UNIT 7 AIR CONDITIONING EQUIPMENT AND THEIR APPLICATIONS

Structure

7.1 INTRODUCTION

The most significant application of refrigeration is in food preservation, whether it is by way of processing or for storage. Processing is done by heating, heat drying, etc., and by refrigeration such as in chilling, freezing or freeze-drying. Storage may be of either chilled or frozen product. Some of the important products, involved in processing are candy, beverages, meat, poultry, fish, bakery and dairy products fruits and vegetables, etc. An interesting feature of the chilled and frozen food industry is the cold chain that must be maintained from the farm to the consumer. An important link in this chain is the transport refrigeration.

Objectives

After studying this unit, you should be able to

- study the food preservation,
- study the transport refrigeration,
- know about freezing equipment, and
- know about comfort air condition.

7.2 FOOD PRESERVATION

7.2.1 Factors Contributing to Food Spoilage

All types of foods, either plant or animal, contain basically three major molecular components, carbohydrates, proteins and fats. These chemical compounds provide vitamins and minerals required by the man.

The destruction of one of the above-mentioned ingredient causes the spoilage of the food. The spoilage period may vary according to the molecular structure of different foods. The spoilage of food comes in the form of bad odour, uncommon colour, bad taste and physical appearance. The result of spoilage on the food may be loss of weight, softening, souring, rotting, wilting or molding or may be in combined form.

- Fruits and vegetables after harvesting soften and rotting starts in lapse of time if not protected properly.
- Milk gives sour taste after its deterioration which is the sign of its spoilage.
- Fatty foods like butter and cheese become dark when spoiled and give sour-odour.
- Eggs lose their weight and give very strong had smell on spoilage.
- Slimy coating is formed on the surface of the meat which is an indication of its spoilage.

The spoilage of the different foods appears in different manner as described above but ultimately it is the decomposition of the molecular components in different forms which makes the food non-eatable.

7.2.2 Causes of Food Spoilage

The preservation of food is defined as the preservation of palatability and nutritive value of food preventing the natural spoilage with respect to time.

The spoilage of the food may start within the food or may be by an external agency but in most of the cases, it is the effect of both combined simultaneously.

Before going to study the preservation of food, it is necessary to study the spoilage agents in detail which are responsible for the destruction of food.

The spoilage agents are mainly divided into two major groups

(a) Enzymes

(b) Micro-organisms

- Bacteria,
- Yeast,
- Molds.

7.2.3 Food Storage Conditions and Distribution

Many meats, fish, fruits, and vegetables are perishable, and their storage life can be extended by refrigeration. Fruits, many vegetables and processed meat, such as sausages, are stored at temperatures just slightly above freezing to prolong their life. Other meats, fish, vegetables, and fruits are frozen and stored many months at low temperatures until they are defrosted and cooked by the consumer.

The frozen-food chain typically consists of the following links: freezing, storage in refrigerated warehouses, display in a refrigerated case at food markets, and finally storage in the home freezer or frozen-food compartment of a domestic refrigerator.

Food Freezing

Early attempts to freeze food resulted in a product laced with ice crystals until it was discovered that the temperature must be plunged rapidly through the freezing zone. Approaches to freezing food includes air-blast freezing, where air at approximately – 30 °C is blown with high velocity over packages of food stacked on fork-lift pallets; contact freezing, where the food is placed between metal plates and surfaces; immersion freezing, where the food is placed in a low-temperature brine; fluidized-bed freezing, where the individual particles are carried along a conveyor belt and kept in suspension by an upward-directed stream of cold air and freezing with a cryogenic substance such as nitrogen or carbon dioxide.

Storage Conditions and Distribution

Fruits and vegetables should be frozen quickly after harvesting and meats frozen quickly after slaughter to maintain high quality. Truckload and railcar-load lots are then moved to refrigerated warehouses where they are stored at – 20 to – 23°C, perhaps for many months. To maintain a high quality in fish, the storage temperature is even lower.

