting every 2h.

Types of air blast freezer

There are many different designs of air blast freezer both for batch and continuous operation. Details are given of a number of types of air blast freezer in common use, with comment on their suitability for various products and methods of processing and also on their limitations.

Continuous air blast freezers

In this type of air blast freezer, the fish are conveyed through the freezer (on trucks or trolleys or they may be loaded on a continuously moving belt or conveyor) usually entering at one end and leaving at the other.

When trucks or trolleys are used, they are loaded at one end of the freezer and progressively moved along the freezer as additional trucks are loaded. Once the freezer is full, a truck has to be removed from the exit end before a fresh truck can be loaded. This batch-continuous operation must always allow the coldest air to flow over the coldest fish; otherwise fish which are well frozen will be subject to warmer air as new trucks are loaded. The movement of the trucks in Figure 8 is therefore in the opposite direction to the air flow in the freezing section. One difficulty with this type of freezer is that when the freezer is fully loaded, a whole row of trucks has to be moved at one time. This is particularly difficult at very low temperatures since special bearings and lubricants are required for the truck wheels and it is difficult to keep the trucks free of frost and ice. Trolleys have been suspended from overhead rails to overcome some of these difficulties but this equipment is cumbersome and still not easy to operate.

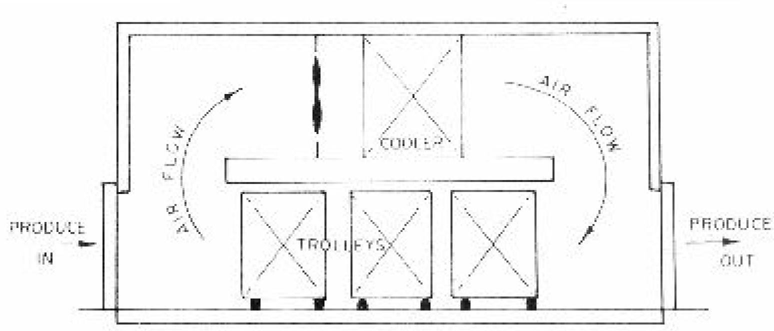


Figure 8 Batch-continuous air blast freezer with counterflow air circulation

To avoid moving trucks within the freezer, a batch-continuous freezer can be designed with a cross flow air arrangement and the freezers may then be loaded from the side as shown in Figure 9. Again in this freezer, once it has been fully loaded, a truck is removed before a fresh one is added. It is a simple matter to keep account of the loading sequence of the freezers by having hand-set clock dials above each entrance which will indicate the time the truck or trolley will be ready for unloading. This cross-flow arrangement allows a cooler with a large frontal area to be built, and frost is also deposited uniformly.

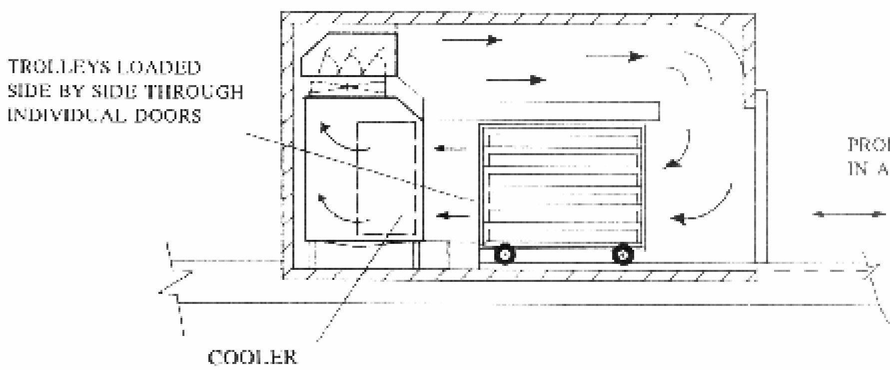


Figure 9 Batch-continuous air blast freezer with crossflow air circulation

Continuous air blast freezers using belts or conveyors for moving the product through the freezer can only be used if the product can be frozen quickly (Figure 10). It is unlikely that a product with a freezing time of more than 30 min would be suitable for this freezer. The reason for the limitation on freezing time is that the freezer will become too long and cumbersome if a long freezing time is required. The freezing time, the freezing requirement in kg/h and the loading density of the product on the belt determine the freezer dimensions.

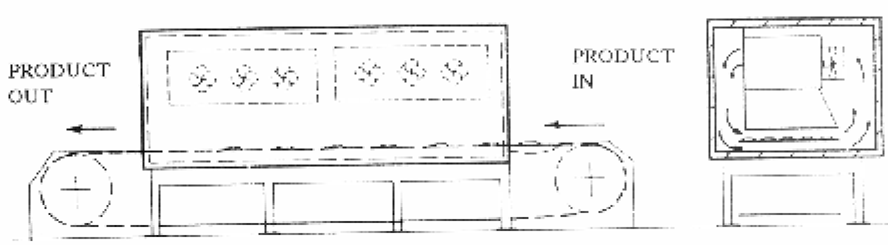


Figure 10 Continuous belt air blast freezer with crossflow air circulation (also constructed with counter current series flow air circulation)

The following example shows how this calculation is made:

Freezing requirement	200 kg/h
Freezing time	18 min
Load on belt 200 x 18 ÷ 60	= 60 kg
Belt loading density	6 kg/m^2
Belt width	1.2 m
Belt loading per unit length 6 x 1.2	= 7.2 kg/m
Belt length 60 ÷ 7.2	= 8.4 m

Allowing for loading and unloading of the fish outside the freezing space, the length of the freezer required for the above requirement would be about 11.4m.

The space required for a continuous belt freezer can be reduced if a double or triple belt is used (Figure 11), or if the belt is arranged in the form of a spiral (Figure 12).

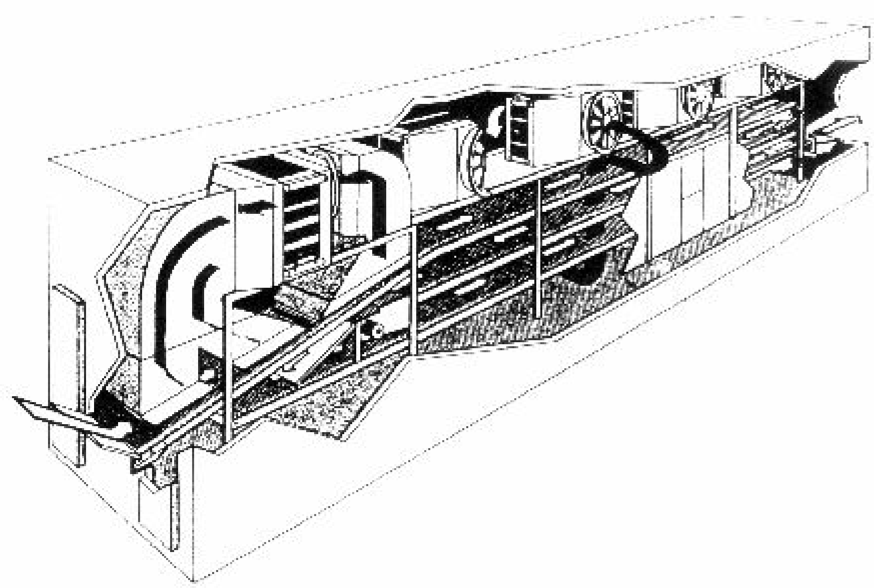


Figure 11 A triple belt air blast freezer

Partially frozen fish tend to adhere to open metal mesh belts and so do not transfer easily to another belt. Double belt and triple belt freezers are therefore more suitable for products such as battered and breaded fish portions, unless certain features are built into the design of the freezer. The semi-fludized freezer described later is a freezer specially designed for this method of operation. Spiral belt freezers are made in a variety of designs and are widely used for IQF products. Continuous belt freezers, Fig 12, generally have their own special problems. The belt has to be flexible, easily cleaned, non corroding, suitable for use in direct contact with food and should not interfere unduly with either the freezing time or adversely affect product quality. Stainless steel mesh link belts or chain link belts are mainly used for this purpose but they have certain disadvantages. Apart from being expensive, they affect the appearance of the product. If fish are loaded directly on the belt, the crinkled or indented appearance of the frozen product is not always acceptable. Open mesh belts can also give rise to difficulty when removing the product after freezing, and some weight loss may be incurred due to slight physical damage. Skin-on fillets call usually be removed quite easily but skinless fillets and fish portions can stick to the belt and cause unacceptable weight losses.

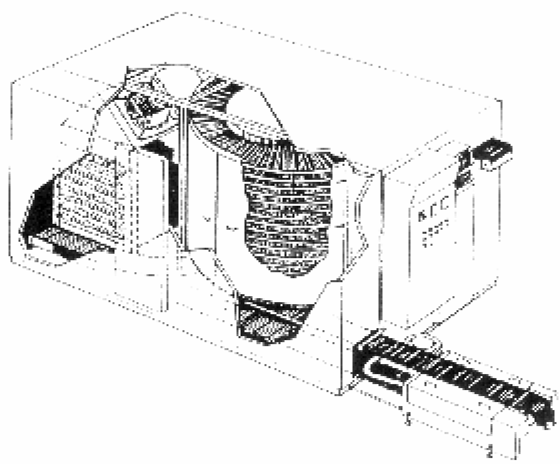


Figure 12 Continuous air blast freezer with the belt arranged in a spiral

Plastic belts made in the form of interlocking links have been used in some continuous freezers. These belts, add about 10 percent to the freezing time. They suffer from the same indentation problems as metal mesh belts but transfer is generally easier. However, their larger mesh makes them unsuitable for small products. If they are only used for the initial part of the freezer, the fish can be surface-hardened and then be transferred to a stainless steel belt. This would allow a two-belt operation in the freezer. In spite of these often minor difficulties in obtaining an ideal belt for continuous belt freezers, many are successfully operated for freezing a variety of products.

Continuous belt freezers can be constructed with either cross-flow or series-flow air circulation. In the series-flow arrangement, the direction of air flow must be such that the coldest fish meet the coldest air. The design of the belt entry and exit must keep the rate of air infiltration to a minimum.

In a continuous freezer, there is no scope for rearranging the volume or space for different products. The belt speed, however, is usually variable and this can be adjusted to accommodate different product freezing times. The capacity of a continuous freezer can therefore vary considerable depending on the product being frozen and its freezing time Table 4 is a freezer capacity list supplied by the manufacturer of one type of continuous freezer and it clearly shows there is a wide variation depending on the type of product being frozen.

Table 4 Variations in the capacity of a continuous freezer

Product	**Product thickness (mm)**	**Capacity (kg/h)**
Plaice fillets	10	100
Cod fillets	18	85
Shrimp (whole)	9	55
Shrimp (meats)	8	150

Another important consideration when using a continuous air blast freezer is whether the freezer will be used continuously. A continuous freezer left in operation but not fully loaded could give rise to higher freezing costs per kg of product frozen.

Batch air blast freezers. Batch air blast freezers use pallets, trolleys or shelf arrangements for loading the product. The freezer is fully loaded, and when freezing is complete, the freezer is emptied and reloaded for a further batch freeze. Apart from this difference in mode of operation, the batch freezer gives rise to bigger fluctuations in the refrigeration load than continuous or batch-continuous freezers (Figure 13).

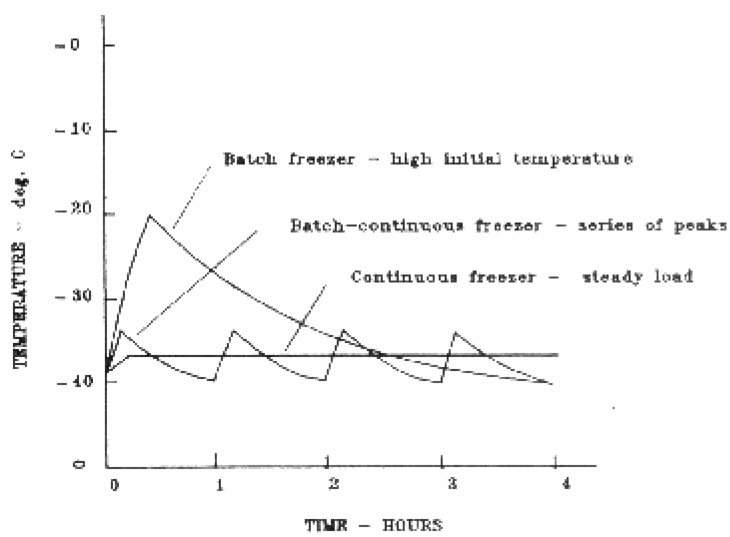


Figure 13 Freezer operating temperatures for different types of air blast freezer

This large fluctuation in refrigeration load means that the refrigeration system will require special control arrangements to cater for the variations. Capacity control or a multiunit system can be used or a competent engineer can manually control the system to match the load. Some refrigeration systems are also better suited to this type of variable load application than others.

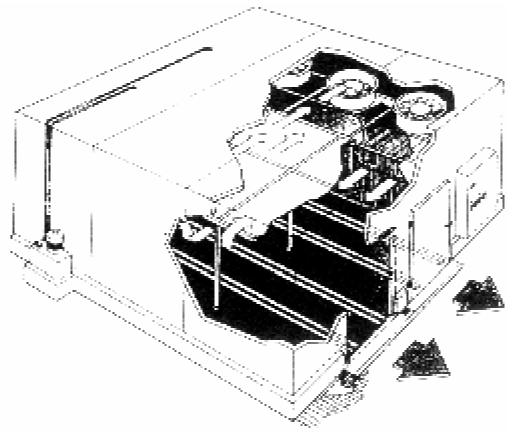


Figure 14 Factory assembled air blast freezer with push through tunnel for two rows of trucks

It is seldom that fish processing can be arranged so that all the fish can be loaded into a batch freezer at the same time. Therefore, if each trolley or pallet is loaded as and when it is ready, the refrigeration peak load will be considerably reduced. This will make the operation similar to a batch-continuous process, but again, care should be taken not to place warm fish upstream of a partly frozen product.

The freezer shown in Figure 14 is a batch tunnel freezer with a push-through arrangement for two lines of trucks. If this design of freezer was used with a batch-continuous operation, warm fish might loaded upstream of partly frozen fish. This freezer should therefore only be fully loaded and operated as a batch freezer.

Another batch freezer arrangement is shown in Figure 15. In this model, the trolleys are loaded from the side of the freezer and the air flows across the three trolleys in line.

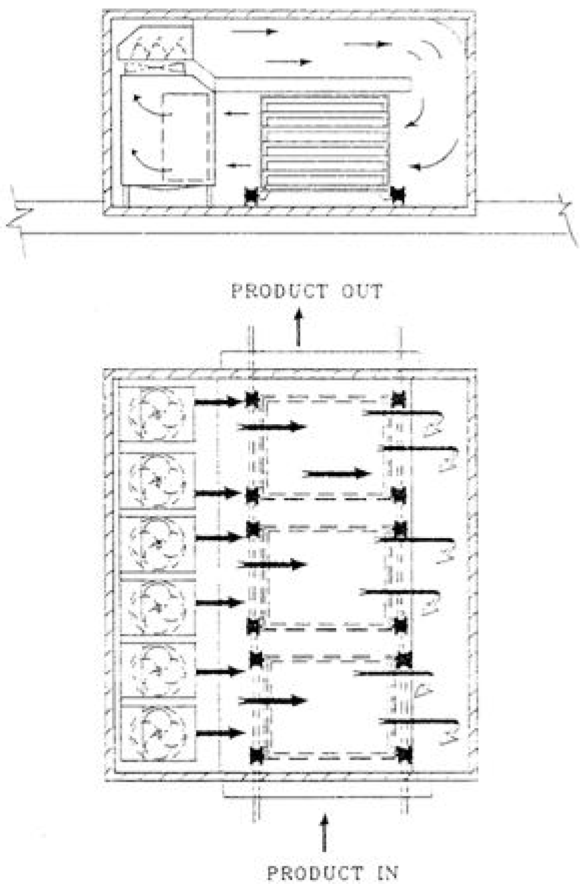


Figure 15 Batch air blast freezer with side loading and unloading

In some air blast freezers, the cooling coil can be at the same level as the working section (Figure 16). This is a fairly good arrangement since the cooler acts as a diffuser and evens out the air flow immediately before it is directed over the fish.

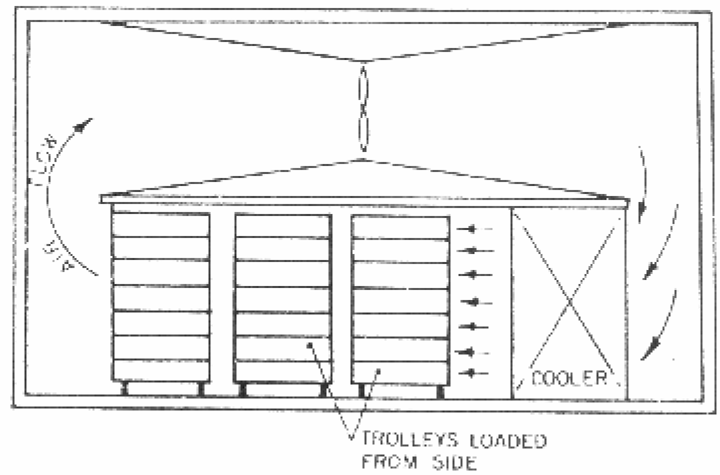


Figure 16 Air blast freezer arrangement showing the cooler acting as an air diffuser

It can be seen that there is a wide variety of air blast freezer arrangements to suit the requirements of different layouts, operating methods and freezing systems. Some air blast freezer designs are not suitable and some of the faults that give rise to long freezing times are shown in the series of diagrams (Figures 17 to 19).

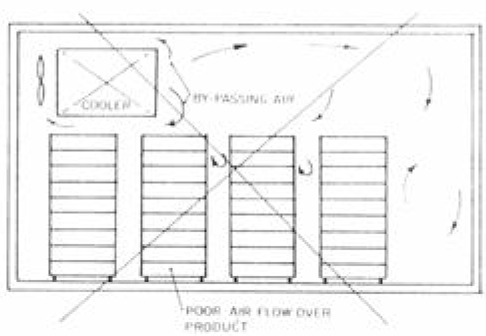


Figure 17 Room freezer with poor air flow over the surface of the product

The freezer arrangement show in Figure 17 is typical of many room freezers that are built. The cooler unit may be mounted at roof level, as shown, or may be a floor-mounted unit. There is no special means of directing the air over the fish and therefore it generally tends to swirl about in the empty spaces in the room and not flow between the shelves or trays loaded on the pallets. The reason for this is that the air takes the path of least resistance and does not readily flow through the comparatively narrow spaces between the product. The air must be ducted so that it has no alternative but to flow over the fish. This is an extremely important feature of a tunnel air blast freezer. Many of the diagrams shown earlier have good layouts which show this.

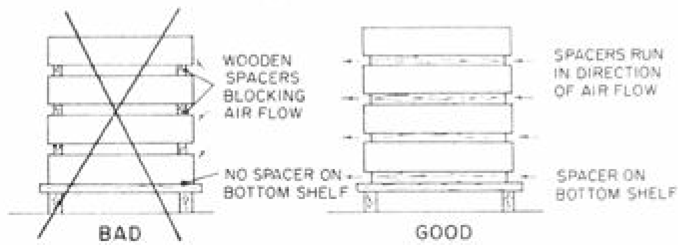


Figure 18 Bad and good use of spacers when stacking produce for freezing

The incorrect method of loading the pallet shown in Figure 18 seems hardly credible but is often used in commercial practice. The mistake can easily be made by an operator who does not observe the direction in which the battens on the base of the pallet are running. Some directional marking on the top of the pallet base may be advisable. The effect of omitting spacers totally is to increase the effective thickness of the product resulting in an unacceptable increase in freezing time.

Poor air flow over the fish but good air flow through the cooler will result in a freezer operating at a temperature below the design value. Poor freezing conditions therefore often mean a low product loading and the air temperature will fall below the design value.

Fluidized and semi-fluidized freezers. One type of air blast freezer fluidizes the product with a strong blast of air from below (Figure 19). The product then behaves like a fluid and when poured into the trough at the input, it moves along the length of the freezer without mechanical assistance and over-flows at the output. This type of freezer has been used successfully for such products as garden peas which are readily separated and kept apart but, as yet, the freezer has not had a wide application for fish or fishery products. Small cooked and shelled shrimp is one of the few fish products that has been successfully frozen by this method.

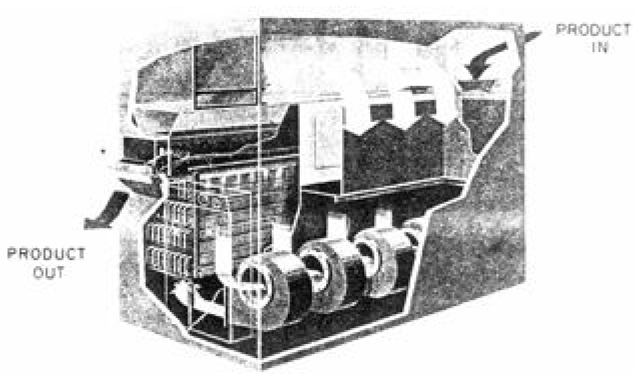


Figure 19 A fluidized flow air blast freezer

A modified fluidized freezer which may be termed a semi-fluidized freezer has also been used for fish-freezing applications (Figure 20). A conventional conveyor is used but at the early stages of freezing, sufficient air is blown from below the belt to agitate the product and ensure that individual portions remain separate until the outer surface has been hardened. This type of freezer can be used with a double belt, with transfer from one to the other midway through the freezing process.