Food moves from the refrigerated warehouses to food markets as needed to replenish the stock there. In the market the food is kept refrigerated in display cases held at 3 to 5°C for dairy products, unfrozen fruits and vegetables. Frozen foods and ice cream are kept at approximately - 20^0. In the United States about 100,000 refrigerated display cases are sold each year.

The consumer finally stores the food in a domestic refrigerator or freezer until used. Five million domestic refrigerators are sold each year in the United States, and for several decades styling and first cost were paramount considerations in the design and manufacture of domestic refrigerators. The need for energy conservation, however, has brought back the engineering challenge in designing these appliances.

7.3 COLD STORAGE

Though cold storage is understood to be merely an application of refrigeration, it is in fact a complete air-conditioning system in which room air is cooled to too much lower temperature over a cooling coil and supplied back to the storage space. The conditions maintained inside the storage space depend on the nature of the product stored. It is to be noted that in cold storages, often, strict control of both temperature and relative humidity is required. Also, the storage life depends a great deal on the temperature at which a product is stored. The required storage conditions for a number of important food products are given in Table 7.1 It is seen that in the case of bananas, there is no storage period. Instead, there is a period of ripening. Bananas cannot he stored after they have ripened. The best temperature for slow ripening is 14.5°C. Further, in the case of milk, the storage temperature is 0.5°C, whereas its highest freezing temperature is – 0.6°C. Thus, air is to be maintained within a close tolerance of 0°C so that milk does not freeze. The same is also true for the pasteurization process.

Table 7.1: Storage Conditions and Properties of Food products

Product	Temperature °C	Relative Humidity %	Approximate Storage Life	Water content %	Highest Freezing point °C
Apples	– 1 to 0	85-90		84.1	– 1.5
Bananas	14.5	95	For ripening in 8-10 days	74.8	–0.8
Butter	0 to 4.4	80-85	2 months	15.5-16.5	–
Milk, Pasteurized	0.5	-	7 days	87	– 0.6
Eggs	– 1.5 to – 0.5	80-85	6-9 months	66	– 2.2
Fish, fresh	0.5 to 1.5	90-96	5-15 days	62-85	– 2.2
frozen	– 23.5 to – 18	90-95	8-10 days	62-85	-
Grapes	– 0.5	85-90	3-8 weeks	81.9	– 1.3
Beef, fresh	0 to 1	88-92	1-6 weeks	62-77	– 2.2
Frozen	– 23.5 to – 18	90-95	9-12 months	62-77	–
Mangoes	10	85-90	2-3 weeks	81.4	– 0.9
Potatoes, late crop	3 to 4.5	85-90	5-8 months	77.8	– 0.6
Tomatoes, green	14 to 21	85-90	2-4 weeks	94.7	– 0.6
Ripe	7 to 10	85-90	2-7 days	94.1	– 0.5

7.4 FREEZERS

Since properly frozen foods have a much longer storage life than cold-stored foods and also retain better quality, the emphasis is on the development of frozen-food storages and techniques of quick freezing. Among the common products that are preserved by freezing are fish, meat, vegetables, such as beans, sprouts, carrots, cauliflower, peas and spinach, various tissues and organs, etc. Frozen shrimp is one of the most valuable foreign-currency earners for India.

7.4.1 Types of Freezer

There are three basic types of freezers:

(a) *Air-blast freezers* in which cold air is blown over the product.

(b) *Contact or plate freezers* in which the product is brought in direct contact with a refrigerated surface.

(c) *Immersion or spray freezers* in which the product is immersed in or sprayed with a liquid refrigerant.

Air blast and contact-plate freezers are the two most common types used in industry. Contact-plate freezers do not have the versatility of the air-blast freezers. The former can only be used to freeze regularly shaped blocks. The latter can he used for a variety of irregular shaped as well as small sized products such as peas, french fries, shrimp, etc., which results in *individual quick-freezing* (IQF) of each piece. Air blast freezers can be freezing tunnel type, belt freezers or fluidized bed type freezers. Immersion freezers use *liquid freezants* at atmospheric pressure, the corresponding temperatures being – 196°C with N_2 and – 30°C with R 12.

To achieve quick freezing in air blast freezers, the air flow rates should be high Figure 7.1 shows the influence of air velocity on freezing time. A high air velocity will mean shorter freezing time but more fan power. An optimum air speed of 5 m/s is recommended for most purposes. In continuous air-blast freezers, even higher speeds, of the order of 10 to 15 m/s, could also be economically employed as that would result in smaller freezer length and lower cost due to reduced freezing time.

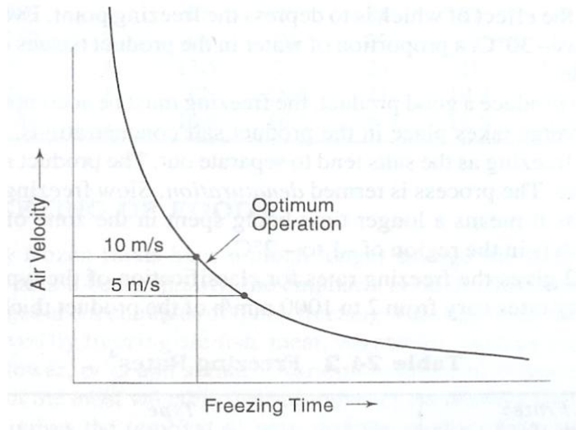


Figure 7.1: Influence of Air Velocity on Freezing Time

Figure 7.2 shows the schematic diagram of an air-blast freezer in which a moving belt carries the product. The belt can also be replaced by trolleys and the product stacked in multilayered trays.

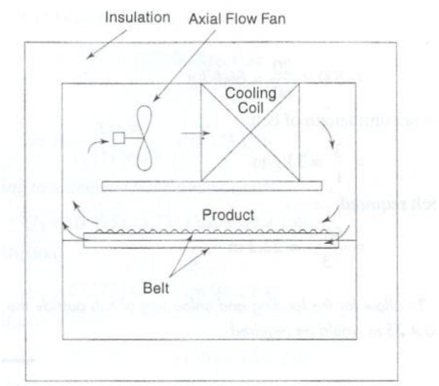


Figure 7.2: Continuous Belt Air-Blast Freezer with Cross-Flow of Air

In well-designed freezers, the fan power is of the order of 25 to 30 per cent of the refrigeration load. If the air-flow rate is very large, the fan power may be greater. As a result of small dehumidified rise and high air flow the temperature rise of air over the product will he very small. An average rise in air temperature of about 1.5-2°C is permissible.

Air-blast freezers with batch operation use trolleys or shelves for loading the product. Those with continuous operation make use of conveyors or belts. The latter are used only if the product can be frozen quickly, the freezing time must not exceeds in 30 minutes, otherwise the length of the freezer will become very large.

7.4.2 Refrigeration Load in Freezers

Example 1 illustrates the procedure for calculating the refrigeration load in freezers. In addition to the product load, other loads that need to be considered are the fan heat, heat leakage through insulation, heat load due to internal lighting, containers and conveyers, heat load due to internal lighting, containers and conveyers, heat load due to defrosting, infiltration load, etc.

Example 7.1

32,400 kg/day of cold fish is to be frozen to –30°C in 10 cm thick blocks each weighing 45 kg. The secondary refrigerant temperature is – 40°C. The evaporating refrigerant temperature is – 47°C. The fish enters at 30°C. The freezing cycle time may be taken as 4 hours. Given:

Specific heat of thawed fish = 3.77 kJ/kg°C

Latent heat of fusion of fish = 251.2 kJ/kg

Specific heat of frozen fish = 1.67 kJ/kg°C

Calculate the number of blocks frozen per cycle and refrigeration duty of the plant for 18 hours running time.