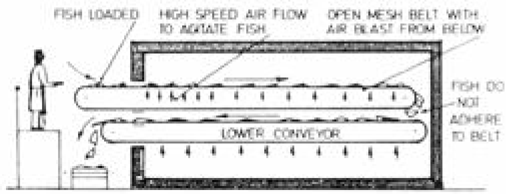


Figure 20 **Semi-fluidized flow freezer with double belt**

There is however some difficulty in judging the correct air flow to produce the slight agitation required and a fixed flow rate is not suitable if a variety of products are to be frozen. Also, with many products there still remains some difficulty in making the transfer from one belt to the other.

Loading a batch air blast freezer. Because of their versatility, batch air blast freezers are often misused by operators who do not realise their freezing limitations.

The size of the refrigeration plant is fixed to match a given freezing requirement at the designed freezer operating condition. However, if the freezer is used for freezing other products which have different space requirements and freezing times, the freezer operating condition will change. Depending on the original design specification, the freezer may therefore be overloaded or underloaded by a change in product.

The examples in Table 5 show what happens when products of different freezing time are loaded in a batch freezer.

Table 5 Optimum loading of a batch air blast freezer

Product	Plant Capacity (t/h)	Load per freeze (t)	Freezing time (h)	Loading frequency	Freezing rate (t/h)
A	1	2	2	Every 2 h	1
B	1	1	1	Every 1 h	1

In both examples in Table 5, the freezer is correctly loaded since the product load matches the plant capacity in the weight of fish that can be frozen in 1 h.

The above freezer would therefore be designed to hold 2 t of product A and when product B is frozen, only 1 t will be loaded and the product distributed to give uniform air flow. If however, 2 t of product B are loaded into the freezer at one time, the refrigeration plant will be overloaded.

This is probably one of the most difficult aspects of freezer operation to explain clearly but in simple terms it means no matter how spacious your freezer and how much product can be loaded, you cannot freeze more fish than the refrigeration plant will allow.

Good performance in batch air blast freezers is obtained by freezing the product in open trays without wrapping. Trays used in air blast freezers should transfer heat readily, be easily emptied and also be robust. Normally they are required to produce a pack that is of regular shape but when the product allows their use, trays with a taper on the sides of about one in eight can be emptied by applying a cold water spray on the underside for a few seconds and then giving a gentle tap on the edge. Trays used in this manner should never be filled above the tray edge or the product will be damaged during release.

Cleaning and drying of trays before re-use is necessary to maintain a high standard of hygiene. Where the rate of production justifies the cost, an automatic tray washer may be installed.

The reader will no doubt find other types of freezer available on the market which have not been mentioned. The design of many of these is based on combinations of two or more of the basic methods described. For instance, a variety of freezers make use of both contact and air blast freezing techniques. Other freezers may be identical in every respect with one of the methods described, but may use some other liquid, gas or contact method for heat transfer. These freezers will be seen to be similar to one of the types described and will therefore have the same advantages and disadvantages.

4.1.2 Plate freezers

Plate freezers and air blast freezers are the types of freezer most commonly used for freezing fish in industrial countries. Plate freezers do not have the versatility of air blast freezers and can only be used to freeze regularly shaped blocks and packages.

Plate freezers can be arranged with the plates horizontal to form a series of shelves and, as the arrangement suggests, they are called horizontal plate freezers (HPF) (Figure 2 1). When the plates are arranged in a vertical plane they form a series of bins and in this form they are called vertical plate freezers (VPF) (Figure 22).

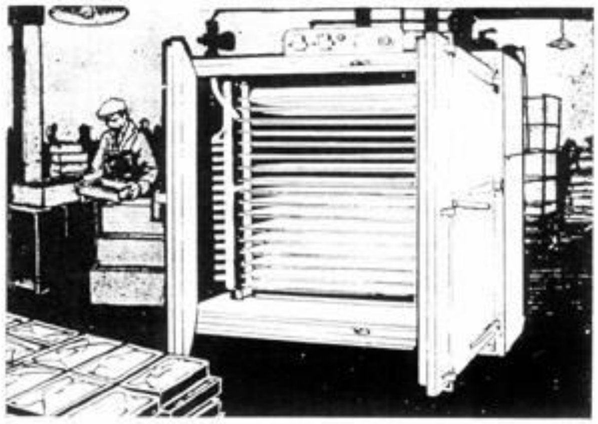


Figure 21 Horizontal plate freezer

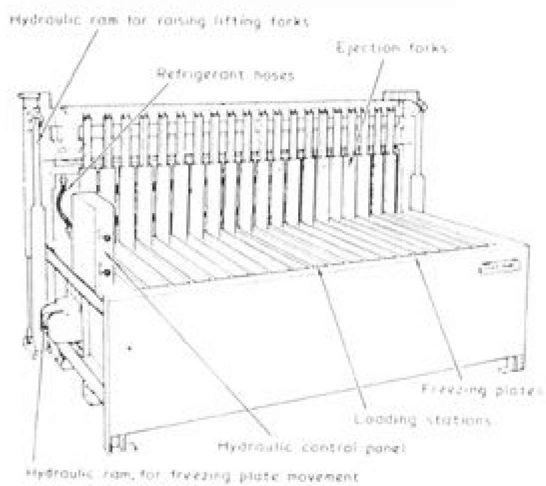


Figure 22 Twenty-station vertical plate freezer with top unloading arrangement

Modern plate freezers have their plates constructed from extruded sections of aluminium alloy arranged in such a manner as to allow the refrigerant to flow through the plate and thus provide heat transfer surfaces on both sides (Figure 23). Plate freezers are fitted with hydraulic systems which move the plates together and apart.

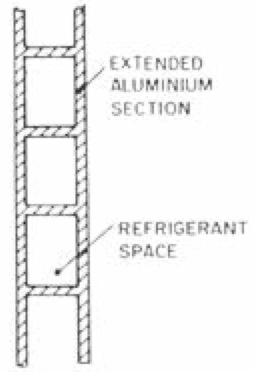


Figure 23 Construction of plates used in contact plate freezers.

Horizontal plate freezers. The two main uses for this type of freezer are the freezing of prepacked cartons of fish and fish products for retail sale and the formation of homogeneous rectangular blocks of fish fillets, called laminated blocks, for the preparation of fish portions. The thickness of package or block frozen is 32 to 100 mm and the freezer can readily adapt from the thicker to the thinner package provided the range required is made known to the supplier at the time of purchase. There is no direct contact between the fish and the freezer plates when freezing by this method since the fish is always packaged before freezing. If the operator is also careful not to spill water on the plates during loading and unloading, the freezer may be operated with only a light brush between each freeze to remove surface frost. The door may be left open overnight to allow the plates to defrost fully after being hosed down with warm water. A hot gas defrost arrangement is the quickest method to defrost an HPF, but even with this method, it may take 30 min or more. The defrosted plates must be completely free from frost or ice and dried before the freezer is used again.

Horizontal plate freezers intended to be operated with a hot gas defrost are fitted with additional pipework which allow the cold refrigerant to be discharged from the bottom of the freezer as the defrost proceeds. Without this special pipework and operating valves, a hot defrost would clear the top plates only and leave the cold refrigerant in the plates at the lower levels. As in all hot gas defrost systems, the refrigeration system must have an adequate load to provide sufficient hot gas for an effective defrost. This system would therefore be better applied when there are two or more freezers operated from a common refrigeration system and each freezer will then be defrosted in turn while the others are in operation.

An HPF will only operate correctly if good contact is made on both the top and bottom surfaces of the pack or tray to be frozen. The faults shown in Figure 24 are some of those which make freezing times longer than necessary. If the product is frozen from one side only due to poor contact on the upper surface, the freezing time could be three or four times as long as the time achieved with good contact on upper and lower surfaces. The plates of the HFP are closed by means of a hydraulically operated piston to make contact with the upper surface of the product. The plate pressure applied to the product can easily be varied between 70 x 280 mbar to suit the product and is increased by a factor of two as the fish expands during freezing.

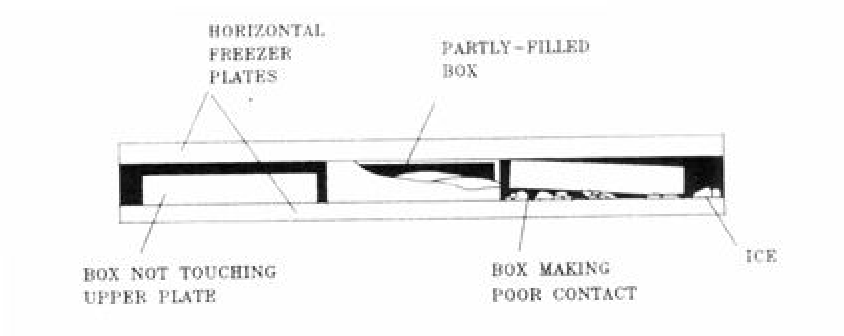


Figure 24 Some reasons for poor performance in a horizontal plate freezer

Vertical plate freezers. The main advantage of this type of freezer is that fish can be frozen in bulk without the requirement to package or arrange on trays. The plates form what is in effect a bin with an open top and fish are loaded directly into this space. This type of freezer is therefore particularly suitable for bulk freezing and it has also been extensively used for freezing whole fish at sea. The maximum size of block made by this method is usually 1 070 mm x 535 mm. Other dimensions however, can be produced in which the thickness can vary from 25 to 130 mm, but will depend on the fish to be frozen. The maximum weight and dimensions are also limited by the physical effort required from the operator to lift the block, and by the ease with which it can be handled so that damage to the fish is kept to a minimum.

In most cases, fish can be loaded between the plates without wrappers and water need not be added either to strengthen the frozen block or improve the contact with the plates. Fish such as cod and haddock produce compact blocks with a block density of approximately 800 kg/m^3 .

With fatty fish such as herring, it has been found advantageous to use wrappers and add some water to fill the voids in the block. Fatty fish do not form blocks which are as firm and strong as blocks made from lean fish especially during seasons when the oil content of the fish is high. Water added helps to strengthen the block, protects the fish during subsequent handling and reduces the effects of dehydration and oxidation during cold storage. Well formed, rigid blocks are particularly important when freezing at sea. The product may be handled under particularly adverse operating conditions and poorly formed blocks, prone to breakage, would result in a high percentage of loose fish. Machine filleting or splitting of the fish for instance, may be difficult if fins and tails are broken. Wrappers have been used when freezing fatty fish in VPFs to protect the exposed fish on the outside of the block. A wrapper that has been found suitable for this purpose is a single layer paper bag, coated internally with polyethylene, and shaped to fit the space between the freezer plates. Wrappers made from polyethylene with a specially roughened outer surface to reduce slippage have also been used.

Fish frozen in wrappers require a longer freezing time due to the insulating properties of the wrapping material. Some types of wrapper would have a considerable effect on freezing time but in sea trials the material described did not increase the freezing time by a significant amount.

Vertical plate freezers are defrosted to release the blocks of fish after each freeze. Fish are in direct contact with the plates and the force required to release the blocks without a defrost could be excessive and result in plate damage. The defrost time need not exceed 3 or 4 min if a suitable supply of defrost gas or hot liquid is available. If a primary refrigerant is used in the plates, a hot gas defrost is generally used. Where there is a multiple installation, the freezers are defrosted in turn with the other units in operation providing the necessary refrigeration load for the compressor. When a secondary refrigerant is used, a reservoir of hot liquid has to be maintained and pumped through the plates to displace the cold liquid present. With this arrangement, it is possible to return the bulk of the cold liquid to the low temperature reservoir at the start of defrost, and also return the warm defrost liquid to the hot liquid reservoir for reheating at the start of the next freeze. This arrangement reduces the quantity of liquid interchanged at each defrost but provision must be made to maintain the liquid charges in both the cold and hot systems at the correct level.

Defrost arrangements such as those described lead to more complicated and expensive refrigeration pipework. Attempts have been made to assist the release of the blocks by coating the plates with a low friction plastic material so that a defrost was unnecessary. Although this worked reasonably well, a defrost was found to be essential to prevent fish sticking to the plates which are at a temperature below 0°C, and thus failing to form a compact block. Freezing times are longer due to the poor contact being made with the plates and because of the lower block density, more storage space is required for a given quantity of fish. The results of some tests that clearly show this difference in loading fish between warm plates and plates at refrigerated temperatures are given in Table 6. The first two results in the table were obtained when the fish were loaded between defrosted plates. The last results, which gave low density blocks and longer freezing times, were obtained when fish were loaded between cold plates.

Table : Variation of freezing time with density and contact area

Block density (kg/m^3)	Contact area (%)	Freezing time (h)
800	48	3.0
780	45	3.0
650	29	3.8
650	21	4.0

Vertical plate freezers can be made with top, side or bottom unloading of the blocks. Generally, top unloading models are preferred since the block is lifted clear of the plates and presented at a suitable height for handling by the freezer operator.

Vertical plate freezers may be supplied in units with up to 30 stations and some thought has to be given to the selection of the correct unit size for each particular requirement. An installation may consist of a number of freezer units which are loaded in rotation. If 12 units are used, and the freezing cycle takes 4h, 1 unit will be defrosted, unloaded and reloaded every 20 min. If this frequency of operation fits in with a suitable work rate and the fish can be handled in and out of the freezers in this time, then the 12 units are suitable for this particular application. Individual units should not be partially loaded, freezing commenced and the rest of the unit loaded later. A further defrost would be necessary and this would reheat the partially frozen fish. The freezer unit size should therefore be matched to the rate at which fish becomes available for freezing. This will ensure that fish are not kept waiting for the unit to be fully loaded and that the freezers are not operated with partial loads for a good deal of the time. If, however, the fish supply rate and the freezer capacity are not matched, it is better to freeze a partial load of fish rather than wait for a full load. Fish can deteriorate quickly at this stage of processing, particularly if it is not chilled and also remains ungutted.

Automatic plate freezers. This type of freezer freezes fish in cartons and is a continuous form of the HPF. Automatic plate freezers are specially designed for a processing line; and units with capacities of up to 2 t/h are available. Their main advantage is that they save the labour required for the loading and unloading of batch plate freezers. However, when this labour saving is related to the total labour requirement for packing and other operations, the saving is often not significant.

Liquid nitrogen freezer.

In this freezer, the product is brought into direct contact with the refrigerant (Figure 26).

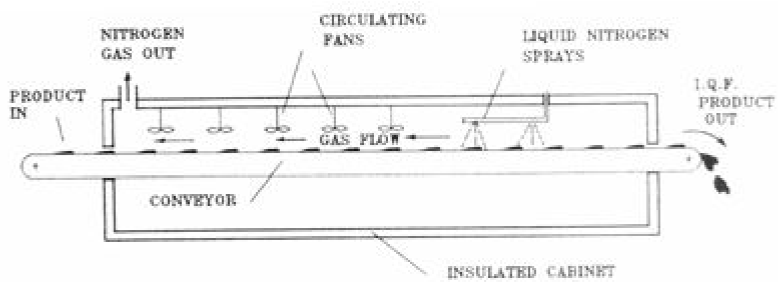


Figure 25 Liquid nitrogen freezer

The fish on the stainless steel conveyor belt initially come into contact with the counter current flow of nitrogen gas at a temperature of about -50°C. As the fish. progress through the precooling stage of the freezer, the gaseous nitrogen partially freezes the fish and up to 50 percent of the product heat is extracted. The product then passes below the liquid spray where freezing is completed by the boiling liquid. The last stage in the freezer provides a few minutes for the fish temperature to reach equilibrium before the fish are discharged.

The main advantage of the liquid nitrogen freezer LNF is that freezing is very quick and the physical size of the freezer is correspondingly small. The freezer is operated without the need for compressors, condensers or coolers; therefore maintenance requirements are minimal and the power required to operate the freezer is very low. Liquid nitrogen must be retained in a vacuum insulated pressure vessel with continuous venting to keep the contents cool and the internal pressure down. One estimate given is that 0.5 percent of the stored contents is lost each day by this method. In addition, about 10 percent has been estimated to be lost during the transfer of liquid from the tanker to the storage vessel although the customer is not charged directly for this loss. This method of freezing is more expensive than most others, being up to four times more costly than conventional air blast freezing. Although the freezer is small and there is no refrigeration machinery requirement, storage space and access is required for the liquid nitrogen tank. The main disadvantage of this type of freezer in most developing countries is that delivery of nitrogen could be expensive and there may be no guarantee of regular supplies.

Carbon dioxide freezer. This type of freezer has been known for a long time and uses liquefied carbon dioxide which is usually a by-product of another industrial process.

The liquefied carbon dioxide is injected into the freezer and comes into direct contact with the product. In this respect, it is similar in operation to an LNF. With large units, it is economically feasible to recover the carbon dioxide and about 80 percent of the refrigerant used can be reliquefied. Carbon dioxide can be contained in insulated vessels at a moderate pressure and losses during storage are therefore negligible. High levels of carbon dioxide in the factory air are dangerous, therefore a freezer using this refrigerant must be vented and the gas discharged outside the building. Again, as is the case with other types of freezer which rely on regular supplies of refrigerant, carbon dioxide freezers would not be suitable for use in remote areas.

Immersion freezers. By using a liquid for the removal of heat from a product, favourable freezing rates can be achieved. Liquid can remove more heat per unit volume than gas (eg. air) but, like gas, a stagnant boundary layer is formed which slows the transfer of the heat. Liquids used for heat transfer must therefore be circulated over the product. Difficulties due to high viscosity often arise when a low temperature liquid is used.

Many liquids that have suitable refrigeration and heat transfer properties are not allowed to be used in direct contact with food. Those that are available are limited in their use because they may cause changes in texture and taste in the food with which they are in direct contact. Immersion in sodium chloride brine was one of the very first methods used to freeze fish since it was a logical progression from the method used to freeze block ice. Brine immersion freezing may still be used for such fish as tuna which are intended to be marketed as a canned product. The fish are large and have a thick skin; therefore the uptake of salt is not great. The little salt that is absorbed is not detrimental to the canned product since salt is usually added to the product before canning in any case. For many other fish freezing applications, adverse effects on texture and taste of the fish due to the absorption of brine have proved to be unacceptable. Even without excessive brine uptake, the surface of the fish will be coated and handling the product after freezing is difficult and messy. Some fish products such as shrimp have been frozen in syrup and salt solutions, and sugar and salt solutions but again there is some degree of absorption with changes in flavour.

Freezing operating temperatures

Bearing in mind that the freezer must reduce the temperature of the product to the intended temperatures of storage, freezers should operate at temperatures which allow this to be accomplished under the most favourable economic conditions (Table 7). When selecting the appropriate freezer operating temperatures, account should also be taken of cost of equipment, operating costs, space requirements, quality considerations and other factors. In some types of freezer, the temperature is fixed by the method of operation, whereas in others, such as air blast and plate freezers, there is scope for varying the temperature to suit any particular requirement.

The following table gives some typical operating temperatures for various freezers:

Table : Freezer operating temperature

Type of freezer	Operating temperature (°C)
Batch air blast	-35 to -37 air
Continuous air blast	-35 to -40 air
Batch plate	-40 refrigerant
Continuous plate	-40 refrigerant
Liquid nitrogen	-50 to -196 refrigerant
Liquid carbon dioxide	-50 to -70
Sodium chloride brine	-21 refrigerant

Space requirements for freezing

The space required for a freezer obviously depends on the capacity and type of freezer. Some factors affecting total freezer space required are given below.

It can generally be assumed that, for a given capacity requirement, the quicker a freezer can freeze the product the smaller will be the physical space required. Freezer space, including that required for loading and unloading the product, is only one factor to be taken into account when calculating the total area requirement. Distinction should be made between floor space required within a building and that required in an open yard outside the covered factory area. Space is required for refrigeration machinery and access for maintenance but for small units, the machinery may be located above or below the freezer unit and will not add to the floor area. With liquid nitrogen and carbon dioxide freezers, no mechanical refrigeration is required, but storage must be made available for the refrigerant. In addition, an area has to be made available for manoeuvring the tanker supplying the refrigerant.

A working area is also required for handling and possibly packaging the product before and after freezing. Trolleys and pallets also require space and if they are doubled up to allow for a rotation system to be used, the floor area occupied by this equipment can be considerable. Packaged products also require a dry area for storing the packaging material which is often printed or marked to identify the product and the company, and this often means ordering in larger quantities.

Total area can therefore be far in excess of the actual freezer space and comparisons made on the basis of this total requirement are often completely different from those made when the freezer unit only is considered.

Labour requirement for freezing

Low labour requirements for loading and unloading freezers are often quoted by manufacturers to impress potential customers. These requirements, however, can be misleading. Freezers which process packaged fish products without the need for physically handling the fish in and out of the freezer unit can rightly be said to require the minimum of labour. Much of the labour may have been transferred to another part of the process. Requirements should therefore be assessed as a whole and savings in the freezer operation may only be identified by studying what has to be done before, during and after freezing.

Few fish products, when dumped on a conveyor belt, can sort themselves out and be loaded into a freezer. Claims for freezers that can be operated in this way are usually based on experiences gained with other food products, such as fruit and vegetables.

Calculation of freezer refrigeration load

The individual items to be taken into account in a refrigeration load calculation depend on the type of freezer. It would be impossible to include all the eventualities in one sample calculation; therefore, a relatively simple one is given below for a HPF and some notes have been added to help with other freezer calculations.

Specification

- 50 mm thick trays of fish each weighting 7.5 kg (6 trays per plate)
- Capacity (32.4 t/day)
- Secondary refrigerant temperature (-40°C)
- Evaporating temperature (47°C)
- Fish initial temperature (10°C)
- Freezing time (1 3/4 h)
- Total cycle time including load/ unload/ defrost (2h)

Load calculation

I Number of freezers

32.4 t/day = 32 400 kg/day

32400 ÷ 7.5 = 4320 blocks/day

24 ÷ 2 = 12 cycles/day

4320 ÷ 12 = 360 blocks/cycle

II Fish load

32400 ÷ 24 = 1 350 kg/h

Enthalpy at 10°C = 85.9 kcal/kg

Enthalpy at -30°C = 4.6 kcal/kg

Change in enthalpy = 81.3 kcal/kg

Heat to be removed = 1 350 x 81.3 = 109 755 kcal/h

The change in enthalpy value (the heat to be removed from the fish during freezing) used in the calculation is obtained from Table 29 or Figure 49 and this is a true measured value for cod.