Solution

Number of blocks/day

$$= \frac{32400}{45} = 720 \text{ blocks/day}$$

Number of freezing cycles/day

$$= \frac{24}{4} = 6$$

Number of blocks frozen per cycle

$$= \frac{720}{6} = 120 \text{ blocks/cycle}$$

Fish loading

$$\dot{m} = \frac{32400}{(24)(3600)} = 0.375 \text{kg/s}$$

Sensible cooling to a freezing temperature of 0°C

$$\dot{Q}_1 = (0.375)(3.77)(30) = 42.4 \text{kW}$$

Latent heat of fusion

$$\dot{Q}_2 = (0.375)(251.2) = 94.2 \text{kW}$$

Sensible cooling to 0-30°C

$$\dot{Q}_3 = (0.375)(1.67)(30) = 18.8\,\text{kW}$$

Total product load

$$\dot{Q}_p = 42.4 + 94.2 + 18.8 = 155.4\,\text{kW}$$

Product load for 18 hours running time

$$Q = 155.4 \times \frac{24}{18} = 207.2\,\text{kW}$$

7.4.3 Freezing Time

The time taken to lower the temperature of the product from its initial temperature to a given temperature at its thermal centre is called the *freezing time*. The final temperature is generally the intended storage temperature of the product. For example, in the case of fish, the recommended storage temperature is – 30°C. To ensure quick freezing, the freezer temperature must be below this temperature. It is desired that after freezing, the temperature of the thermal centre should be reduced to at least – 20°C so that the average temperature of the fish is near the storage temperature of – 30°C. The freezing time will, therefore, be the time required to reduce the thermal centre from its initial temperature to – 20°C. The *residence time* of the product in the freezer is, therefore, equal to its freezing time.

A precise calculation of the freezing time for irregular-shaped product is difficult. But for uniformly-shaped products such as rectangular blocks, suitable relations have been proposed. However, they often do not take into account the precooling from the initial temperature to the final temperature. They assume that the product has been chilled initially, and that all extraction of heat is at the freezing temperature. The presence of other factors such as packing, etc., may also give erroneous results. Nevertheless, calculations by the finite-difference method, using a computer, give very good results.

A solution for the calculation of temperature distribution throughout a mass, in which a change of state is occurring, has been proposed by Neuman for freeze-drying. The same can be applied for freezing. The equations expressing the temperature as a function of the time and position in an infinite slab with a change of state are available but are not given in this text because they involved mathematics for which reader may not be prepared. In calculating freezing time it is assumed that surface comes to temperature of freezing media immediately.

7.5 TRANSPORT REFRIGERATION

The ‘cold chain’ principle of food handling and distribution is that the product will be maintained at suitable conditions all the way to the point of sale. This requires transport and various kinds of storage.

The transport of cooled produce, using mechanical refrigeration, was one of the first major uses, dating back to 1880 and only 20 years after the first static cold storage.

7.5.1 Refrigerated Trucks and Trailers

These vehicles are refrigerated to maintain temperatures of either 1.5 to 4°C for cold foods or – 18°C for frozen foods. The types of refrigeration systems used are given below.

Product Subcooling

With the use of improved insulating materials, it is possible to drastically cut the transmission load of vehicles. In that case, use may be made of the storage capacity of the product itself for cold by subcooling it to as low a temperature as possible before transporting for short distances. Thus even after reaching the destination, the temperature of the product is below the temperature of the storage requirement. Examples are tankers for milk, orange juice, etc.

Using Water Ice

The top of the product can be suitably iced. Again, it is a satisfactory method for short distances and for some products only. The refrigerating effect produced by the melting of ice is 335.4 kJ/kg.

Water Ice in Bunker with Forced Air Circulation

Figure 7.3 shows the sketch of an ice bunker that is fitted in front of an insulated vehicle. Air is sucked over ice by the blower taking its drive from the engine. A half HP blower will add a heat equivalent of 0.37 kW. A mixture of ice and salt can also be used for lower temperatures up to – 9°C.

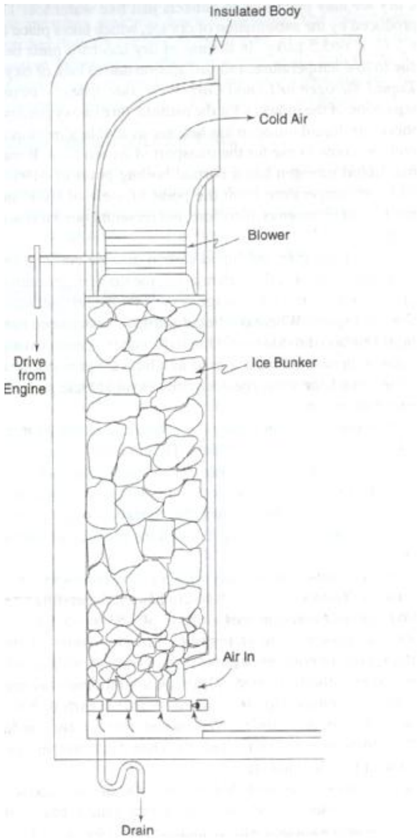


Figure 7.3: Ice Bunker in Transport Refrigeration

Using Dry Ice

Dry ice is used in many small retail trucks for the delivery of frozen food, such as ice-cream. The usual positioning of the dry-ice blocks is in the ceiling. The cooling is by natural convection. When forced convection is employed, dry ice may be placed in bunkers just like water ice. The refrigerating effect produced by the sublimation of dry ice, which takes place at a temperature of – 78.5°C, is 605.5 kJ/kg. In the use of dry ice, care must be taken to avoid bums due to low temperature, and suffocation due to lack of oxygen.

Using Liquid Nitrogen or Liquid Carbon Dioxide Spray

Due to the expansion of the industry for the manufacture of oxygen, by liquefaction of atmospheric air, liquid nitrogen has become available almost as a by-product. It has, therefore, come in use for the transport of frozen food. It may, however, be noted that liquid nitrogen has a normal boiling point of –195.6°C. This is an extremely low temperature from the point of view of COP and refrigeration economy. Liquid nitrogen is, therefore, not recommended if it is not available as a by-product.

Eutectic Plates with Station Charging

Eutectic plates forming channels are placed all round the body of the vehicle. They contain an eutectic solution which can be frozen by a refrigerant flowing in a coil immersed in the solution. The coil is connected to a mechanical refrigeration system at the charging station. Cooling is produced by the evaporation of the primary refrigerant in the coil. When the solution is frozen, the truck loaded with the product for delivery is ready for departure.

Eutectic Plates with Vehicle-Mounted Condensing Unit

This system is becoming increasingly popular because of economy as well as reliability for the transport of frozen foods. Eutectic plates are used for maintaining the product at the required temperature. However, when the frozen eutectic has melted, the vehicle-mounted condensing unit can be started. Further, the condensing unit has an auxiliary drive mounted on the vehicle when it is in use and an electric motor drive for use at the charging station.

Mechanical Refrigeration with Independent Engine or Electric Motor

The mechanical-refrigeration system mounted on the vehicle has an independent engine. Some are also equipped with an electric motor for stand-by operation at the charging station. These units are available in two ranges:

(a) 5.86 to 10.3 kW capacity at 1.5°C.

(b) 1.76 to 5.28 kW capacity at – 18°C in a 40°C environment.

Mechanical Refrigeration Deriving Power from Vehicle Engine or Transmission

There are many practical designs available. The refrigeration compressor may be either directly coupled to the engine, or may take off the power through transmission. In one design, the engine runs an alternator. The A.C. current is rectified and is used to run D.C. motors for compressor and fans. The refrigeration is, however, produced only when the vehicle engine is in operation.

7.5.2 Refrigerated Railway Cars

Most refrigerated railway cars use ice bunkers with water ice or ice-and-salt mixture. The recharging of ice is required at intermediate stations on the route. Nowadays, the mechanical-refrigeration system is being increasingly adopted. It is provided with an independent diesel-generator set so that refrigeration is independent of the car movement. The normal generator capacity is 20 kW.