An approximate figure can also be calculated by using the following values:

a. Specific heat of fish above freezing, 0.9 kcal/kg °C
b. Latent heat of the fish, 60 kcal/k
c. Specific heat of fish below 0°C, 0.4 kcal/ kg °C

Using these values, the above calculation for fish refrigeration load would be:

Heat to remove on cooling to 0°C

1 350 x 0.9 x 10 =12 150 kcal/h

Latent heat to remove 1 350 x 60 =81 000 kcal/h

Heat to remove on cooling to -30°C

1 350 x 0.4 x 30 =16 200 kcal/h

Total heat to remove from fish **109 350 kcal/h**

Total refrigeration requirement with allowances:

Method I - Add 30% = 109 744 x 1.3 =142 681 kcal/h

Method II - Assume 18 h/day running

109 755 x 24 ÷ 18 **=146 340 kcal/h**

These methods give nearly the same allowance and both calculations are only used here to show the reader how these refrigeration allowances can be applied by different designers.

In the above example, it is the freezing cycle time that is used in the calculation, not the actual freezing time of the block of fish. Account has therefore been taken of the time it takes to load and unload the fish and any minor delays. This time is therefore more realistic when calculating freezer size.

The calculation of fish load gives the refrigeration requirement to freeze the fish only. Depending on the type of freezer used, other heat loads have to be taken into account and added to this value to determine the total refrigeration requirement. Some of these additional heat loads are:

- Fan heat
- Pump heat from circulating pump
- Heat leak through freezer insulation
- Heat load due to pallets, trays, trolleys, etc.
- Head load due to a defrost procedure
- Heat load due to air infiltration
- Heat load due to internal lighting

Once the total load has been calculated, a factor is added which will take care of peak loading, and eventual deteriorating of the freezer and refrigeration equipment. There are no fixed rules for applying this operating factor since it will vary with the equipment and type of operation. Only experience can be used to make a fair judgement but, if no expert guidance is available, applying the factor of only 18h running time in every 24h, shown in the calculation, should make adequate provision in most cases.

Refrigeration capacity is sometimes quoted in terms of the power of the condensing unit's electric motor. There is such a loose relationship between them, that motor power is at best only a very rough guide. Refrigeration capacity is sometimes quoted in terms of kcal/day or quantity of fish frozen per day without specifying what is meant by a day; is it 24h or is it a working day of 8h? In order to avoid confusion, capacity should be quoted as an hourly rate in kcal/h and it should be made clear whether this is the gross capacity of the condensing unit for all duties or the net heat extraction rate available for freezing the fish only. If there is likely to be confusion, both the gross and net values should be given.

Another common error is to ignore the intended operating conditions when quoting the refrigeration capacity. It is important that compressor capacities should not be quoted at standard rating conditions or any other unrelated condition. The following additional information should also be specified by the contractor:

Refrigeration machinery:

- Number and type of compressors
- Compressor operating conditions
- Total refrigeration capacity
- Refrigeration capacity of each compressor in kilo calories per hour at design condition
- Power of compressor motors in Watts or kilowatts
- Maximum electrical power requirement in Watts or kilowatts
- Compressor safety arrangements
- Condensers, number and type
- Water consumption in cubic metres per hour
- Circulating pumps for condenser
- Fan power requirements for condenser
- Sketch of machinery layout showing total space required

Refrigeration system:

- Refrigerant used
- Type of system
- Initial refrigerant charge in kilograms
- Power of circulating pumps for refrigerant
- Standby arrangements, if any
- Method of temperature control, if any
- Temperature control limits

Refrigerated mobile vans

Cold chain-A **cold chain** or cool **chain** is a temperature-controlled **supply chain**. An unbroken **cold chain** is an uninterrupted series of refrigerated production, storage and distribution activities, along with associated equipment and logistics, which maintain a desired low-temperature range. It is used to preserve and to extend and ensure the shelf life of products, such as fresh agricultural produce, seafood, frozen food, photographic film, chemicals, and pharmaceutical drugs. Such products, during transport and when in transient storage, are sometimes called **cool cargo**. Unlike other goods or merchandise, cold chain goods are perishable and always en route towards end use or destination, even when held temporarily in cold stores and hence commonly referred to as cargo during its entire logistics cycle.

Uses

Cold chains are common in the food and pharmaceutical industries and also in some chemical shipments. One common temperature range for a cold chain in pharmaceutical industries is 2 to 8 °C (36 to 46 °F). but the specific temperature (and time at temperature) tolerances depend on the actual product being shipped. Unique to fresh produce cargoes, the cold chain requires to additionally maintain product specific environment parameters[1] which include air quality levels (carbon dioxide, oxygen, humidity and others), which makes this the most complicated cold chain to operate.

This is important in the supply of vaccines to distant clinics in hot climates served by poorly developed transport networks. Disruption of a cold chain due to war may produce consequences similar to the smallpox outbreaks in the Philippines during the Spanish–American War.[5]

There have been numerous events where vaccines have been shipped to third world countries with little to no cold chain infrastructure (Sub-Sahara Africa) where the vaccines were inactivated due to excess exposure to heat.[citation needed] Patients that thought they were being immunized, in reality were put at greater risk due to the inactivated vaccines they received. Thus great attention is now being paid to the entire cold chain distribution process to ensure that simple diseases can eventually be eradicated from society.

Traditionally all historical stability data developed for vaccines was based on the temperature range of 2–8 °C (36–46 °F). With recent development of biological products by former vaccine developers, biologics has fallen into the same category of storage at 2–8 °C (36–46 °F) due to the nature of the products and the lack of testing these products at wider storage conditions.

The cold chain distribution process is an extension of the good manufacturing practice (GMP) environment that all drugs and biological products are required to adhere to, enforced by the various health regulatory bodies. As such, the distribution process must be validated to ensure that there is no negative impact to the safety, efficacy or quality of the drug substance. The GMP environment requires that all processes that might impact the safety, efficacy or quality of the drug substance must be validated, including storage and distribution of the drug substance.

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Cold chains need to be evaluated and controlled:

- Carriers and logistics providers can assist shippers. These providers have the technical ability to link with airlines for real time status, generate web-based export documentation and provide electronic tracking.
- The use of refrigerator trucks, refrigerator cars, refrigerator ships, refrigerator containers, and refrigerated warehouses is common.
- Shipment in insulated shipping containers or other specialised packaging.
- Temperature sensors may need to be National Institute of Standards and Technology (NIST) traceable depending on the body monitoring the cold chain.
- Documentation is critical. Each step of the custody chain needs to follow established protocols and to maintain proper records. Customs delays occur due to inaccurate or incomplete customs paperwork, so basic guidelines for creating a commercial invoice should be followed to ensure the proper verbiage, number of copies, and other details.

During the distribution process one should monitor that process until one builds a sufficient data set that clearly demonstrates the process is in compliance and in a state of control. Each time the process does not conform to the process, the event should be properly documented, investigated and corrected so that the temperature excursion do not occur on future shipments. Any anomaly is thus considered to be a Non Conformance and should be assigned as a trackable event. The event must be reported immediately when it is identified and it is the expectation of the FDA that all adverse events be documented and investigated. The investigation should be completed in a timely manner and must come to some form of a "root cause" and also some form of "corrective action". The system may potentially stay in a Validated state if the root cause identifies that a Standard Operating Procedure (SOP) was not followed or followed incorrectly. If however a SOP needs to be changed or modified, then the system must be re-validated to demonstrate that the change to the SOP maintains the integrity of the process/system. A Non-Conformance may also generate a Corrective Action Preventative Action (CAPA), again, a documented process to make corrective or preventative actions to SOP's and other documents.

Non Conformances and CAPA's are an essential part of the overall Quality System in the cGMP environment. Tracking and trending of these events will also allow businesses to monitor the overall "health" of the systems in place. Excessive Non Conformances can quickly identify areas of concern for management and allow for corrective actions to be taken. During regulatory inspections of quality systems, inspectors will frequently ask to review a list of all "open" Non Conformances" so that they can quickly assess how an organization is processing these events and ensuring they are dealt with in a timely manner.

Thus the process is continually evolving and correcting for anomalies that occur in the process. Eventually the process can evolve into periodic monitoring once sufficient data demonstrates that the process is in a state of control. Any anomaly that occurs once a process is in a state of control may result in the process being invalidated and not in control and could potentially result in product withdraw from the market to ensure patient safety. A formal product withdraw is only done when the quality, safety or efficacy of a product is questionable. A single anomaly would not necessarily require a product withdraw if there is sufficient stability data that demonstrates that excursions will not affect product quality.

It is necessary to develop an internal documentation system as well as multi-party communication standards and protocols to transfer or create a central repository or hub to track information across the supply chain. These systems would monitor equipment status, product temperature history, and custody chain, etc. These help ensure that a food, pharmaceutical, or vaccine is safe and effective when reaching its intended consumer. It is also important to have a complete chain of custody for the entire life cycle of a product, so there is documented evidence as to whom had control of the product throughout the lifecycle of the product, up to the final users consumption of the product.

MODULE III

Overview of Psychrometry and humidification-dehumidification processes

Psychrometry (from the Greek Adonis-which means "cold") is the science and practice of air mixtures and their control. Science deals mainly with dry air, water, steam mixtures, and the specific heat of dry air and its volume. It also deals with heat, water, heat of evaporation or condensation, and the specific heat of water vapor in the link to moisture mixed with dry air. Psychrometry is a specialized field of thermodynamics.

What is Humidification Process?

The process in which the moisture or water vapor or humidity is added to the air without changing its dry bulb (DB) temperature is called as humidification process. This process is represented by a straight vertical line on the psychrometric chart starting from the initial value of relative humidity, extending upwards and ending at the final value of the relative humidity. In actual practice the pure humidification process is not possible, since the humidification is always accompanied by cooling or heating of the air. Humidification process along with cooling or heating is used in number of air conditioning applications. Let us see how these processes are obtained and how they are represented on the psychrometric chart.

This article describes psychrometric processes like humidification, cooling and humidification, and heating and humidification. The article describes how these processes are achieved and how they are represented on the psychrometric chart.

Cooling and Humidification Process

Cooling and humidification process is one of the most commonly used air conditioning application for the cooling purposes. In this process the moisture is added to the air by passing it over the stream or spray of water which is at temperature lower than the dry bulb temperature of the air. When the ordinary air passes over the stream of water, the particles of water present within the stream tend to get evaporated by giving up the heat to the stream. The evaporated water is absorbed by the air so its moisture content, thus the humidity increases. At the same time, since the temperature of the absorbed moisture is less than the DB bulb temperature of the air, there is reduction in the overall temperature of the air. Since the heat is released in the stream or spray of water, its temperature increases.

One of the most popular applications of cooling and humidification is the evaporative cooler, also called as the desert cooler. The evaporative cooler is the sort of big box inside which is a small water tank, small water pump and the fan. The water from the tank is circulated by the pump and is also sprayed inside the box. The fan blows strong currents of air over the water sprays, thus cooling the air and humidifying it simultaneously. The evaporative cooler is highly effective cooling devise having very low initial and running cost compared to the unitary air conditioners. For cooling purposes, the cooling and humidification process can be used only in dry and hot climates like desert areas, countries like India, China, Africa etc. This cooling process cannot be used in hot and high humidity climates.

The cooling and humidification process is also used in various industries like textile, where certain level of temperature and moisture content has to be maintained. In such cases large quantity of water is sprayed, and large blowers are used to blow the air over the spray of water.

During the cooling and humidification process the dry bulb of the air reduces, its wet bulb and the dew point temperature increases, while its moisture content and thus the relative humidity also increases. Also, the sensible heat of the air reduces, while the latent heat of the air increases resulting in the overall increase in the enthalpy of the air.

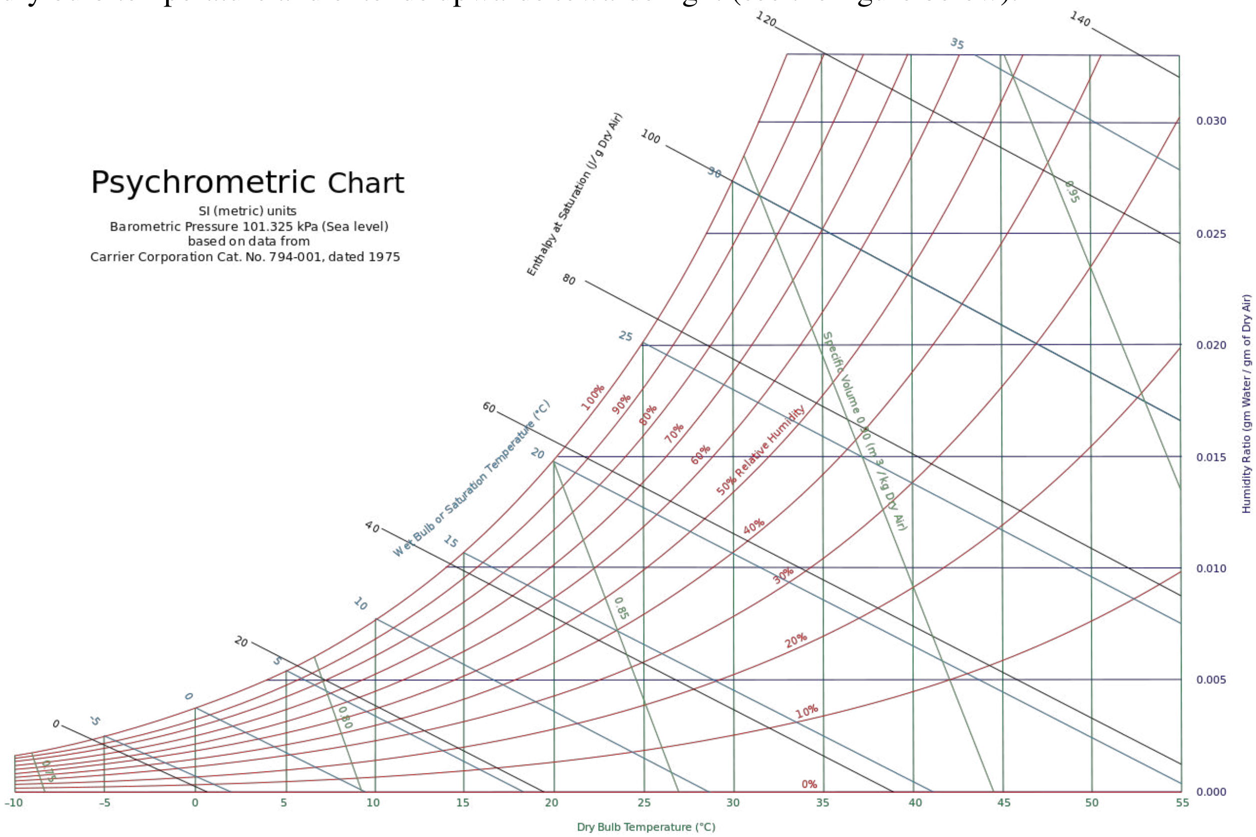
Cooling and humidification process is represented by an angular line on the psychrometric chart starting from the given value of the dry bulb temperature and the relative humidity and extending upwards toward left.

Heating and Humidification Process

In heating and humidification psychrometric process of the air, the dry bulb temperature as well as the humidity of the air increases. The heating and humidification process is carried out by passing the air over spray of water, which is maintained at temperature higher than the dry bulb temperature of air or by mixing air and the steam.

When the ordinary air is passed over the spray of water maintained at temperature higher than the dry bulb temperature of the air, the moisture particles from the spray tend to get evaporated and get absorbed in the air due to which the moisture content of the air increase. At the same time, since the temperature of the moisture is greater than the dry bulb temperature of the air, there is overall increase in its temperature.

During heating and humidification process the dry bulb, wet bulb, and dew point temperature of the air increases along with its relative humidity. The heating and humidification process is represented on the psychrometric chart by an angular line that starts from the given value of the dry bulb temperature and extends upwards towards right (see the figure below).



Theory of drying and mechanism of moisture transfer in drying

Drying is a mass transfer process consisting of the removal of water or another solvent by evaporation from a solid, semi-solid or liquid. This process is often used as a final production step before selling or packaging products. To be considered "dried", the final product must be solid, in the form of a continuous sheet (e.g., paper), long pieces (e.g., wood), particles (e.g., cereal grains or corn flakes) or powder (e.g., sand, salt, washing powder, milk powder). A source of heat and an agent to remove the vapor produced by the process are often involved. In bioproducts like food, grains, and pharmaceuticals like vaccines, the solvent to be removed is almost invariably water. Desiccation may be synonymouswith drying or considered an extreme form of drying.

In the most common case, a gas stream, e.g., air, applies the heat by convection and carries away the vapor as humidity. Other possibilities are vacuum drying, where heat is supplied by conduction or radiation (or microwaves), while the vapor thus produced is removed by the vacuum system. Another indirect technique is drum drying (used, for instance, for manufacturing potato flakes), where a heated surface is used to provide the energy, and aspirators draw the vapor outside the room. In contrast, the mechanical extraction of the solvent, e.g., water, by filtration or centrifugation, is not considered "drying" but rather "draining".

In some products having a relatively high initial moisture content, an initial linear reduction of the average product moisture content as a function of time may be observed for a limited time, often known as a "constant drying rate period". Usually, in this period, it is surface moisture outside individual particles that is being removed. The drying rate during this period is mostly dependent on the rate of heat transfer to the material being dried. Therefore, the maximum achievable drying rate is considered to be heat-transfer limited. If drying is continued, the slope of the curve, the drying rate, becomes less steep (falling rate period) and eventually tends to nearly horizontal at very long times. The product moisture content is then constant at the "equilibrium moisture content", where it is, in practice, in equilibrium with the dehydrating medium. In the falling-rate period, water migration from the product interior to the surface is mostly by molecular diffusion, i,e. the water flux is proportional to the moisture content gradient. This means that water moves from zones with higher moisture content to zones with lower values, a phenomenon explained by the second law of thermodynamics. If water removal is considerable, the products usually undergo shrinkage and deformation, except in a well-designed freeze-drying process. The drying rate in the falling-rate period is controlled by the rate of removal of moisture or solvent from the interior of the solid being dried and is referred to as being "mass-transfer limited". This is widely noticed in hygroscopic products such as fruits and vegetables, where drying occurs in the falling rate period with the constant drying rate period said to be negligible.

Different principles of drying

The following are some general methods of drying:

- Application of hot air (convective or direct drying). Air heating increases the drying force for heat transfer and accelerates drying. It also reduces air relative humidity, further increasing the driving force for drying. In the falling rate period, as moisture content falls, the solids heat up and the higher temperatures speed up diffusion of water from the interior of the solid to the surface. However, product quality considerations limit the applicable rise to air temperature. Excessively hot air can almost completely dehydrate the solid surface, so that its pores shrink and almost close, leading to crust formation or "case hardening", which is usually undesirable. For instance in wood (timber) drying, air is heated (which speeds up drying) though some steam is also added to it (which hinders drying rate to a certain extent) in order to avoid excessive surface dehydration and product deformation owing to high moisture gradients across timber thickness. Spray drying belongs in this category.
- Indirect or contact drying (heating through a hot wall), as drum drying, vacuum drying. Again, higher wall temperatures will speed up drying but this is limited by product degradation or case-hardening. Drum drying belongs in this category.
- Dielectric drying (radiofrequency or microwaves being absorbed inside the material) is the focus of intense research nowadays. It may be used to assist air drying or vacuum drying. Researchers have found that microwave finish drying speeds up the otherwise very low drying rate at the end of the classical drying methods.
- Freeze drying or lyophilization is a drying method where the solvent is frozen prior to drying and is then sublimed, i.e., passed to the gas phase directly from the solid phase, below the melting point of the solvent. It is increasingly applied to dry foods, beyond its already classical pharmaceutical or medical applications. It keeps biological properties of proteins, and retains vitamins and bioactive compounds. Pressure can be reduced by a high vacuum

pump (though freeze drying at atmospheric pressure is possible in dry air). If using a vacuum pump, the vapor produced by sublimation is removed from the system by converting it into ice in a condenser, operating at very low temperatures, outside the freeze drying chamber.

- Supercritical drying (superheated steam drying) involves steam drying of products containing water. This process is feasible because water in the product is boiled off, and joined with the drying medium, increasing its flow. It is usually employed in closed circuit and allows a proportion of latent heat to be recovered by recompression, a feature which is not possible with conventional air drying, for instance. The process has potential for use in foods if carried out at reduced pressure, to lower the boiling point.

Theory of drying

Drying is one of the oldest methods of preserving food. Primitive societies practised the drying of meat and fish in the sun long before recorded history. Today the drying of foods is still important as a method of preservation. Dried foods can be stored for long periods without deterioration occurring. The principal reasons for this are that the microorganisms which cause food spoilage and decay are unable to grow and multiply in the absence of sufficient water and many of the enzymes which promote undesired changes in the chemical composition of the food cannot function without water.

Preservation is the principal reason for drying, but drying can also occur in conjunction with other processing. For example in the baking of bread, application of heat expands gases, changes the structure of the protein and starch and dries the loaf.

Losses of moisture may also occur when they are not desired, for example during curing of cheese and in the fresh or frozen storage of meat, and in innumerable other moist food products during holding in air.

Drying of foods implies the removal of water from the foodstuff. In most cases, drying is accomplished by vaporizing the water that is contained in the food, and to do this the latent heat of vaporization must be supplied. There are, thus, two important process-controlling factors that enter into the unit operation of drying:

(a) transfer of heat to provide the necessary latent heat of vaporization,

(b) movement of water or water vapour through the food material and then away from it to effect separation of water from foodstuff.

BASIC DRYING THEORY

Three States of Water

Pure water can exist in **three states, solid, liquid and vapour**. The state in which it is at any time depends on the temperature and pressure conditions and it is possible to illustrate this on a **phase diagram**, as in **Fig. 7.1**.

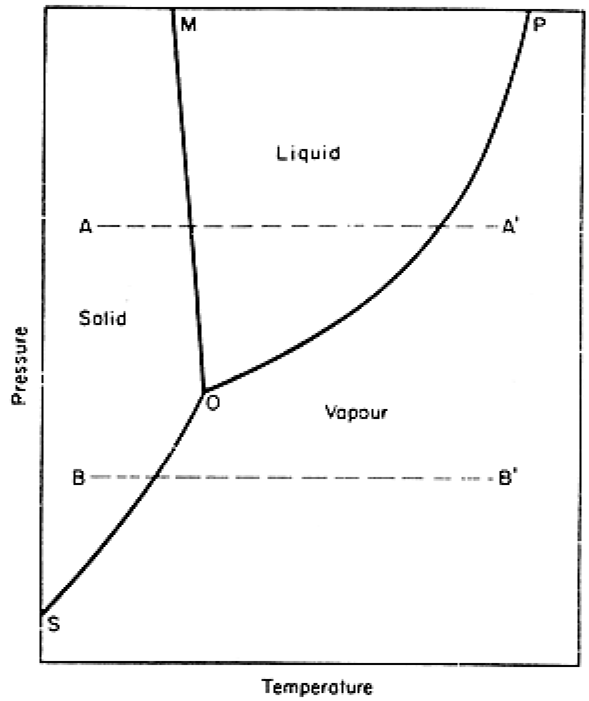


Figure 7.1 Phase diagram for water

If we choose any condition of temperature and pressure and find the corresponding point on the diagram, this point will lie, in general, in one of the three labelled regions, solid, liquid, or gas. This will give the state of the water under the chosen conditions.

Under certain conditions, two states may exist side by side, and such conditions are found only along the lines of the diagram. Under one condition, all three states may exist together; this condition arises at what is called the triple point, indicated by point O on the diagram. For water it occurs at 0.0098°C and 0.64 kPa (4.8 mm of mercury) pressure.

If heat is applied to water in any state at constant pressure, the temperature rises and the condition moves horizontally across the diagram, and as it crosses the boundaries a change of state will occur. For example, starting from condition A on the diagram adding heat warms the ice, then melts it, then warms the water and finally evaporates the water to condition A'. Starting from condition B, situated below the triple point, when heat is added, the ice warms and then sublimes without passing through any liquid state.

Liquid and vapour coexist in equilibrium only under the conditions along the line OP. This line is called the vapour pressure/temperature line. The vapour pressure is the measure of the tendency of molecules to escape as a gas from the liquid. The **vapour pressure/temperature curve** for water is shown in **Fig. 7.2**, which is just an enlargement for water of the curve OP of Fig. 7.1.

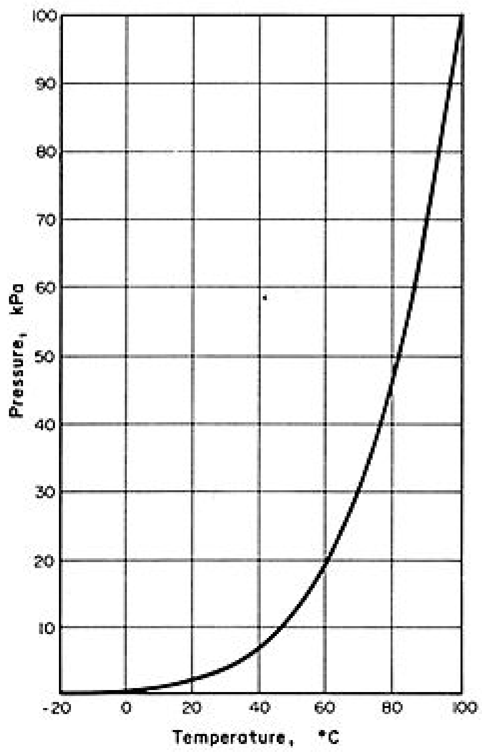


Figure 7.2. Vapour pressure/temperature curve for water

Boiling occurs when the vapour pressure of the water is equal to the total pressure on the water surface. The boiling point at atmospheric pressure is of course 100°C. At pressures above or below atmospheric, water boils at the corresponding temperatures above or below 100°C, as shown in Fig. 7.2 for temperatures below 100°C.

Heat Requirements for Vaporization

The energy, which must be supplied to vaporize the water at any temperature, depends upon this temperature. The quantity of energy required per kg of water is called the **latent heat of vaporization**, if it is from a liquid, or**latent heat of sublimation** if it is from a solid. The heat energy required to vaporize water under any given set of conditions can be calculated from the latent heats given in the steam table in Appendix 8, as steam and water vapour are the same thing.

- **EXAMPLE 7.1. Heat energy in air drying**

A food containing 80% water is to be dried at 100°C down to moisture content of 10%. If the initial temperature of the food is 21°C, calculate the quantity of heat energy required per unit weight of the original material, for drying under atmospheric pressure. The latent heat of vaporization of water at 100°C and at standard atmospheric pressure is 2257 kJ kg^{-1}. The specific heat capacity of the food is 3.8 kJ kg^{-1} $°C^{-1}$ and of water is 4.186 kJ $kg^{-1}°C^{-1}$. Find also the energy requirement/kg water removed.

Calculating for 1 kg food

Initial moisture = 80%
800 g moisture are associated with 200 g dry matter.
Final moisture = 10 %,
100 g moisture are associated with 900 g dry matter,
Therefore (100 x 200)/900 g = 22.2 g moisture are associated with 200 g dry matter.
1kg of original matter must lose (800 - 22) g moisture = 778 g = 0.778 kg moisture.

Heat energy required for 1kg original material
= heat energy to raise temperature to 100°C + latent heat to remove water
= (100 - 21) x 3.8 + 0.778 x 2257
= 300.2 + 1755.9
= <u>2056 kJ</u>.

Energy/kg water removed, as 2056 kJ are required to remove 0.778 kg of water,
= 2056/0.778
= <u>2643 kJ</u>.

Steam is often used to supply heat to air or to surfaces used for drying. In condensing, steam gives up its latent heat of vaporization; in drying, the substance being dried must take up latent heat of vaporization to convert its liquid into vapour, so it might be reasoned that 1 kg of steam condensing will produce 1 kg vapour. This is not exactly true, as the steam and the food will in general be under different pressures with the food at the lower pressure. Latent heats of vaporization are slightly higher at lower pressures, as shown in **Table 7.1**. In practice, there are also heat losses and sensible heat changes which may require to be considered.

TABLE 7.1
LATENT HEAT AND SATURATION TEMPERATURE OF WATER

Absolute pressure (kPa)	Latent heat of vaporization ($kJ\ kg^{-1}$)	Saturation temperature (°C)
1	2485	7
2	2460	18
5	2424	33
10	2393	46
20	2358	60
50	2305	81
100	2258	99.6
101.35 (1 atm)	2257	100
110	2251	102
120	2244	105

200	2202	120
500	2109	152

EXAMPLE 7.2. Heat energy in vacuum drying

Using the same material as in Example 7.1, if vacuum drying is to be carried out at 60°C under the corresponding saturation pressure of 20 kPa abs. (or a vacuum of 81.4 kPa), calculate the heat energy required to remove the moisture per unit weight of raw material.

Heat energy required per kg raw material
= heat energy to raise temperature to 60°C + latent heat of vaporization at 20 kPa abs.
= (60 - 21) x 3.8 + 0.778 x 2358
= 148.2 + 1834.5
= 1983 kJ.

In freeze drying the latent heat of sublimation must be supplied. Pressure has little effect on the latent heat of sublimation, which can be taken as 2838 kJ kg^{-1}.

EXAMPLE 7.3. Heat energy in freeze drying

If the foodstuff in the two previous examples were to be freeze dried at 0°C, how much energy would be required per kg of raw material, starting from frozen food at 0°C?

Heat energy required per kilogram of raw material= latent heat of sublimation
= 0.778 x 2838
= 2208 kJ.

Heat Transfer in Drying

We have been discussing the heat energy requirements for the drying process. The rates of drying are generally determined by the rates at which heat energy can be transferred to the water or to the ice in order to provide the latent heats, though under some circumstances the rate of mass transfer (removal of the water) can be limiting. All three of the mechanisms by which heat is transferred - conduction, radiation and convection - may enter into drying. The relative importance of the mechanisms varies from one drying process to another and very often one mode of heat transfer predominates to such an extent that it governs the overall process.

As an example, in air drying the rate of heat transfer is given by:

$$q = h_s A(T_a - T_s) \quad (7.1)$$

where q is the heat transfer rate in J s^{-1}, h_s is the surface heat-transfer coefficient J m^{-2} s^{-1} °C^{-1}, A is the area through which heat flow is taking place, m^2, T_a is the air temperature and T_s is the temperature of the surface which is drying, °C.

To take another example, in a roller dryer where moist material is spread over the surface of a heated drum, heat transfer occurs by conduction from the drum to the foodstuff, so that the equation is

$$q = UA(T_i - T_s)$$

where U is the overall heat-transfer coefficient, T_i is the drum temperature (usually very close to that of the steam), T_s is the surface temperature of the food (boiling point of water or slightly above) and A is the area of drying surface on the drum.

The value of U can be estimated from the conductivity of the drum material and of the layer of foodstuff. Values of U have been quoted as high as 1800 J m^{-2} s^{-1} °C^{-1} under very good conditions and down to about 60 J m^{-2} s^{-1} °C^{-1} under poor conditions.

In cases where substantial quantities of heat are transferred by radiation, it should be remembered that the surface temperature of the food may be higher than the air temperature. Estimates of surface temperature can be made using the relationships developed for radiant heat transfer although the actual effect of combined radiation and evaporative cooling is complex. Convection coefficients also can be estimated using the standard equations.

For freeze drying, energy must be transferred to the surface at which sublimation occurs. However, it must be supplied at such a rate as not to increase the temperature at the drying surface above the freezing point. In many applications of freeze drying, the heat transfer occurs mainly by conduction.

As drying proceeds, the character of the heat transfer situation changes. Dry material begins to occupy the surface layers and conduction must take place through these dry surface layers which are poor heat conductors so that heat is transferred to the drying region progressively more slowly.

Dryer Efficiencies

Energy efficiency in drying is of obvious importance as energy consumption is such a large component of drying costs. Basically it is a simple ratio of the minimum energy needed to the energy actually consumed. But because of the complex relationships of the food, the water, and the drying medium which is often air, a number of efficiency measures can be worked out, each appropriate to circumstances and therefore selectable to bring out special features important in the particular process. Efficiency calculations are useful when assessing the performance of a dryer, looking for improvements, and in making comparisons between the various classes of dryers which may be alternatives for a particular drying operation.

Heat has to be supplied to separate the water from the food. The minimum quantity of heat that will remove the required water is that needed to supply the latent heat of evaporation, so one measure of efficiency is the ratio of that minimum to the energy actually provided for the process. Sensible heat can also be added to the minimum, as this added heat in the food often cannot be economically recovered.

Yet another useful measure for air drying such as in spray dryers, is to look at a heat balance over the air, treating the dryer as adiabatic with no exchange of heat with the surroundings. Then the useful heat transferred to the food for its drying corresponds to the drop in temperature in the drying air, and the heat which has to be supplied corresponds to the rise of temperature of the air in the air heater. So this adiabatic air-drying efficiency, □, can be defined by:

□ $= (T_1 - T_2)/(T_1 - T_a)$ (7.2)

where T_1 is the inlet (high) air temperature into the dryer, T_2 is the outlet air temperature from the dryer, and T_a is the ambient air temperature. The numerator, the gap between T_1 and T_2, is a major factor in the efficiency.

EXAMPLE 7.4. Efficiency of a potato dryer

A dryer reduces the moisture content of 100 kg of a potato product from 80% to 10% moisture. 250 kg of steam at 70 kPa gauge is used to heat 49,800 m^3 of air to 80°C, and the air is cooled to 71°C in passing through the dryer. Calculate the efficiency of the dryer. The specific heat of potato is 3.43 kJ kg^{-1} $°C^{-1}$. Assume potato enters at 24°C, which is also the ambient air temperature, and leaves at the same temperature as the exit air.

In 100 kg of raw material there is 80% moisture, that is 80 kg water and 20 kg dry material,
total weight of dry product = 20 x (10/9)
= 22.2 kg
weight of water = (22.2 - 20)
= 2.2 kg.
water removed = (80 - 2.2)
= 77.8 kg.

Heat supplied to potato product
= sensible heat to raise potato product temperature from 24°C to 71°C + latent heat of vaporization.

Now, the latent heat of vaporization corresponding to a saturation temperature of 71°C is 2331 kJ kg^{-1}

Heat (minimum) supplied/100 kg potato
$= 100 \times (71 - 24) \times 3.43 + 77.8 \times 2331$
$= 16 \times 10^3 + 181 \times 10^3$
$= 1.97 \times 10^5$ kJ.
Heat to evaporate water only $= 77.8 \times 2331$
$= 1.81 \times 10^5$ kJ

The specific heat of air is 1.0 J kg^{-1} $°C^{-1}$ and the density of air is 1.06 kg m^{-3} (Appendix 3)
Heat given up by air/100 kg potato
$= 1.0 \times (80 - 71) \times 49{,}800 \times 1.06$
$= 4.75 \times 10^5$ kJ.

The latent heat of steam at 70 kPa gauge is 2283 kJ kg^{-1}
Heat in steam = 250 x 2283

= 5.71×10^5 kJ.

Therefore (a) efficiency based on latent heat of vaporisation only:

= $(1.81 \times 10^5)/ (5.71 \times 10^5)$

= 32%

(b) efficiency assuming sensible heat remaining in food after drying is unavailable

= $(1.97 \times 10^5)/ (5.71 \times 10^5)$

= 36%

(c) efficiency based heat input and output, in drying air

= (80 – 71)/ (80 – 24)

= 16%

Whichever of these is chosen depends on the objective for considering efficiency. For example in a spray dryer, the efficiency calculated on the air temperatures shows clearly and emphatically the advantages gained by operating at the highest feasible air inlet temperature and the lowest air outlet temperatures that can be employed in the dryer.

Examples of overall thermal efficiencies are:

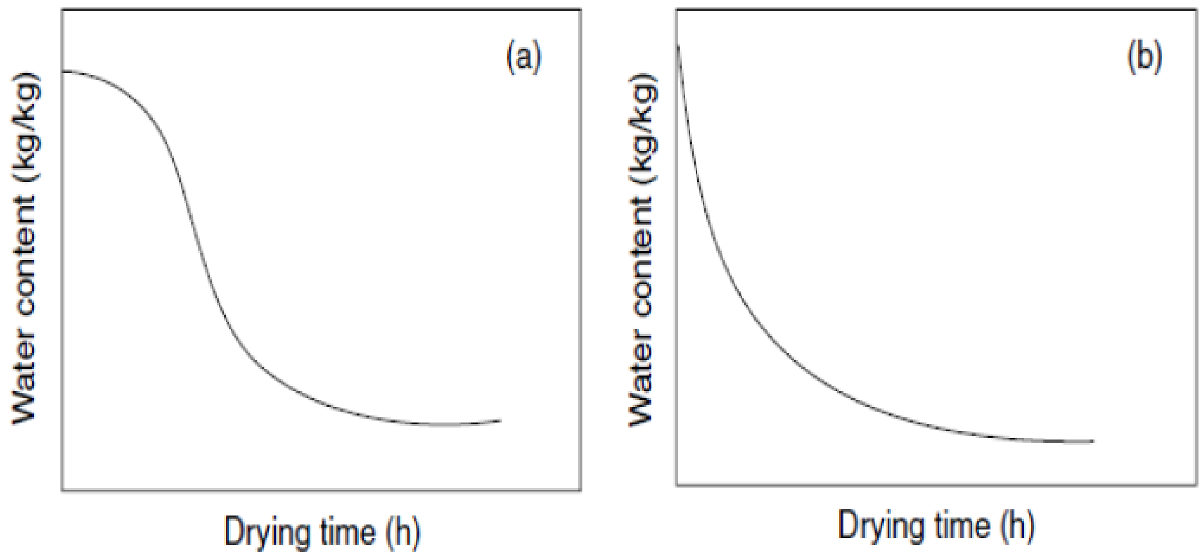
drum dryers 35-80%
spray dryers 20-50%
radiant dryers 30-40%

After sufficient energy has been provided to vaporize or to sublime moisture from the food, some way must be found to remove this moisture. In freeze-drying and vacuum systems it is normally convenient to condense the water to a liquid or a solid and then the vacuum pumps have to handle only the non-condensible gases. In atmospheric drying a current of air is normally used.

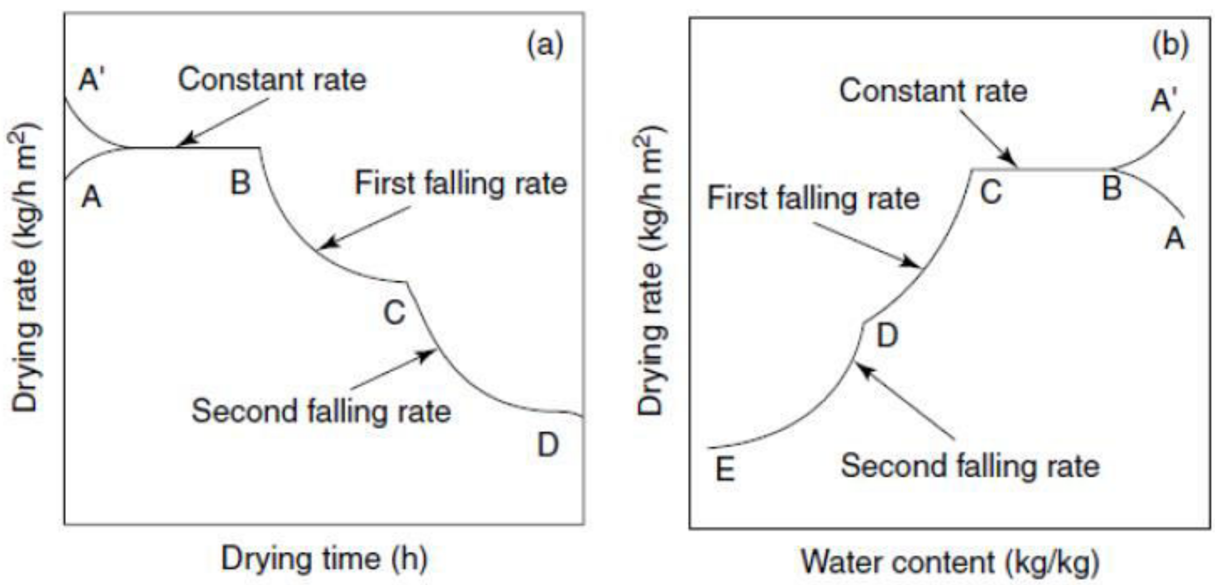
Drying Curve

- Drying curve usually plots the drying rate versus drying time or moisture contents.
- Three major stages of drying can be observed in the drying curve.

1. Transient early stage, during which the product is heating up (transient period)
2. Constant rate period, in which moisture is comparatively easy to remove
3. Falling rate period, in which moisture is bound or held within the solid matrix



Typical drying curves (water content versus drying time): (a) with a lag period, (b) without a lag period



- Typical drying rate curves: (a) drying rate versus drying time and (b)drying rate versus water content Critical moisture content: The moisture content at the point when the drying period changes from a constant to a falling rate.
- The drying behaviours of food materials depend on the porosity, homogeneity, and hygroscopic properties.
- Hygroscopic food materials enter into the falling rate faster compared to non-hygroscopic food materials.