7.5.3 Marine Refrigeration

A special feature of marine transport is the varying climate, ranging from extreme hot to extreme cold, through which the ship has to pass during the course of its journey. The insulation and fittings should be suitable both for warm and cold water routes. Thus a vapour barrier for moisture should be provided on both sides of the insulation. Corkboard continues to be favoured as an insulation because of its many desirable characteristics, such as structural strength, fire-resistant property, low permeability for moisture, etc.

In the case of cargo, the refrigeration system should be capable of providing any temperature between – 23.5 and 12.5°C. R 12 with reciprocating compressors is presently used as a refrigerant. R 22 is not recommended because of its problem of critical oil miscibility. Compound compression is employed. Parallel operation is not recommended with R 12 as there is a tendency for oil to migrate and flood one compressor while starving another. Accordingly, each evaporator has an independent compressor. This involves the use of a large number of compressors. The system can be made more economical by the use of parallel brine circuits in cooler coils and fewer condensing units. Capacity control is obtained by speed variation or cylinder cut-outs and cylinder unloading. Condensers are of the shell-and-tube type using sea water for cooling.

Corrosion-resistant cupro-nickel material is, therefore, used for tubes and end covers. A receiver capable of holding 20 per cent more in addition to the whole charge is essential. The liquid line should emerge from both ends of the condenser, and later joining into one. This ensures continuous draining of the liquid during *roll* or *pitch* of the ship.

In addition to the cargo, ships must have their own stores. These stores have to be much bigger for passenger vessels. They also have a ventilated area for some of the items, such as onions and potatoes.

Fishing vessels use ice for short distances from the shore, but deep-sea fishing trawlers which remain away for months together must have mechanical refrigeration.

7.5.4 Refrigeration in Air Transport

Refrigerated air transport of some commodities can be justified on the basis of saving in the time and preservation of quality. In some passenger aircraft, the cargo compartments are cooled by the air-conditioning system itself. In cargo aircraft, the perishables are pre-cooled before shipment. For transit refrigeration, if necessary, refrigerant packages of water ice, dry ice or other substances are used.

7.6 AIR CONDITIONING

7.6.1 Comfort Air Conditioning

Effective temperature (ET) is defined as that temperature of saturated air at which the subject would experience the same feeling of comfort as experienced in the actual unsaturated environment. Figure 7.4 shows, for example, a line of ET = 21.7°C. At lower humidities, the DBTs of air can be higher for the same ET and for the same feeling of comfort. Thus at a higher DBT, the body would lose more heat in the form of latent heat, i.e., by the evaporation of perspiration. An increase in temperature can also he compensated by an increase in velocity. For example, an increase of 2 to 3°C in DBT can be compensated by increasing the air velocity from 0.1 to 0.3 m/s.

Based on the concept of effective temperatures some *comfort charts* have been developed. To mention one, there is the Fanger's comfort chart. These may be referred to when a compromise in the inside design conditions is to be achieved. In addition to the comfort charts, some comfort equations have also been developed.

The general practice is to recommend the following optimum inside design conditions for comfort for summer air conditioning:

ET	21.7°C
DBT	25 ± 1°C
RH	50 ± 5%

The corresponding room air velocity is 0.4 m/s. The points of equal comfort are shown in Figure 7.4.

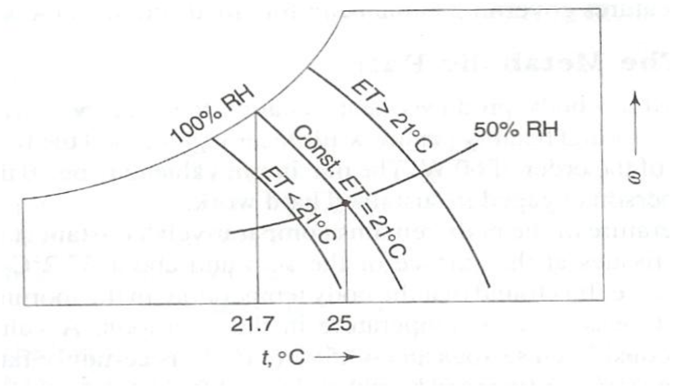


Figure 7.4 : Effective Temperature Lines

During winter, the body gets acclimatized to withstand lower temperatures. Consequently, a DBT of 21°C at 50 per cent RH and 0.15-0.2 m/s air velocity is quite comfortable.