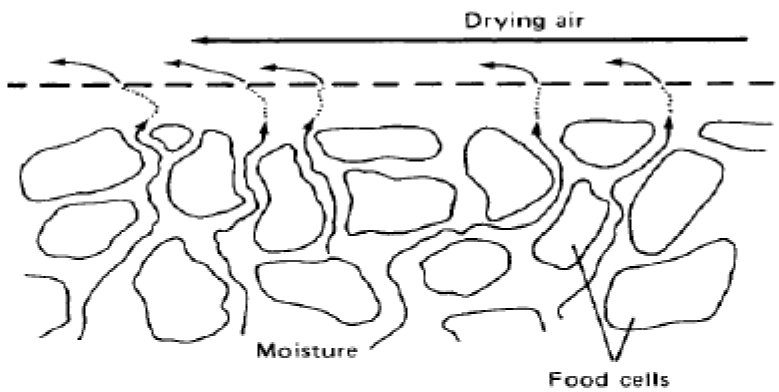
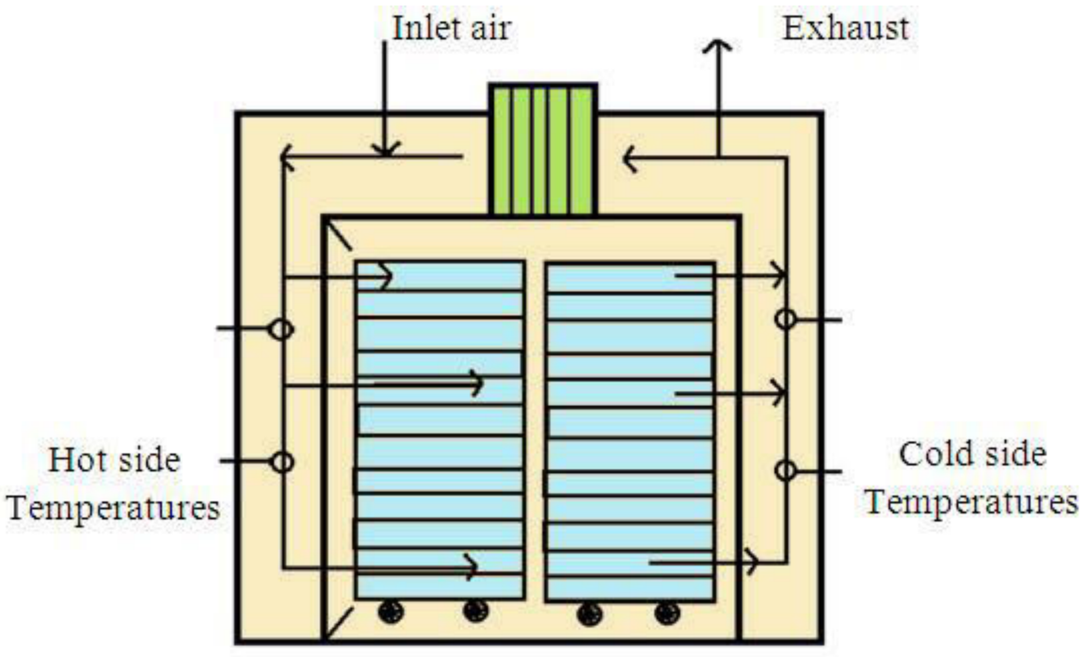


Fig. 15.2 Movement of moisture during drying.

<u>Different Types of Dryers</u>

Tray Dryer A tray Dryer is an enclosed insulated chamber in which trays are placed on top of each other in trolleys. Tray Dryer are used where heating and drying are essential parts of manufacturing process in industries such as Chemicals, Dye stuff, Pharmaceutical, Food Products, Colors etc. The material to be dried either wet or solids are placed in the trays. Heat transfer is by circulation of hot air by electric heaters or steam in radiator coils. Blower fans are installed inside to ensure proper circulation and transfer of heat. A control panel to control the temperature and other parameters is fixed outside the dryer. These dryers are available in Mild Steel, Stainless Steel or construction. Tray dryer is used for drying of pigments, food, bakery, electrodes, chemical and plastic powders.
The Drying ovens are normally available with choice of heating mode, as electrically heated / steam heated & thermic fluid heated**.**



A highly effective recirculating air system is provided. The heated air, is recirculated with fresh air in selected proportions for optimum drying. The system is designed so that the materials at the top & the bottom dry simultaneously.

Uniform air circulation, controlled temperature, sturdy construction and large working space are the valuables of the oven which is suitably designed to cover wide temperature range, loading and unloading is faster and simple. In higher capacities trays trolley rolls in and out of the chamber. For continuous operation a spare trolley can be had for loading while the drying cycle is taking place. Digital temperature controller with digital timer are supplied to facilitate working day and night.

Tray Dryer Working Principle

In tray dryer hot air is continuously circulated. Forced convection heating takes place to remove moister from the solids placed in trays.

Simultaneously the moist air is removed partially.

Wet solid is loaded in to the trays. Trays are placed in the chamber.

Fresh air is introduced through in let, which passes through the heaters and gets heated up.

The hot air is circulated by means of fans at 2 to 5 metre per second.

Turbulent flow lowers the partial vapour pressure in the atmosphere and also reduces the thickness of the air boundary layer.

The water is picked up by the air. As the water evaporates from the surface, the water diffuses from the interior of the solids by the capillary action.

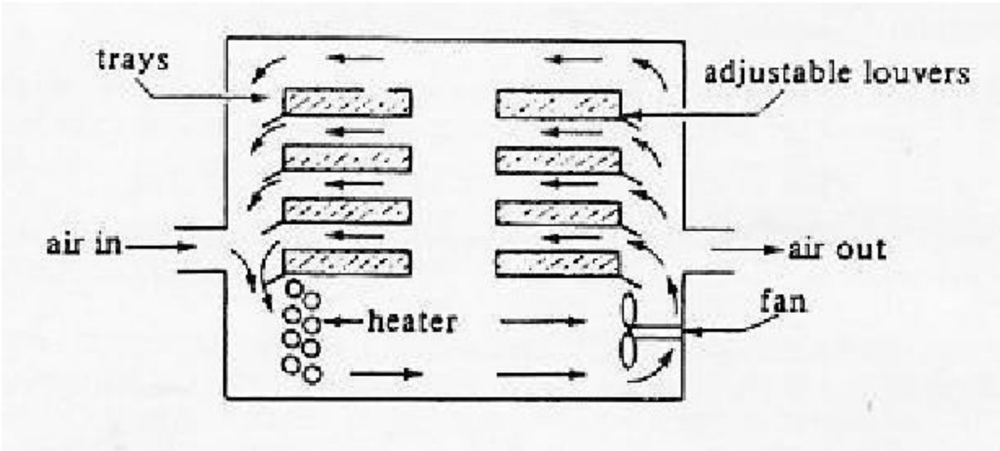
These events occur in a single pass of air. The time of contact is short and amount of water picked up in a single pass is small.

Therefore the discharged air to the tune of 80 to 90 % is circulated back through the fans. Only 10 to 20% of fresh air is introduced.

Moist air is discharged through outlet. Thus constant temperature and uniform air flow over the materials can be maintained for achieving uniform drying.

At the end of the drying trays or trucks are pulled out of the chamber and taken to a tray dumping station.

Tray Dryer Diagram:



Tray Dryer Manufacture Construction & Specifications:

The Tray dryer should be of robust construction built on formed angles of 3mm+ thick sheet and suitably reinforced with angles and sections.

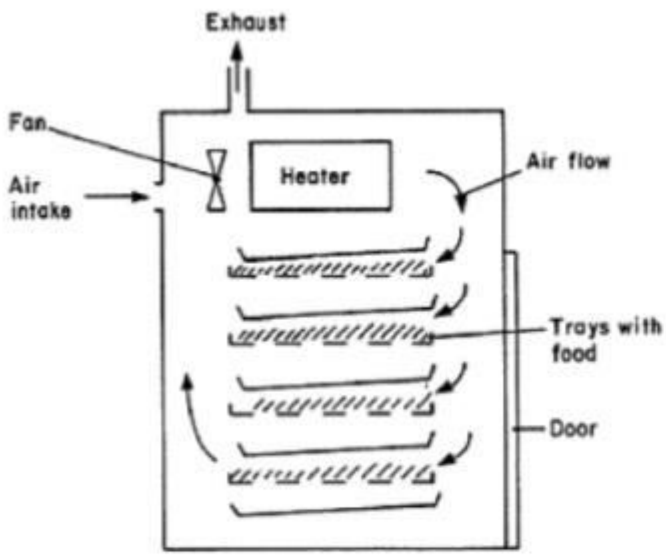
The dryers external walls should be manufactured from 1.6mm thick Stainless Steel sheets of 304 quality or more.

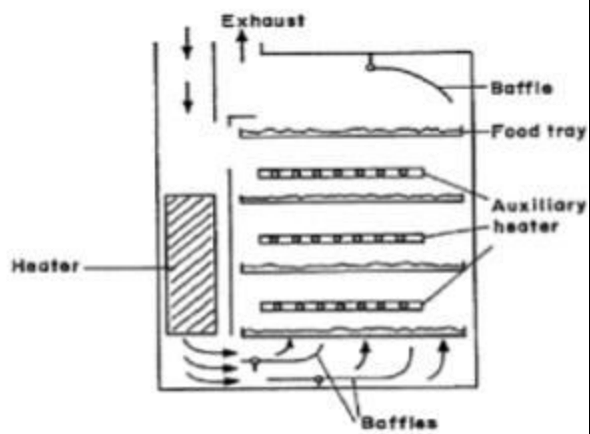
The internal of the dryer is built of 1.6 mm thick quality sheets. The internal structure should be fully TIG welded and all the internals have ground smooth surfaces.

It should be insulated with minimum 50 mm thick glasswool insulation and Cladded with S,S, Polished sheets.

The dryer should be having a fresh air inlet through 20 Micron PP cloth filters and a adjustable air outlet flap and a door at the front. The door is explosion proof and is locked with the help of spring loaded ball latches with suitable pressure. Door lips are having Neoprene rubber Gasket to prevent leakages.

Cabinet Tray Dryers





Drying cabinet with auxiliary heaters.

The design and manufacture of the dryer is of high standard of GMP and has an aesthetic look. It is buffed externally to 150 grit matt finish and internally buffed to 220 grit mirror finish.

The Air inside the Tray Dryer is heated by “U” tube S.S.304 air heaters each of 1 KW.The heaters are fitted on the sides of the dryer to facilitate uniform heating. Maximum temperature attained inside the dryer is 100′ C and will be indicated and controlled by a Digital Temperature indicator cum controller over full range of heating load.

Total heating load for it will be

12 Trays Dryer – 4 KW

24 Trays Dryer – 6 KW

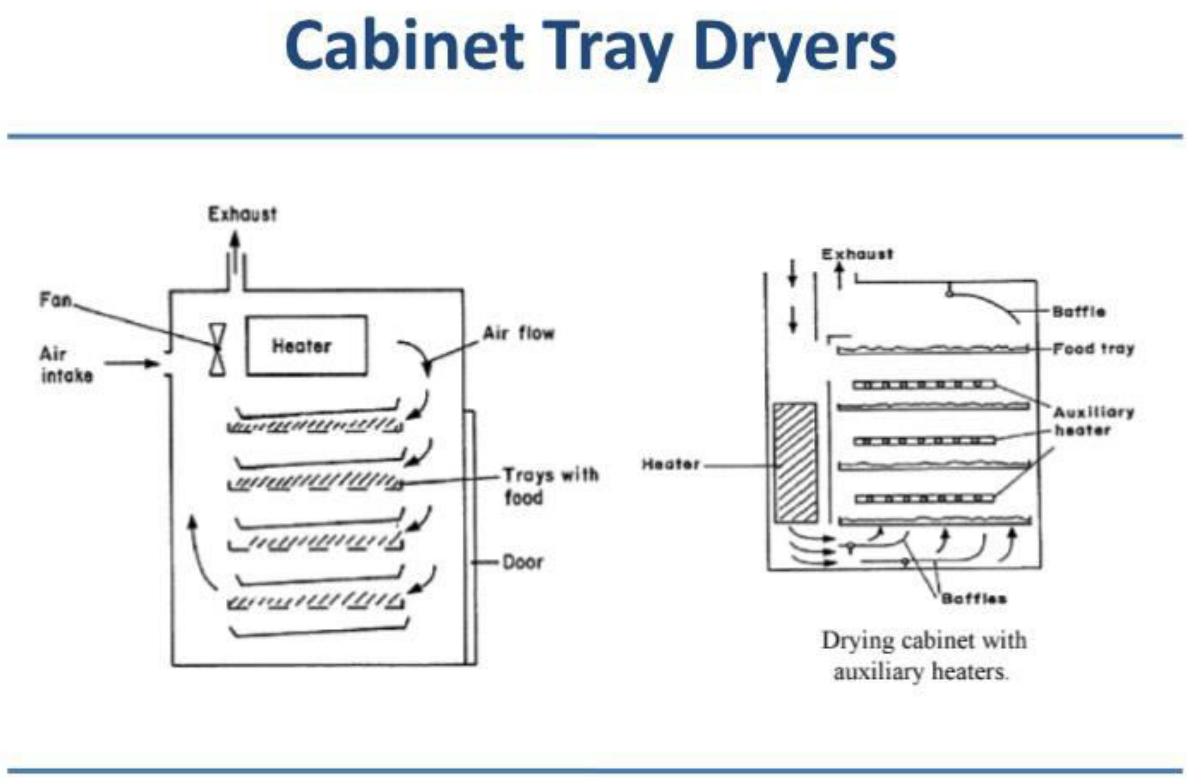
48 Trays Dryer – 12 KW

96 Trays Dryer – 24 KW

The heaters will be inserted inside tubular pipe to prevent it from becoing RED HOT. The terminals of the heaters will be brought outside the dryer to make it more safe for operations for solvent based products.

Racks And Trolleys

Racks are provided for trays insdie the Dryer. They are of fixed type for 12 and 24 Tarys Models. For 48 and 96 Trays Models. Racks are provided with wheels to slide them in and out of the Dryer. An additional S.S, trolley for Racks for outside movement can be provided on request



Drum Dryer –

The drum dryer is also called as an roller dryer or film drum dryer.

Drying drum, also named drum dryer, is a machine for drying process, which people call drum drying. It's a special kilnthat usually co-works with burning system, like coal burner or oil burner. The heat goes through its inner cylinder, dehydrating the material inside. The materials can be added in and withdrawn during the drying process, so it can work continuously.

The drum dryer consists of a hollow roller with a smoothly polished external surface heated internally by steam.

It rotates on its longitudinal axis. The liquid to be dried is placed in a trough known as feed pan.

The liquid is picked up by the roller as it rotates covering the surface in a thin film is removed mechanically by a scrapper known as doctor knife.

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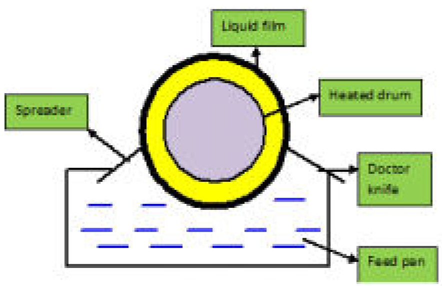


Working Principle

Principle of double drum dryers

Drum dryers are used for the continual drying of solutions, suspensions and pastes of different consistencies and viscosities. The drums are usually heated with steam. Using a dosing system, the wet product is distributed between the drums. The gap between the drums can be set between 0.1 and 2 mm.

The wet product applied is distributed evenly on the hot drums and the moisture content evaporates during the partial rotation of the drums. After approximately a ¾ turn, the now dry product is removed by a scraper. Depending on its consistency, it falls as a film, in scales or as a powder and can be fed into the next processing stage via the appropriate conveyor.

Principle of single drum dryer

In principle, the single drum dryer functions similarly to the double drum dryer.
In this apparatus, product application takes place however via a product sump and is sprayed out and/or is applied from above via product application drums.
The dried product is removed by a scraper and can be fed back in for further processing.

CONSTRUCTION

The construction of the drum dryer consists of a hollow steel drum of 0.6 to 3 meters diameter and 0.6 to 4.0 m length which is horizontally mounted and its external surface is smoothly polished for the easy removal of the dried cake.

Below the drum pan is placed with the feed in the manner that the drum dips partially in to the pan consisting of feed. One side of the drum a spreader is placed which is used to spread the material on to the drum and on the other side a doctors knife is placed to scrap or peel off the dried materials from the metal drum. After peeling of the material collect the materials in the conveyor or storage bin.

WORKING

- The drying of the material is done by the process of steam when passed in to the drum. Due to the metallurgic nature of the drum the heat absorption is more.
- By the mechanism of the conduction the heat get transferred in to the drum and drying process takes place, the drying capacity is directly proportional to the drum surface area.
- the liquid material which is present in the pan gets adhere to the drum and gets dried by revolving at the rate of 1 to 10 revolution.
- The materials is completely dried during its journey during its revolutions.
- The dried materials is scrapped by the knife and that falls in to the bin.

PHARMACEUTICAL APPLICATIONS

- Solutions, slurries, suspensions and more are dried in this dryer.
- Milk products, starch products, ferrous salts, suspensions of zinc oxide, suspensions of the kaolin, yeast, pigments, malt extracts, antibiotics, glandular extracts, insecticides, DDT, calcium and barium carbonates are dried in this dryer.

ADVANTAGES

1. It takes les time to dry.
2. Thermo sensitives drugs can also be dried.
3. Drum dryers occupies less space.
4. In order to reduce the temperature of drying the drum can be enclosed in a vacuum chamber.
5. Rapid drying takes place due to rapid heat and mass transfer.

DISADVANTAGES

1. Maintenance cost is high.
2. Skilled operators are essential to thickness control of the film.
3. It is not suitable less solubility products.

Spray Dryer –Spray Drying is a method of producing a dry powder from a liquid or slurry by rapidly drying with a hot gas. This is the preferred method of drying of many thermally-sensitive materials such as foods and pharmaceuticals. A consistent particle size distribution is a reason for spray drying some industrial products such as catalysts. Air is the heated drying medium; however, if the liquid is a flammable solvent such as ethanol or the product is oxygen-sensitive then nitrogen is used.[1]

All spray dryers use some type of atomizer or spray nozzle to disperse the liquid or slurry into a controlled drop size spray. The most common of these are rotary disk and single-fluid high pressure swirl nozzles. Atomizer wheels are known to provide broader particle size distribution, but both methods allow for consistent distribution of particle size.[2] Alternatively, for some applications two-fluid or ultrasonic nozzles are used. Depending on the process needs, drop sizes from 10 to 500 µm can be achieved with the appropriate choices. The most common applications are in the 100 to 200 µm diameter range. The dry powder is often free-flowing.[3]

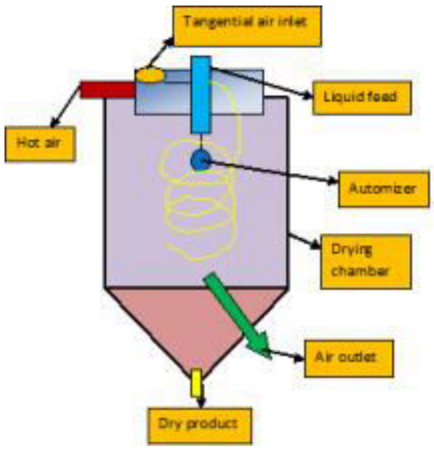
The most common type of spray dryers are called single effect. There is a single source of drying air at the top of the chamber (see n°4 on the diagram). In most cases the air is blown in the same direction as the sprayed liquid (co-current). A fine powder is produced, but it can have poor flow and produce a lot of dust. To overcome the dust and poor flow of the powder, a new generation of spray dryers called multiple effect spray dryers have been produced. Instead of drying the liquid in one stage, drying is done through two steps: the first at the top (as per single effect) and the second with an integrated static bed at the bottom of the chamber. The bed provides a humid environment which causes smaller particles to clump, producing more uniform particle sizes, usually within the range of 100 to 300 µm. These powders are free-flowing due to the larger particle size.

The fine powders generated by the first stage drying can be recycled in continuous flow either at the top of the chamber (around the sprayed liquid) or at the bottom, inside the integrated fluidized bed. The drying of the powder can be finalized on an external vibrating fluidized bed.

The hot drying gas can be passed in as a co-current, same direction as sprayed liquid atomizer, or counter-current, where the hot air flows against the flow from the atomizer. With co-current flow, particles spend less time in the system and the particle separator (typically a cyclone device). With counter-current flow, particles spend more time in the system and is usually paired with a fluidized bed system. Co-current flow generally allows the system to operate more efficiently.

A spray dryer takes a liquid stream and separates the solute or suspension as a solid and the solvent into a vapor. The solid is usually collected in a drum or cyclone. The liquid input stream is sprayed through a nozzle into a hot vapor stream and vaporized. Solids form as moisture quickly leaves the droplets. A nozzle is usually used to make the droplets as small as possible, maximizing heat transfer and the rate of water vaporization. Droplet sizes can range from 20 to 180 µm depending on the nozzle.[3] There are two main types of nozzles: high pressure single fluid nozzle (50 to 300 bars) and two-fluid nozzles: one fluid is the liquid to dry and the second is compressed gas (generally air at 1 to 7 bars).

Spray dryers can dry a product very quickly compared to other methods of drying. They also turn a solution, or slurry into a dried powder in a single step, which can be advantageous as it simplifies the process and improves profit margins.



A spray dryer is the device which is used for the drying of all types of materials and mostly the thermolabile, hygroscopic drugs or the materials that under goes chemical decomposition.

Description, Principle, Construction, Working, Applications

DESCRIPTION

In the spray dryer the liquid to be dried is sprayed in the form of mist. The minute droplets are readily evaporated and gets converted in to the solid particles, which fall to the bottom of the chamber.

The vapours are transferred in to the separator where the fine dry particles which are carried along with the vapours are separated and collected. Spray dryers are available in many forms and deigns.

A typical spray dryer consist of a drying chamber which is just like the cyclone separator, so as to ensure the good circulation of a air to facilaite heat and mass transfer and also to ensure that the dried particles are separated by the centrifugal action.

The character of the particles depends on the liquid to be converted in the form of droplets. As such it is important to use the right type of the atomiser.

Two types of atomiser are used, they are

1. Jet atomiser
2. Rotary atomiser

Jet atomiser are easily blocked resulting in variation of the droplets size. Rotary atomiser are preferred to avoid this problems.

PRINCIPLE

- In the spray dryer the fluid to be driedis atomised in to the fine droplets, which are thrown radially in to a moving stream of hot gas.

- The temperature of the droplets is immediately increased and fine droplets get dried instantaneously in the form of spherical particles.
- This proces complets in a few seconds before the droplets reach the wall of the dryer.

CONSTRUCTION

The construction of the spray dyer consists of a large cylindrical drying chamber with a short conical bottom made up of stain less steel with the diameter of the drying chamber ranges between 2.5 to 9 m and height is 25 m or more. An inlet for the hot air is palced in the roof of the chamber. Another inlet spray disk atomiser is set in the roof. The spray disk atomiser is about 300 mm in diameter and rotates at a speed of 3000 to 50000 revolutions per min. Bottom of the dryer is connected to a cyclone separator.