In addition to the maintenance of temperature, humidity and air velocity, it is also important to maintain the purity of room air. Even if there are no sources of production of pollutants within the conditioned space, the carbon dioxide content of air increases because of the occupants. It is, therefore, necessary to introduce fresh air or ventilation air into the space. The requirement of ventilation air is much more when some occupants are smoking. In the case of auditoriums, because of very large occupancy, the ventilation air requirement is very large. Hence there is the need to prohibit smoking in auditoriums and assembly halls. Table 7.2 gives the ventilation air requirements for some applications.

Table 7.2: Ventilation Air Requirements

Application	Smoking status	Recommended Cmm/person	Minimum	
			Cmm/person	Cmm/m floor area
Apartments	Some	0.56	0.28	-
Offices and factories	Occasional-some	0.28-0.6	0.21	-
Restaurants	Some	0.4	-	-
Board rooms	Very heavy	1.4	0.56	0.03
Department stores	None	0.21	0.14	0.0015
Theatres	None	0.21	0.14	-
Hostel rooms	Heavy	0.84	0.7	-
Hospital wards	None	0.84	-	-
Hospital operation theatres	None	All outdoor	-	-

***** Cubic meter per min

7.7 MISCELLANEOUS

7.7.1 Textile Industry

Textiles, like paper, are sensitive to changes in humidity and to a lesser extent changes in temperature. The yarn in modern textile plants moves at tremendous speeds, and changes in the flexibility and strength of the textile or generation of static electricity must be prevented.

7.7.2 Photographic Processing

The photographic-products industry is a large user of air conditioning and refrigeration. Raw photographic material deteriorates rapidly in high temperatures and humidities, and other materials used in coating film require careful control of temperature.

7.7.3 Year-Round Air-Conditioning

In many countries, the summers and winters both are very uncomfortable. Under such adverse weather conditions, it is necessary to have an air conditioning system which will provide comfort conditions throughout the year. Year round air-conditioning must be capable of maintaining a specified temperature and humidity within the air-conditioned spaces regardless of outside weather conditions.

7.7.4 Poultry Products

Poultry meat is preserved both by chilling and freezing. Chilling requires a lower capital investment whereas freezing offers quality and flexibility of operation.

A major fraction of poultry meat is processed and transported by liquid chilling by the use of flake ice. Air chilling results in a considerable amount of dehydration at the surface. The approximate time required for chilling to 7°C is about 115 minutes for dressed birds, 50 minutes for eviscerated birds and 25 minutes for cut-up ones.

As for freezing, the use of air-blast tunnels operating at air temperatures of – 29 to – 40°C and air velocities of 2.5 m/s or more is recommended. This ensures rapid freezing which is essential to obtain good quality and appearance.

Cooling is also required in poultry farms. A temperature higher than 29°C results in reduced egg production of lesser weight and thinner shells. A temperature of 24°C is recommended for poultry-keeping.

7.7.5 Fishery Products

Refrigeration is required in many ways in the processing, preservation and transport of fresh and frozen fish and their products. Care starts from the stage of catching in fishing boats and trawlers.

Icing of fish is first done to chill it to a temperature of 0°C. The melt-water also helps to wash off the slime and bacteria. Often the fish are stored in tanks using *refrigerated sea water* at – 1°C. It is found that *shrimp* when stored with refrigerated sea water is superior to that stored with ice. The storage life of chilled fish is normally 10 – 15 days.