WORKING

Drying of the materials in the spray dryer involves 3 stages

1. Atomization of the liquid
2. Drying of the liquid droplets
3. Recovery of the dried products

Atomization of the liquid to form liquid droplets:

- The feed is introduced through the atomizer either by gravity or by using suitable pump to form fine droplets.
- The properties of the final products depend on the droplets form, hence the selection of the type of a atomizer is important.
- Atomizer of any type, pneumatic atomizer, pressure nozzle and spinning disc atomizer may be used.
- The rate of feed is adjusted in such a way that the droplets should be completely dried reaching the walls of the drying camber.
- At the same time, the product should not be over heated.

Drying of the liquid droplets:

- Fine droplets are dried in the drying camber by supplying hot air through the inlet.
- The surface of the liquid drop is dried immediately to form a tough shell.
- Further the liquid inside must escape by diffusing through the shell at a particular rate.
- At the same time heat transfer from outside to inside takes place at a rate greater than liquid diffusion rate.
- As a result heat inside mounts up which allows the liquid to evaporates at faster rate.
- This tendency of a liquid leadsto rise in the internal pressure which causes the droplets to swell.
- The shells thickness decreases where as permeability for vapour increases.
- If the shell is neither elastic nor permeable it ruputur and the internal pressure escapes.
- The temperature of the air is adjusted in such a way that the droplets should be compeletly dried before reaching the walls of the drying chamber.
- The products should not be over heated at the same time.

Recovery of the dried products:

- Centrifugal force of the atomizer drives the droplets to follow helical path.

- Particles are dried during their journey and finally fall at the conical bottom.
- All these processe are completed in a few seconds.
- Particles size of the final products ranges from the 2 to 500 mm.
- Particles size depends on solid content in the feed, liquid viscosity, feed rate and disc speed.
- Spray dryer of maximum size have got evaporating capacity up to 2000 kg per hour.

PHARMACEUTICAL APPLICATIONS

1. Spray dryer can be used for drying of ny substances both in solution or in suspension.
2. Spray dryer are very useful for the drying of thermolabile substances.
3. Citric acid, borax, sodium phosphate, hexamine, gelatine and extracts are dried by a spray dryer.
4. The suspensions of starch, barium sulphate and calcium phosphate are also dried by the spray dryer.
5. Milk, soap and detergents too are dried by a spray dryer.
6. Spray dryer are used compulsorily if:

- The products is a better form than that obtained by any other dryer.
- The quantity of the materials to be dried is large.
- The products is hygroscopic or undergoes chemical decompisition.

7. Some of the products that are dried using the spray dryer are acacia, adrenaline, bacitracin, blood, boric acid, calcium sulphate, coffee extract, dextran, fruit juices, ferrous sulphate, pepsin, pancreatin, plasma, serum, soaps, sodium phosphate, starch, sulphur, vaccines vitamines, yeast etc.

ADVANTAGES

1. In this the drying is a continuous proces and drying is very rapid. Drying completes within 3 to 30 seconds.
2. Labour costs are low as it combines the function of an evapotator, crystaillzer, a dryer, a size reduction unit and a classifier.
3. By using suitable atomiser the products of uniform and controlled size can be obtained. Free flowing products of uniform spheres is formed which is very convenient for tabletting process.
4. Fine droplets formed provides larges surface area for heat and mass transfer. Product shows excellent solubility.
5. Either the solutions or suspensions ar thin paste can be dried in one step to get the final product ready for package.
6. It is suitable for the drying of the sterile products.
7. Reconstituted products appears more or less similar to the fresh materials.
8. Globules of an emlusion cn be dried with the dispersed phase inside and layer of the continuous phase outside. On the reconstitution the emulsion will be formed.

DISADVANTAGES

1. The spray dryers is very bulky (height of 25 m and diameter of 9 m) and expensive.
2. Such a huge equipment is not always easy to operates.
3. The thermal efficiency is low, as much heat is lost in the discharged gases.

Fluidized Bed Dryer

Fluidized (fluid) bed dryers are used extensively in the pharmaceutical industries to reduce moisture content of pharmaceutical powder and granules. They have also found use in the drying of suspension, slurries, solutions, dilute paste or sludges. A typical fluidized bed dryer consists of the following components.

- Air preparatory unit.
- Product container.
- Exhaust filter.
- Exhaust blower.
- Control panel.
- Air distribution plate.
- Spray nozzle.
- Solution deliver.

In fluidized bed dryer, hot air is passed at high pressure through a perforated bottom of the container containing the wet solids. The wet solids are lifted from the bottom and suspended in a stream of air (fluidized state). The hot air then surrounds every granules. Heat transfer is accomplished by direct contact between the wet solid and hot gases. The vapourized liquid is carried away by the drying gasses. Sometimes to save energy, the exit gas is partially recycled.

The choice of distributor used during and drying process apart from ensuring uniform and stable fluidization also prevents

1. Poor fluidization quality of solids in certain regions in the fluidized bed dryer.
2. Plugging of distributor –perforated holes.
3. Solids from dropping into wind box or gas plenum located beneath the fluidized bed.

The pressure drops across the distributor, must be high enough to ensure good and uniform fluidization.

Contents

Parameters to be controlled in fluidized bed dryers (system)

In order to improve operation, efficiency and reproduability of a fluidized bed dryer, some parameters need to be controlled. These parameters are categorized into:

- Apparatus parameters: Those controlled by equipment.
- Process parameters: These controlled by process.
- Product parameters: Those controlled by product.

Apparatus/Equipment Parameter

- **Position of the air distribution plate**: This parameter influences the pattern.
- **Shape of the instrument**: The annular based design gives better product.
- **Nozzle height:** Nozzle height plays a vital role when fluidized bed dryer is used as a coating machine. The atomized coating solution should not get dried before reaching the tablet surface.

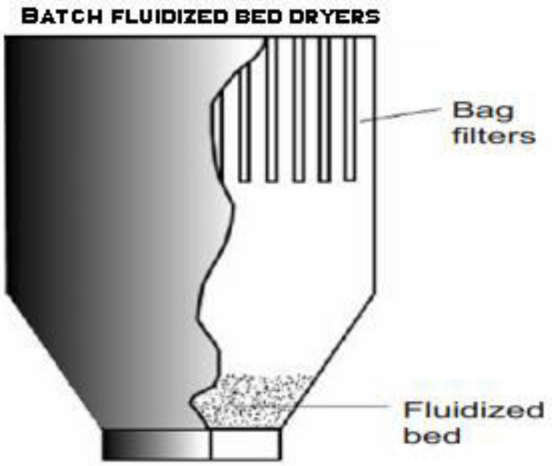
Process/Operating Parameter

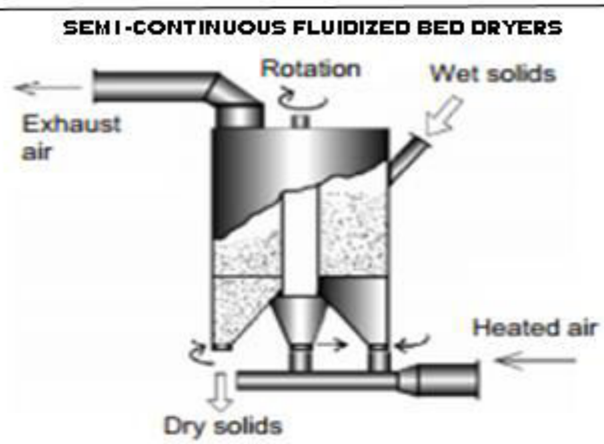
- **Temperature**: Increased temperature leads to increased moisture diffusivity and hence increased drying rate and decreased drying time. The nature of the material plays an important role in the choosing operating temperature.
- **Humidity:** Faster drying is achieved when the moisture content of the inlet air is maintained at its minimum.
- **Air flow rate/gas velocity**: Increasing gas velocity increases drying rate but should be maintained at optimized rate (not to fast or too slow). Gas velocity has no effect on particles with high internal resistance to moisture transfer.

Product Parameters

- Moisture content of the feed material.
- Feed rate/batch size.
- Product moisture content.
- Particle size, shape and diameter.

There are various types of fluidized bed dryer and an individual's familiarity with the specific characteristics of these various types enables one to make a logical and cost effective selection of fluidized bed dryer for a drying operation. In many instances, several different types may provide similar performance at the same cost. It should be noted also that not all modified fluidized bed dryers are necessarily better than the conventional dryers in terms of product quality, or energy efficiency, or drug performance.





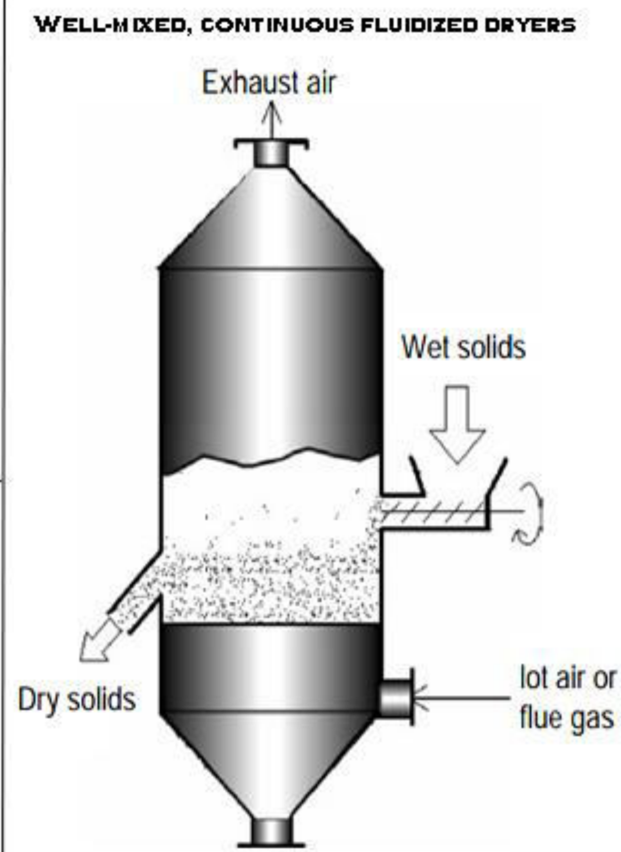


PHOTO CREDIT: HANDBOOK OF INDUSTRIAL DRYING, TAYLOR& FRANCIS GROUP, LLC.

Conventional fluidized bed dryers include;

- Batch fluidized bed dryers.
- Semi-continuous fluidized bed dryers.
- Well-mixed, continuous fluidized dryers.
- Plug flow fluidized bed dryer.

Various types of modified fluidized bed dryers have been developed and are applied in many industrial processes to overcome some of the problems encountered while using conventional fluidized bed dryer and for a drying process. They include but not limited to;

- Hybrid fluidized bed dryers
- Pulsating fluidized bed dryers
- Fluidized bed dryer with immersed heat exchange.
- Mechanically assisted fluidized bed dryer.
- Vibrated fluidized bed dryer.
- Agitated fluidized bed dryer/swirl fluidizers.
- Fluidized bed dryers of inert particles.
- Spouted bed dryer.
- Recirculating fluidized bed dryer.

- Jetting fluidized bed dryer.
- Super heated steam fluidized bed dryer.
- Fluidized bed freeze dryer.
- Heat pump fluidized dryers.

Pharmaceutical uses of fluidized bed dryers

- Used to make effervescent granulations

Advantages of Fluidized bed Dryer

- High rates of moisture removal due to excellent gas-particle constant which results to high heat and mass transfer rates.
- High thermal efficiency is usually achieved if part of the thermal energy for drying is supplied by internal heat exchanger
- Lower capital and maintenance cost
- Reduced contact time for drying.
- Ease of control.

Disadvantages of Fluidized Dryer

- High pressure drops results as a result of the need to suspend the entire bed in gas which equally leads to high energy consumption.
- Requires increased gas handling due to extensive recirculation of exhausts gas for high thermal efficiency operation.
- Poor fluidization and low flexibility especially if the feed is too wet.
- Not the best choice of equipment when organic solvents need to be removed during drying.
- Non uniform product quality for certain types of fluidized bed dryer.
- Entertainment of fine particles.
- High potential of attrition; and in some cases agglomeration of fine particles.
- The conventional hot air fluidized bed dryer is not a good choice of dryer when handling toxic or flammable solids since there is danger of fire or explosion of flammability limits are exceeded.

Freeze Dryer

Freeze drying is the removal of ice or other frozen solvents from a material through the process of sublimation and the removal of bound water molecules through the process of desorption.

Lyophilization and freeze drying are terms that are used interchangeably depending on the industry and location where the drying is taking place. Controlled freeze drying keeps the product temperature low enough during the process to avoid changes in the dried product appearance and characteristics. It is an excellent method for preserving a wide variety of heat-sensitive materials such as proteins, microbes, pharmaceuticals, tissues & plasma.

SUBLIMATION

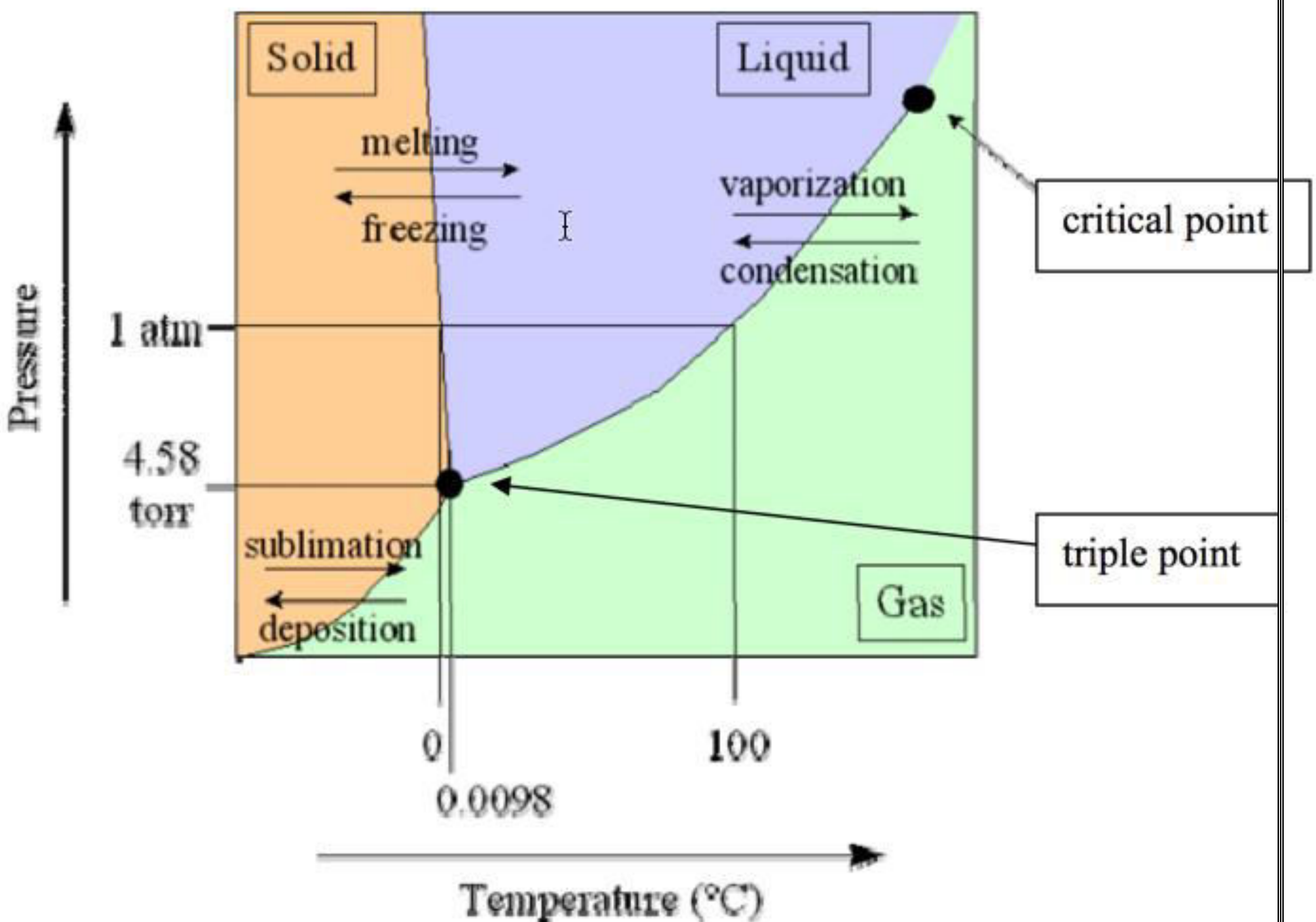
Sublimation is when a solid (ice) changes directly to a vapor without first going through a liquid (water) phase. Thoroughly understanding the concept of sublimation is a key building block to gaining knowledge of freeze drying.

As shown below on the phase diagram for water, low pressures are required for sublimation to take place.

Sublimation is a phase change and heat energy must be added to the frozen product for it to occur.

Sublimation in the freeze drying process can be described simply as:

1. FREEZE - The product is completely frozen, usually in a vial, flask or tray.
2. VACUUM - The product is then placed under a deep vacuum, well below the triple point of water.
3. DRY – Heat energy is then added to the product causing the ice to sublime.



The steps required to lyophilize a product in a batch process can be summarized as follows:

- Pretreatment / Formulation
- Loading / Container (Bulk, Flask, Vials)
- Freezing (Thermal Treatment) at atmospheric pressure
- Primary Drying (Sublimation) under vacuum
- Secondary Drying (Desorption) under vacuum
- Backfill & Stoppering (for product in vials) under partial vacuum
- Removal of Dried Product from Freeze Dryer

In addition to providing an extended shelf-life, successful freeze-drying should yield a product that has a short reconstitution time with acceptable potency levels. The process should be repeatable with well defined temperature, pressure and time parameters for each step. Visual and functional characteristics of the dried product are also important for many applications.

FREEZE DRYING EQUIPMENT

The main components of freeze drying equipment are:

- Refrigeration System
- Vacuum System
- Control System
- Product Chamber or Manifold
- Condenser

PHYSICAL PROPERTIES OF MATERIALS AND FORMULATION

Understanding the physical properties of materials that are freeze-dried is a key part in developing a successful lyophilization process. Although a few products are simple crystalline materials, the vast majority of products that are lyophilized are amorphous and form glassy states when frozen.

Processing and formulation development are important steps often taken to make a product ready for freeze drying and usable for its specific application. The choice of excipients added to a formulation can severely affect the thermal characteristics of the product and its ability to be freeze dried in a reasonable amount of time.

RECIPE FOR FREEZE DRYING

Lyophilization in a shelf freeze dryer requires the design of a working process or cycle which is sometimes referred to as a "recipe". Typically, there are multiple steps involved for both freezing and drying of the product. Individual temperature, pressure and time settings need to be determined for each step.

Each specific product or formulation that is lyophilized requires the development of a freeze drying process that is based on the unique characteristics of the product, the amount of product and the container used. There is no universal "safe" recipe that will work with every product.

FREEZING

It is extremely important that the sample be fully and completely frozen prior to pulling a vacuum and starting the drying process. Unfrozen product may expand outside of the container when placed under a vacuum.

With simple manifold freeze dryers, the product is placed in a vial or flask depending on quantity, and then frozen in a separate piece of equipment. Options include standard laboratory freezers, shell baths, and direct immersion in liquid nitrogen.

Shell (bath) freezing involves rotating a flask containing the sample in a freezing bath so the sample freezes on the walls of the flask. This freezing method maximizes the product surface area and minimizes its thickness. It is best not to freeze a large block of sample in the bottom of a flask because the sample will be too thick for efficient water removal. Also, the flask might break due to uneven stress.

Flask Shell Freezing in a Shell Bath

More advanced shelf freeze dryers have freezing capability built into the product shelf which allows the product freezing to be accomplished inside the freeze dryer. Product is either pre-loaded into vials which are then transferred to the shelf or it is loaded in bulk form directly onto a product tray.

Shelf freeze dryers allow the precise control of cooling rates which affects product freezing rates and crystal size. Larger ice crystals improve the speed of the freeze drying process because of the larger vapor pathways left behind in the dried portion of the product as the ice crystals are sublimated.

Slower shelf cooling rates do not necessarily yield larger ice crystals because of the effects of super-cooling. When the super-cooled liquid finally freezes, it happens extremely quickly resulting in smaller ice crystals. In a clean room environment with very few particulates for ice nucleation, there is a significantly greater amount of super-cooling.

Some biological products can not tolerate large ice crystals and they must be freeze dried with smaller ice crystal sizes.

PRIMARY DRYING

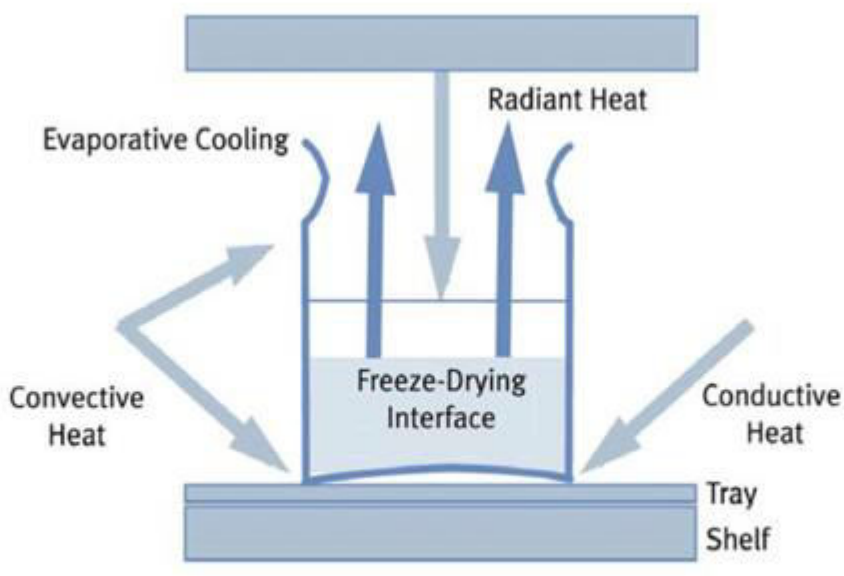
The drying portion of freeze drying is actually a two part process consisting of Primary Drying and Secondary Drying. The bulk of water removed from the product during freeze drying is via sublimation of all of the free ice crystals during the primary drying step. Organic solvents are also removed during primary drying.

Primary drying (sublimation) is a slow process conducted at cooler temperatures, safely below the product's critical collapse temperature. Sublimation requires heat energy to drive the phase change process from solid to gas. All three methods of heat transfer - conduction, convection and radiation, must be considered when freeze drying a product.

In a simple manifold dryer, heat is transferred to the flask/product primarily through convection and radiation from the surrounding environment. With little control over heat flow into the product, it is more difficult to control the process. When working with products with low collapse temperatures, it may be necessary to wrap or insulate the flask to slow down the rate of heat transfer and avoid collapse.

In a shelf freeze dryer, most of the heat is transferred into the product through conduction and it is important to maximize the surface contact of the product/container/tray with the shelf. However, the effects of radiation and convection also need to be considered for product uniformity and process control purposes.

Radiant heat from the inside walls of the product chamber will cause product/vials on the perimeter of the shelf to dry more quickly than product in the center of the shelf (known in freeze-drying as the "edge effect"). Radiation coming through the acrylic doors commonly used on pilot and R&D freeze dryers has an even greater effect and product located in the front of these dryers will typically dry the fastest of all. For this reason, production freeze dryers are designed with metal doors and small view ports. A piece of aluminum foil can be hung in front of the product on the inside of a pilot freeze dryer as a shield – of course this will block the view of the product and not allow observation during the process.



<u>Heat Transfer in a Shelf Freeze Dryer</u>

SECONDARY DRYING

In addition to the free ice that is sublimed during primary drying, there remains a substantial amount of water molecules that are bound to the product. This is the water that is removed (desorbed) during secondary drying. Since all of the free ice has been removed in primary drying, the product temperature can now be increased considerably without fear of melting or collapse.

Secondary drying actually starts during the primary phase, but at elevated temperatures (typically in the 30ºC to 50ºC range), desorption proceeds much more quickly. Secondary drying rates are dependant on the product temperature. System vacuum may be continued at the same level used during primary drying; lower vacuum levels will not improve secondary drying times.

Amorphous products may require that the temperature increase from primary to secondary drying be controlled at a slow ramp rate to avoid collapse.

Secondary drying is continued until the product has acceptable moisture content for long term storage. Depending on the application, moisture content in fully dried products is typically between 0.5% and 3%. In most cases, the more dry the product, the longer its shelf life will be. However, certain complex biological products may actually become too dry for optimum storage results and the secondary drying process should be controlled accordingly.

Advantages

Once the water is removed from foods, they become very light. This makes for easier portability of large amounts of food and cheaper transportation of the food. Freeze-dried foods tend to retain most of their nutritional quality, taste, shape and size. They do not require refrigeration, and can last for months or years. Freeze-dried foods can also be rehydrated very quickly, unlike dehydrated foods.

Disadvantages

The main disadvantage of freeze-dried foods is that they are quite expensive due to the specialized equipment needed for this process. Freeze-dried foods also take up almost as much space as fresh foods, while dehydrated foods take up less space.

Solar Dryer-The solar dryer is a relatively simple concept. The basic principles employed in a solar dryer are:

- Converting light to heat: Any black on the inside of a solar dryer will improve the effectiveness of turning light into heat.

- Trapping heat: Isolating the air inside the dryer from the air outside the dryer makes an important difference. Using a clear solid, like a plastic bag or a glass cover, will allow light to enter, but once the light is absorbed and converted to heat, a plastic bag or glass cover will trap the heat inside. This makes it possible to reach similar temperatures on cold and windy days as on hot days.
- Moving the heat to the food. Both the natural convection dryer and the forced convection dryer use the convection of the heated air to move the heat to the food.

There are a variety of solar dryer designs. Principally, solar dryers can be categorized into three groups: a) natural convection dryers, which are solar dryers that use the natural vertical convection that occurs when air is heated and b) forced convection dryers, in which the convection is forced over the food through the use of a fan and c) tunnel dryers.

While several different designs of the solar dryers exist, the basic components of a solar dryer are illustrated in Figure 1. In the case of a forced convection dryer, an additional component would be the fan.

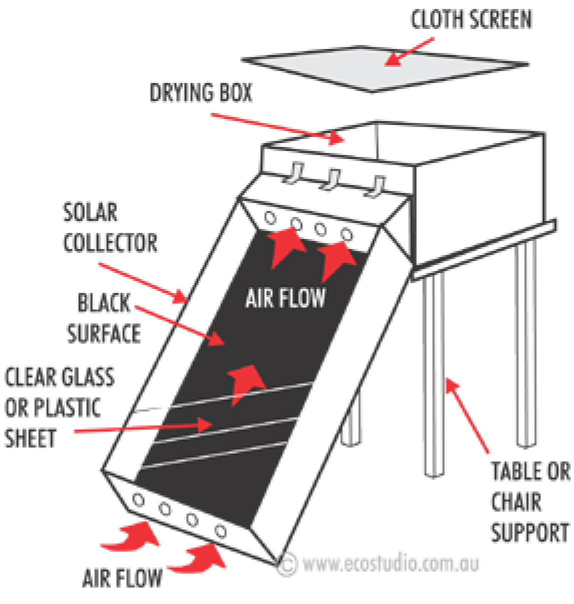


Figure 1: Basic components of a solar dryer.

The structure of a tunnel dryer is relatively simple. The basic design components of a tunnel dryer are the following:

- A semi circular shaped solar tunnel in the form of a poly house framed structure with UV stabilized polythene sheet
- The structure is, in contrast to the other dryer designs, large enough for a person to enter

The design of a tunnel dryer is illustrated in Figure 2. In addition, the technology teaser image at the top of this description is an image of the inside of a tunnel dryer.

Figure 2: A basic design of the tunnel solar dryer

Natural Convection Dryer Large scale design

Generally, natural convection dryers are sized appropriately for on-farm use. One design that has undergone considerable development by the Asian Institute of Technology in Bangkok, Thailand is shown in Figure 3. This natural covenction dryer is a large scale structure: the collector is 4.5 meters long and 7 meters wide and the drying bin is 1 meter long and 7 meters wide. The structure consists of three main components: a solar collector, a drying bin and a solar chimney. The drying bin in this design is made of bamboo matting. In addition to the collector, air inside the solar chimney is heated which also increases the thermal draught through the dryer. The solar chimney is covered with black plastic sheet in order to increase the thermal absorption. A disadvantage of the dryer is its high structural profile which poses stability problems in windy conditions, and the need to replace the plastic sheet every 1-2 years.

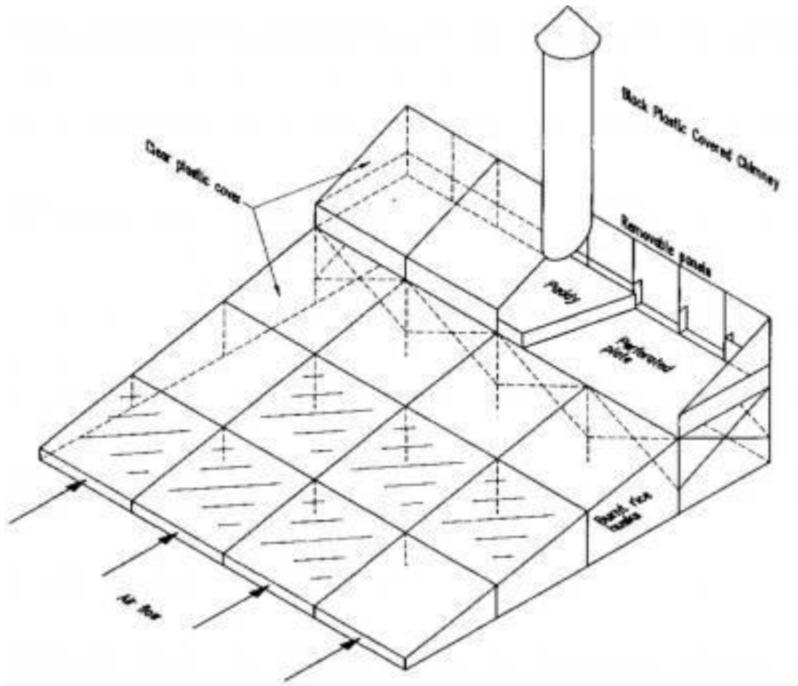


Figure 3: Natural Convection Solar Dryer (Click image to enlarge) Source: FAO, no date
http://www.fao.org/docrep/t1838e/T1838E0v.htm

Figure 4 shows a smaller design for a natural convection dryer. The capacity of this dryer is ten times smaller than the capacity for food drying in the larger design. However, the design is simple to build and is less susceptible to stability problems.

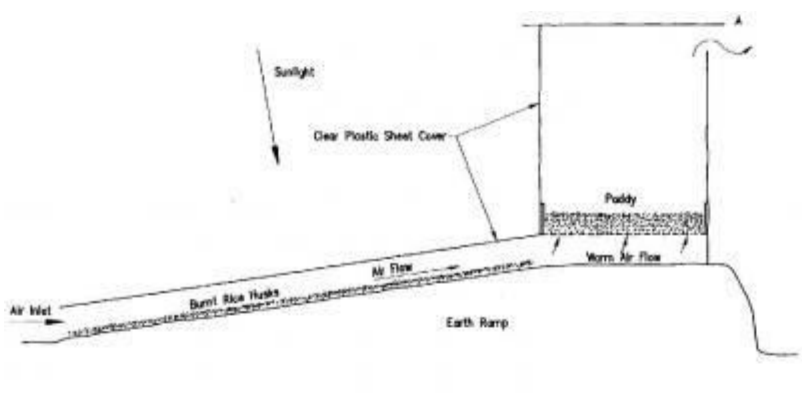


Figure 4: Small scale solar dryer (click image to enlarge). Source: FAO, no date.
http://www.fao.org/docrep/t1838e/T1838E0v.htm

Natural Convection dryer small scale design

These solar food dryers are basically wooden boxes with vents at the top and bottom. Food is placed on screened frames which slide into the boxes. A properly sized solar air heater with south-facing plastic glazing and a black metal absorber is connected to the bottom of the boxes.

Air enters the bottom of the solar air heater and is heated by the black metal absorber. The warm air rises up past the food and out through the vents at the top (see Figure 5). While operating, these dryers produce temperatures of 130–180° F (54–82° C), which is a desirable range for most food drying and for pasteurization. With these dryers, it’s possible to dry food in one day, even when it is partly cloudy, hazy, and very humid. Inside, there are thirteen shelves that will hold 35 to 40 medium sized apples or peaches cut into thin slices.

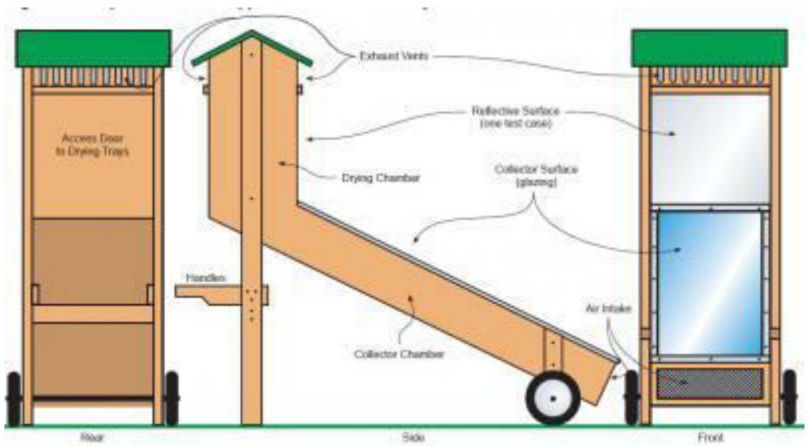


Figure 5: Small natural convection solar dryer design.(click image to enlarge) Source: HomePower, 1999

In the case of forced convection dryers, the structure can be relatively similar. However, the forced convection dryer requires a power source for the fans to provide the air flow. The forced convection dryer doesn't require an incline for the air flow however, the collector can be placed horizontallly with the fan at one end and the drying bin at the other end. In addition, the forced convection dryer is less dependent on solar energy as it provides the air flow itself; this allows the design to work in weather conditions in which the natural convection dryer doesn't work. As inadequate ventilation is a primary cause of loss of food in solar food dryers, and is made worse by intermittent heating, it is essential to realize proper ventilation. Adding a forced convection flow, for instance provided through a PV- solar cell connected to a fan, will prevent the loss of food.

Rotary dryer

The **rotary dryer** is a type of industrial dryer employed to reduce or minimize the liquid moisture content of the material it is handling by bringing it into direct contact with a heated gas.

Single Shell Rotary Drum Dryer

The dryer is made up of a large, rotating cylindrical tube, usually supported by concrete columns or steel beams. The dryer slopes slightly so that the discharge end is lower than the material feed end in order to convey the material through the dryer under gravity. Material to be dried enters the dryer, and as the dryer rotates, the material is lifted up by a series of internal fins lining the inner wall of the dryer. When the material gets high enough to roll back off the fins, it falls back down to the bottom of the dryer, passing through the hot gas stream as it falls. This gas stream can either be moving toward the discharge end from the feed end (known as co-current flow), or toward the feed end from the discharge end (known as counter-current flow). The gas stream can be made up of a mixture of air and combustion gases from a burner, in which case the dryer is called a direct heated dryer. Alternatively, the gas stream may consist of air or another (sometimes inert) gas that is preheated. When the gas stream is preheated by some means where burner combustion gases do not enter the dryer, the dryer known as an indirect-heated type. Often, indirect heated dryers are used when product contamination is a concern. In some cases, a combination of direct-indirect heated rotary dryers are also available to improve the overall efficiency.

Brief Introduction Rotary dryer is suitable to dry metallic and nonmetallic mineral, clay in cement industrial and coal slime in coal mine etc. Rotary dryer can be widely used to dry various materials, and it is simple to be operated.

Applications

Rotary Dryers have many applications but are most commonly seen in the mineral industry for drying sands, limestone, stones and soil, ores, fertilizers, wood chips, coal, iron sulphate, filter cakes, sewage sludge, etc.

Can also be applied on food industry mainly for liquids as well as for granular material such as food grains, cereals, pulses, coffee beans, fermented tea leaves, etc

TunnelDryer -

Tunnel dryer is a direct continuous type of dryer. It is a largest scale dryer.

Principle: In this dryer, the materials to be dried are sent to the air heated tunnel for drying purpose. The material is entered at one end and the dried material is colleted at the other end of the tunnel. The outgoing material met the incoming air to ensure maximum drying and the out going air contacted the wettest material so that the air was as nearly saturated as possible.

Mechanism of action: One of the doors of the tunnel is opened and the materials to be dried are placed to the trolleys and trucks are pushed slowly in the tunnel and then door is closed. Hot air is circulated and passed through the rail truck and perforated trolleys. The hot air then followed are recirculated with the help of fans and the material becoming dried. The moist air is passed out through the exhaust after completion of drying. The door is opened and the trolleys are taken out of the funnel and some new trolleys with the wet materials are introduced into the trucks and the process is repeated.

Application:

1. In research laboratories and QC department for drying glass wires and small apparatus.
2. In drying of packaging materials plastic caps, spoons, injectable vials, glass containers, etc.
3. In sterilization of containers.

Advantages:

1. Comparing with the compartmental dryers tunnel dryers has the advantage of continuous operation.
2. A large amount of materials can be dried.
3. Tunnel dryers are used for drying of paraffin wax, gelatin, soap, pottery, etc.

Disadvantages:

1. High labor cost for loading and unloading.
2. Thermolabile substances can't be dried.
3. Drying rage is slow, so time consuming.
4. It is not suitable for small scale production.
5. It is a non-agitated process.
6. Drying of liquid materials is not possible.
7. There is a chance of accident when doors are opened before stopping the hot air circulation.

LSU (Louisiana State University) Dryer

Design of Husk Fire Furnace- Preliminary combustion studies of rice husk in a pot furnace indicated an optimum rate of combustion to be 70 kg husk/m2 hr with 60 percent excess air. The following considerations were incorporated in designing a husk-fired furnace:

1. Setting up a mixing chamber adjoining the furnace, in which the missing of the products of the products of combustion with ambient air should take place inorder to attain the necessary temperature off the gas-air mixture

2. Arresting the flying ash and sparks from going into the drying chamber.

3. An arrangement permitting the rapid change in the direction of the flue gases either to the chimney or to the drying chamber.

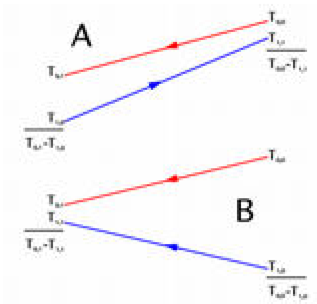
4. The furnace should ensure the best combustion of the fuel.

MODULE IV

HEAT EXCHANGER

A **heat exchanger** is a device used to transfer heat between a solid object and a fluid, or between two or more fluids. The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment. The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air. Another example is the heat sink, which is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant.

Flow arrangement



Countercurrent (A) and parallel (B) flows

There are three primary classifications of heat exchangers according to their flow arrangement. In *parallel-flow* heat exchangers, the two fluids enter the exchanger at the same end, and travel in parallel to one another to the other side. In *counter-flow* heat exchangers the fluids enter the exchanger from opposite ends. The counter current design is the most efficient, in that it can transfer the most heat from the heat (transfer) medium per unit mass due to the fact that the average temperature difference along any unit length is *higher*. See countercurrent exchange. In a *cross-flow* heat exchanger, the fluids travel roughly perpendicular to one another through the exchanger.

For efficiency, heat exchangers are designed to maximize the surface area of the wall between the two fluids, while minimizing resistance to fluid flow through the exchanger. The exchanger's performance can also be affected by the addition of fins or corrugations in one or both directions, which increase surface area and may channel fluid flow or induce turbulence.

The driving temperature across the heat transfer surface varies with position, but an appropriate mean temperature can be defined. In most simple systems this is the "log mean temperature difference" (LMTD). Sometimes direct knowledge of the LMTD is not available and the NTU method is used.

Types

There are different types of heat exchangers used in food industry for different products.

Double pipe heat exchangers are the simplest exchangers used in industries. On one hand, these heat exchangers are cheap for both design and maintenance, making them a good choice for small industries. On the other hand, their low efficiency coupled with the high space occupied in large scales, has led modern industries to use more efficient heat exchangers like shell and tube or plate. However, since double pipe heat exchangers are simple, they are used to teach heat exchanger design basics to students as the fundamental rules for all heat exchangers are the same

Double pipe heat exchanger

Double pipe heat exchanger design is rather straightforward. It uses one heat exchanger pipe inside another. After determining the required heat exchanger surface area, for either counter flow or parallel flow, the pipe sizes and number of bends for the double pipe heat exchanger can be selected.

- **Introduction**

In double pipe heat exchanger design, an important factor is the type of flow pattern in the heat exchanger. A double pipe heat exchanger will typically be either counterflow or parallel flow. Crossflow just doesn't work for a double pipe heat exchanger. The flow pattern and the required heat exchange duty allows calculation of the log mean temperature difference. That together with an estimated overall heat transfer coefficient allows calculation of the required heat transfer surface area. Then pipe sizes, pipe lengths and number of bends can be determined.

- **General Configuration and Characteristics of a Double Pipe Heat Exchanger**

A double pipe heat exchanger, in its simplest form is just one pipe inside another larger pipe. One fluid flows through the inside pipe and the other flows through the annulus between the two pipes. The wall of the inner pipe is the heat transfer surface. The pipes are usually doubled back multiple times as shown in the diagram at the left, in order to make the overall unit more compact.

The term 'hairpin heat exchanger' is also used for a heat exchanger of the configuration in the diagram. A hairpin heat exchanger may have only one inside pipe, or it may have multiple inside tubes, but it will always have the doubling back feature shown. . Some heat exchanger manufacturers advertise the availability of finned tubes in a hairpin or double pipe heat exchanger. These would always be longitudinal fins, rather than the more common radial fins used in a crossflow finned tube heat exchanger.

- **Counterflow and Parallel Flow in a Double Pipe Heat Exchanger**

A primary advantage of a hairpin or double pipe heat exchanger is that it can be operated in a true counterflow pattern, which is the most efficient flow pattern. That is, it will give the

highest overall heat transfer coefficient for the double pipe heat exchanger design.
Also, hairpin and double pipe heat exchangers can handle high pressures and temperatures well. When they are operating in true counterflow, they can operate with a temperature cross, that is, where the cold side outlet temperature is higher than the hot side outlet temperature.

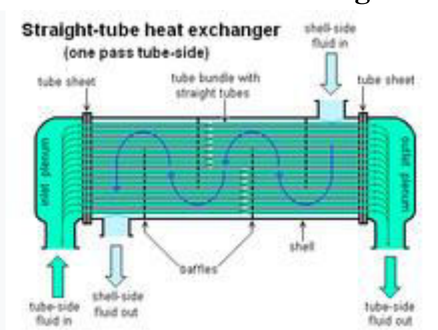
For example, in the diagrams in this section, consider Fluid 1 to be the hot fluid and Fluid 2 to be the cold fluid. Then, in the counterflow diagram at the left, you can see that the cold side outlet temperature, T_{2out}, can approach the hot side entering temperature, T_{1in}, which is higher than the hot side outlet temperature, T_{2out}. For the parallel flow shown at the right, T_{2out} can only approach T_{1out}; it could not be greater.

- **Double Pipe Heat Exchanger Design**

Determination of the heat transfer surface area needed for a double pipe heat exchanger design can be done using the basic heat exchanger equation: $Q = UA\ \Delta T_{lm}$, where:
Q is the rate of heat transfer between the two fluids in the heat exchanger in Btu/hr,

U is the overall heat transfer coefficient in BTU/hr-ft^2-^{o}F,
A is the heat transfer surface area in ft^2, and

ΔT_{lm} is the log mean temperature difference in ^{o}F, calculated from the inlet and outlet temperatures of both fluids. Shell and tube heat exchanger



A shell and tube heat exchanger

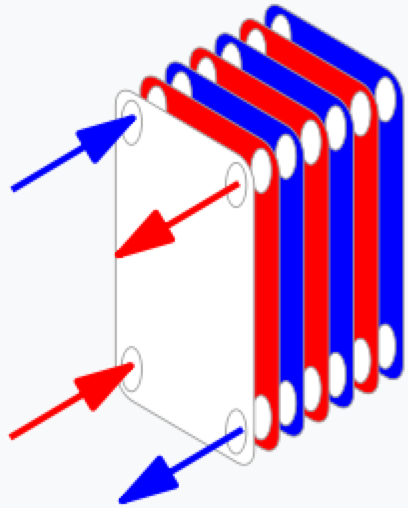
Main article: Shell and tube heat exchanger

Shell and tube heat exchangers consist of series of tubes. One set of these tubes contains the fluid that must be either heated or cooled. The second fluid runs over the tubes that are being heated or cooled so that it can either provide the heat or absorb the heat required. A set of tubes is called the tube bundle and can be made up of several types of tubes: plain, longitudinally finned, etc. Shell and tube heat exchangers are typically used for high-pressure applications (with pressures greater than 30 bar and temperatures greater than 260 °C).[2]This is because the shell and tube heat exchangers are robust due to their shape.
Several thermal design features must be considered when designing the tubes in the shell and tube heat exchangers: There can be many variations on the shell and tube design. Typically, the ends of each tube are connected to plenums (sometimes called water boxes) through holes in tubesheets. The tubes may be straight or bent in the shape of a U, called U-tubes.

- Tube diameter: Using a small tube diameter makes the heat exchanger both economical and compact. However, it is more likely for the heat exchanger to foul up faster and the small size makes mechanical cleaning of the fouling difficult. To prevail over the fouling and cleaning problems, larger tube diameters can be used. Thus to determine the tube diameter, the available space, cost and fouling nature of the fluids must be considered.
- Tube thickness: The thickness of the wall of the tubes is usually determined to ensure:
  - There is enough room for corrosion

    - That flow-induced vibration has resistance
    - Axial strength
    - Availability of spare parts
    - Hoop strength (to withstand internal tube pressure)
    - Buckling strength (to withstand overpressure in the shell)
- Tube length: heat exchangers are usually cheaper when they have a smaller shell diameter and a long tube length. Thus, typically there is an aim to make the heat exchanger as long as physically possible whilst not exceeding production capabilities. However, there are many limitations for this, including space available at the installation site and the need to ensure tubes are available in lengths that are twice the required length (so they can be withdrawn and replaced). Also, long, thin tubes are difficult to take out and replace.
- Tube pitch: when designing the tubes, it is practical to ensure that the tube pitch (i.e., the centre-centre distance of adjoining tubes) is not less than 1.25 times the tubes' outside diameter. A larger tube pitch leads to a larger overall shell diameter, which leads to a more expensive heat exchanger.
- Tube corrugation: this type of tubes, mainly used for the inner tubes, increases the turbulence of the fluids and the effect is very important in the heat transfer giving a better performance.
- Tube Layout: refers to how tubes are positioned within the shell. There are four main types of tube layout, which are, triangular (30°), rotated triangular (60°), square (90°) and rotated square (45°). The triangular patterns are employed to give greater heat transfer as they force the fluid to flow in a more turbulent fashion around the piping. Square patterns are employed where high fouling is experienced and cleaning is more regular.
- Baffle Design: baffles are used in shell and tube heat exchangers to direct fluid across the tube bundle. They run perpendicularly to the shell and hold the bundle, preventing the tubes from sagging over a long length. They can also prevent the tubes from vibrating. The most common type of baffle is the segmental baffle. The semicircular segmental baffles are oriented at 180 degrees to the adjacent baffles forcing the fluid to flow upward and downwards between the tube bundle. Baffle spacing is of large thermodynamic concern when designing shell and tube heat exchangers. Baffles must be spaced with consideration for the conversion of pressure drop and heat transfer. For thermo economic optimization it is suggested that the baffles be spaced no closer than 20% of the shell’s inner diameter. Having baffles spaced too closely causes a greater pressure drop because of flow redirection. Consequently, having the baffles spaced too far apart means that there may be cooler spots in the corners between baffles. It is also important to ensure the baffles are spaced close enough that the tubes do not sag. The other main type of baffle is the disc and doughnut baffle, which consists of two concentric baffles. An outer, wider baffle looks like a doughnut, whilst the inner baffle is shaped like a disk. This type of baffle forces the fluid to pass around each side of the disk then through the doughnut baffle generating a different type of fluid flow.

Fixed tube liquid-cooled heat exchangers especially suitable for marine and harsh applications can be assembled with brass shells, copper tubes, brass baffles, and forged brass integral end hubs..



Conceptual diagram of a plate and frame heat exchanger.

A single plate heat exchanger

An interchangeable plate heat exchanger applied to the system of a swimming pool

Plate heat exchangers

Another type of heat exchanger is the plate heat exchanger. These exchangers are composed of many thin, slightly separated plates that have very large surface areas and small fluid flow passages for heat transfer. Advances in gasket and brazing technology have made the plate-type heat exchanger increasingly practical. In HVAC applications, large heat exchangers of this type are called *plate-and-frame*; when used in open loops, these heat exchangers are normally of the gasket type to allow periodic disassembly, cleaning, and inspection. There are many types of permanently bonded plate heat exchangers, such as dip-brazed, vacuum-brazed, and welded plate varieties, and they are often specified for closed-loop applications such as refrigeration. Plate heat exchangers also differ in the types of plates that are used, and in the configurations of those plates. Some plates may be stamped with "chevron", dimpled, or other patterns, where others may have machined fins and/or grooves.

When compared to shell and tube exchangers, the stacked-plate arrangement typically has lower volume and cost. Another difference between the two is that plate exchangers typically serve low to medium pressure fluids, compared to medium and high pressures of shell and tube. A third and important difference is that plate exchangers employ more countercurrent flow rather than cross current flow, which allows lower approach temperature differences, high temperature changes, and

increased efficiencies.

Scraped surface heat exchanger

Another type of heat exchanger is called "(dynamic) scraped surface heat exchanger". This is mainly used for heating or cooling with high-viscosity products, crystallization processes, evaporation and high-fouling applications. Long running times are achieved due to the continuous scraping of the surface, thus avoiding fouling and achieving a sustainable heat transfer rate during the process.

Extended Surface or Finned tube heat exchanger

Finned tube heat exchanger for heat transfer between air, gas and liquids or steam. Heat exchanger with finned heating surfaces, so-called finned tube heat exchanger, offer the possibility of heat transfer between gases and liquids significantly space-saving and is more efficient to implement than it is possible with straight tubes. Maxxtec finned tube heat exchangers are designed to transfer heat from clean air and gases with high efficiency on liquids or vapors, and vice versa. In this way the media can be heated, cooled or condensed, in a closely space. Finned tube heat exchangers can be used for different applications and in a variety of designs. Maxxtec offers various heat exchangers for economizer, air heater, heaters for gases, air heaters or capacitors in fin-tube design.

Application examples for finned tube heat exchanger:

Finned tube heat exchangers are often used in power plants as an exhaust gas heat exchanger to increase the efficiency factor. Further applications in power plants are the preheating of combustion air as well as the condensation of exhaust steam from steam or ORC turbines.

In industrial dryers finned tube heat exchangers will be used for heating of air by hot water, steam or thermal oil in large quantities.

In many industrial production processes, such as for the air conditioning of buildings, finned tube heat exchangersare used as an air cooler for cooling down or re-cooling of liquids. Due to the problems with Legionella, the high consumption of fresh water, as well as the elaborate water treatment, closed cooling circuits with finned tube heat exchangers will be used instead of cooling towers with open water circuit.

Advantages-

- Robust construction of finned tube heat exchanger that can withstand contrarious operating conditions over a long period.
- Maximum transmission quality
- High condensation rate
- Wide application and temperature spectrum (range)
- Very good value for money
- Ideal for gas-liquid or gas-vapor heat transfer
- Available as stainless steel finned tube heat exchanger
- Highest reliability of operation through extensive quality inspection
- Many years of experience in various fields of application

Theory and operation of extrusion systems used in food industry

Macaroni is an extruded hollow pasta

Food extrusion is a form of extrusion used in food processing. It is a process by which a set of mixed ingredients are forced through an opening in a perforated plate or die with a design specific to the food, and is then cut to a specified size by blades. The machine which forces the mix through the die is an **extruder**, and the mix is known as the **extrudate**. The extruder consists of a large, rotating screw tightly fitting within a stationary barrel, at the end of which is the die.

Extrusion enables mass production of food via a continuous, efficient system that ensures uniformity of the final product. Food products manufactured using extrusion usually have a high starch content. These include some pasta, breads (croutons, bread sticks, and flat breads), many breakfast cereals and ready-to-eat snacks, confectionery, pre-made cookie dough, some baby foods, full-fat soy, textured vegetable protein, some beverages, and dry and semi-moist pet foods.

Process

A non-vacuum short goods pasta extruder from 1958

In the extrusion process, raw materials are first ground to the correct particle size, usually the consistency of coarse flour. The dry mix is passed through a pre-conditioner, in which other ingredients are added depending on the target product; these may be liquid sugar, fats, dyes, meats or water. Steam is injected to start the cooking process, and the preconditioned mix (extrudate) is then passed through an extruder. The extruder consists of a large, rotating screw tightly fitting within a stationary barrel, at the end of which is the die. The extruder's rotating screw forces the extrudate toward the die, through which it then passes. The amount of time the extrudate is in the extruder is the **residence time**.

The extruded product usually puffs and changes texture as it is extruded because of the reduction of forces and release of moisture and heat. The extent to which it does so is known as the **expansion ratio**. The extrudate is cut to the desired length by blades at the output of the extruder, which rotate about the die openings at a specific speed. The product is then cooled and dried, becoming rigid while maintaining porosity.

The cooking process takes place within the extruder where the product produces its own friction and heat due to the pressure generated (10–20 bar). The process can induce both protein denaturation and starch gelatinization under some conditions.

Many food extrusion processes involve a high temperature over a short time. Important factors of the extrusion process are the composition of the extrudate, screw length and rotating speed, barrel temperature and moisture, die shape, and rotating speed of the blades. These are controlled based on the desired product to ensure uniformity of the output.

Moisture is the most important of these factors, and affects the mix viscosity, acting to plasticize the extrudate. Increasing moisture will decrease viscosity, torque, and product temperature, and increase bulk density. This will also reduce the pressure at the die. Most extrusion processes for food processing maintain a moisture level below 40%, that is low to intermediate moisture. High-moisture extrusion is known as **wet extrusion**, but it was not used much before the introduction of twin screw extruders (TSE), which have a more efficient conveying capability. The most important rheological factor in the wet extrusion of high-starch extrudate is temperature

The amount of salt in the extrudate may determine the colour and texture of some extruded products. The expansion ratio and airiness of the product depend on the salt concentration in the extrudate, possibly as a result of a chemical reaction between the salt and the starches in the extrudate. Colour changes as a result of salt concentration may be caused by "the ability of salt to change the water activity of the extrudate and thus change the rate of browning reactions". Salt is also used to distribute minor ingredients, such as food colours and flavours, after extrusion; these are more evenly distributed over the product's surface after being mixed with salt.

Effects

- Destruction of certain naturally occurring toxins
- Reduction of microorganisms in the final product
- Slight increase of iron-bioavailability
- Creation of insulin-desensitizing starches (a potential risk-factor for developing diabetes)[7][8]
- Loss of lysine, an essential amino acid necessary for developmental growth and nitrogen management
- Simplification of complex starches, increasing rates of tooth decay
- Increase of glycemic index of the processed food, as the "extrusion process significantly increased the availability of carbohydrates for digestion"[10]
- Destruction of Vitamin A (beta-carotene)
- Denaturation of proteins.

Extruded Products

The various types of food products manufactured by extrusion typically have a high starch content. *Directly expanded* types include breakfast cereals and corn curls, and are made in high temperature, low moisture conditions under high shear. *Unexpanded* products include pasta, which is produced at intermediate moisture (about 40%) and low temperature. *Texturized* products include meat analogues, which are made using plant proteins ("textured vegetable protein") and a long die to "impart a fibrous, meat-like structure to the extrudate", and fish paste.[15] Confectionery made via extrusion includes chewing gum, liquorice, and toffee.

Some processed cheeses and cheese analogues are also made by extrusion. Processed cheeses extruded with low moisture and temperature "might be better suited for manufacturing using extrusion technology" than those at high moisture or temperature. Lower moisture cheeses are firmer and chewier, and cheddar cheese with low moisture and an extrusion temperature of 80 °C was preferred by subjects in a study to other extruded cheddar cheese produced under different conditions. An extrudate mean residence time of about 100 seconds can produce "processed cheeses or cheese analogues of varying texture (spreadable to sliceable)".

Other food products often produced by extrusion include some breads (croutons, bread sticks, and flat breads), various ready-to-eat snacks, pre-made cookie dough, some baby foods, some beverages, and dry and semi-moist pet foods. Specific examples include cheese curls, macaroni, Fig Newtons, jelly beans, sevai, and some french fries. Extrusion is also used to modify starch and to pellet animal feed.

Comparing with single screw extruder, twin screw extruder has several advantages:

1. Lower energy consumption. The power consumption of the twin screw extruder is about 30% lower than single rod extruder.
2. Excellent exhaust ability. This is self-cleaning function of intermeshing extruder make the material obtain a complete surface renewal during the degassing section.
3. Easy material feeding. As the twin screw extruder is transported by the principle of positive displacement material,So you can add high viscosity or very low material and ribbon, paste, powder and so on.
4. Suitable for heat-sensitive materials. Material in the twin screw extruder stay a short time with less heat friction.
5. More easy way for extruder screw and barrel disassemble, clean and replace. Extruder barrel also have self-cleaning function.
6. Excellent compounding, plasticizing ability

Advantages & Disadvantages Extrusion Process

- **Advantages**
  - Continuous
  - High production volumes
  - Low cost per pound
  - Efficient melting
  - Many types of raw materials
  - Good mixing (compounding)

- **Disadvantages**
  - Limited complexity of parts

- Uniform cross-sectional shape only

MODEL QUESTIONS

Subject: Food Process Engineering

Subject code : FT-503

Stream : Food Technology (5th Semester)

GROUP – A

i) In plate heat exchanger the plates are corrugated a)to enhance the rigidity of the plates, b)to improve heat transfer, c)both of these, d)none of these.

ii)In shell & tube heat exchanger, the baffles a)give support to the entire structure, b)enhance heat transfer, c)both of these, d)none of these.

iii)LMTD is used when ΔT_A & ΔT_B a)exactly same, b)almost same, c)not very close to each other, d)none of these.

iv)When ΔT_A & ΔT_B are equal or very close to each other, the ΔT_L is taken as a)LMTD, b)arithmetic mean of temp. differences, c)both of these. d)none of these.

v)In the equation $Q=UA\Delta T$, a)U=thermal conductivity and unit is W/mK, b)U=thermal conductivity and unit is W/m^2K, c)heat transfer coefficient and unit is W/mK, d) heat transfer coefficient and unit is W/m^2K.

vi)Milk can be dried using a)spray dryer, b)drum dryer, c) both of these, d)none of these.

vii)A wood slab 20 cm thick has one face at -12^{o}C and the other face at 21^{o}C. If the mean thermal conductivity of wood in this temperature range is $0.28Jm^{-1}\ s^{-1}\ {}^0C^{-1}$, what is the rate of heat transfer through $1m^2$ of wall?

a)92.2 Js^{-1}, b)184.8 Js^{-1}, c)46.2 Js^{-1}, d)none of these.

viii)Plank's equation describes the a)prefreezing, b)phase change, c)post freezing, d)all of these.

ix)In extruder, materials can be processed containing moisture as low as a)5-10%, b)15-20%, c)20-25%, d)none of these.

x)The moisture content of the sun dried fruits remains in the range as a)5-10%, b)15-20%, c)20-25%, d)none of these.

xi)In canning operation , when the cans are passing through exhaust box the lids of the cans should be a)sufficiently air tight, b)moderately air tight, c)sufficiently loose, d)none of these.

xii)In large canneries, before can filling the cans are cleaned by a)jet of air , b)jet of water, c) both of these, d)none of these.

xiii)In extruder the barrel design is a)machine constant, b)primary variable, c)secondary variable, d)none of these.

xiv) Shortest drying time obtained among the following is

a) Fluidised bed drying b) Drum drying c) Spray drying

d) Freeze drying

xv) If the numerical values of the moisture content of a material in dry basis and wet basis are compared,

a) the former value will be greater than the later one.

b) the later value will be greater than the former one.

c) they will be the same.

d) all of these may be correct.

xvi) Nitrogen is used as cryogen in its form of

a) liquid state b) solid state c) both a) and b) d) gaseous state

GROUP B

2. Discuss about the factors on which the heat load of a cold storage depend.

3. What is LMTD? When does it become significant?

4. What are Fouling? What are its cause and remedy? What are its effects? (1+2+2=5)

5. Describe Plate Freezer.

6. What are the different parts of a single screw extruder? What is compression ratio? (2.5+2.5=5)

7. Draw a neat labeled diagram of rising film evaporator and briefly explain its function.

8. Discuss about critical moisture content and case hardening. (2.5+2.5=5)

9. Describe tray dryer.

GROUP C

10.a)Draw and label different parts of the seam of a can.

b) What do you mean by the can specification 202x308?

c) Discuss about the temp. and pressure of milk homogenization.

d)What are the advantages and limitation of homogenization process? (5+2+4+4=15)

11.a)State and explain Plank's equation in determining freezing time.

b) What are the limitations of Plank's equation?

c) It is wished to freeze 15 tonnes of fish per day from an initial temperature of 10^0C to a final temperature of -8^0C, using a stream of cold air. The heat transfer coefficient from the air to the evaporator coil is 22 $Jm^{-2}s^{-1}\,{}^0C^{-1}$ .Calculate the surface of the evaporator coil required if the logarithmic measurement of temperature drop across the coil is 12^Oc. Given the specific heat of fish is 3.18 kJ $kg^{-1}\,{}^0C^{-1}$ above freezing and 1.67 kJ $kg^{-1}\,{}^0C^{-1}$ below freezing and latent heat is 276 kJ kg^{-1} . 5+3+8=15

12. a)Compare conventional drying with solar drying.

b)Which factors should be considered for installation of a solar dryer?

c) What is insolation?

d)What is the principle of fluidized bed dryer?

e)Which types of materials can be dried in it?

g)What are its advantages and limitations?

(4+3+1+2+2+3=15)

13.a)Which factors should be considered to install and design a cold storage?

b)Discuss about different types of spraying devices of a spray dryer. (10+5=15)

14.a)Compare and contrast single screw extruder with twin screw extruder.

b)Discuss about the nutritional changes of extruded foods.

c)Discuss the problems which may arise during the processing of extruded foods.

d) What are the advantages of extruded foods?

(5+5+2+3=15)

15.a)What is drying ? Classify the methods used for drying with example.

b)A material shows a constant drying rate of 0.15 kg H_2O/ (min.kg dry matter.) and has an a_w of 1 at moisture contents above 1.10 kg H_2O/kg dry matter. How long will it take to dry this material from an initial moisture content of 75% (wet basis) to a final moisture content of 8% (wet basis)? (5+10=15)

16.a)With a neat sketch describe the operation of a fluidized bed dryer.

b)A dryer is fed with wet solid to reduce the moisture content from 80% to 15%. The product leaving the dryer is admitted to an oven which further brings down the moisture to 2%. If the dryer can handle 1000 kg of wet solid per day, calculate,

i)The weight of product leaving the dryer and the oven per day.

ii)The percentage of the original water that is removed in the dryer and the oven. (5+10=15)

17.a) What are the basic units of a cold storage?

b) What are the qualities that should be possessed by an insulation material of a cold storage?

c) What is cold chain?

d) What is refrigerated van?

e) What do you mean by vapour barrier? 2+2+5+3+3=15

18.a) Describe any one type of evaporator with its diagram.

b) Milk containing 3.7% fat and 12.8% total solids is to be concentrated to produce a product containing 7.9% fat. What is the yield of product from 100 kg milk and what is the total solids concentration in the final product, assuming that there are no losses during the process? 8+7=15

19.a) Describe immersion freezer.

b) A spherical food product is being frozen in an air-blast freezer. The initial product temperature is 10^0C and the cold air is (-40^0C). The product has a 7cm. diameter with a density of 1000 kg/m^3. The initial freezing temperature is (-1.25^0C), the thermal conductivity of the frozen product is 1.2W/(mK), and the latent heat of fusion is 250 kJ/kg, compute the freezing time. Convective heat transfer coefficient is 50W/(m^2K). Given : Shape constants for spheres P =1/6 and R =1/24.

c) What are the limitations of Plank's equation? 4+8+3=15