Again, more and more of fish are being frozen these days. The valued varieties of fish that are frozen include salmon, shrimp, shell fish, etc. *Individual quick freezing* (IQF) techniques are preferred for these products. Quick freezing has many advantages. It prevents bacterial spoilage and ensures rapid handling, packaging and good appearance of the product, and also makes optimum utilization of the freezer space. Quick-freezing is achieved by using low refrigeration temperatures

7.7.6 Bakeries

Bread is the most important bakery product. During the preparation of the mix for the dough, the heat of hydration and heat of friction of the churner, equivalent to the electrical input power, are generated. As the temperature of dough should not exceed 24 – 25°C, the best way to keep the temperature low is to add chilled water at 2 – 4°C for the preparation of the mix. The mixer is jacketed with a direct expansion coil at a temperature of 0°C.

The doughs are then placed in troughs for fermentation for a period of 3½ to 5 hours. During the process, the temperature may rise by 4 – 6°C. It is, therefore, desirable to keep them in a room at a temperature of 26°C.

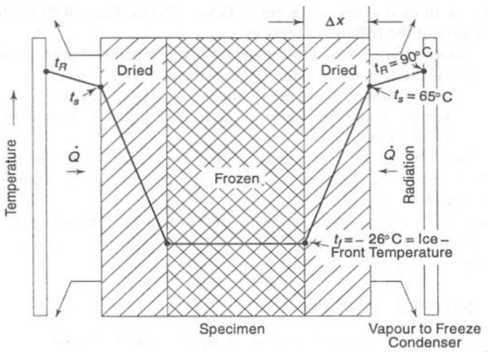
Refrigeration is needed in the manufacture of other bakery products also in order to maintain uniformity of the product, prevent spoilage and for storage.

7.7.7 Freeze Drying

Freeze drying is a successful process of liquid separation from a product in a frozen state, achieved by sublimation under vacuum. The sublimation serves to obtain a product that retains even its volatile components and initial quality, and the vacuum is used to maintain the physical state as frozen and to direct the vapour flow. At present, the main problems to the application of the process in general are; (a) the relatively high cost of the freeze-dried product by sublimation-dehydration due to high vacuum, (b) very low temperature refrigeration to pre-freeze the product and then to condense the sublimated vapour, (c) the complicated operational control and (d) the long duration of the freeze-drying time. Characteristically, however, the cost is not the determining factors for the manufacture of certain products including blood plasma, life-saving drugs such as gamma-globulin, and high value food products such as mushrooms, shrimp, prawns, etc.

Figure 7.5 shows a model of the freeze-drying process with radiant heating. The profile shows the temperature distribution.

The dehydration takes place in a vacuum chamber. The pressure in the chamber must be maintained below the triple-point pressure, normally below 5 mm Hg, otherwise the product will begin to thaw.



igure 7.5 : Temperature Distribution during Freeze-Drying of a Specimen with Radiant Heating

7.7.8 Dairy Refrigeration

Most dairy plants pre-cool milk to 2.5°C before processing for the separation of cream and blending for producing standardized quality. There are hot as well as cold milk separators. In the latter, the separation process takes place at a temperature of 4°C. After separation and blending, the milk is sent for pasteurization which is accomplished by heating followed by the chilling of milk. Heating is done either by hot water or steam and holding the milk at 62°C for about 3 minutes. The milk is then cooled first by water from a cooling tower and then by chilled water. The rate of flow of chilled water should be such that its rise in temperature is not more than 5.5°C. When a direct-expansion system is used for cooling, the refrigerant flow is controlled by an automatic expansion valve so that the temperature does not drop below – 2°C lest the milk may freeze. A water chilling equipment normally consists of an *ice-bank* type water chiller consisting of an insulated tank with water, direct-expansion coil and pump. This system ensures a constant temperature of chilled water of 0 – 1°C. Also, it takes care of load fluctuations by allowing excess refrigeration to be stored in the form of ice on immersed coils.

Refrigeration is also required for cooling the cream before churning and the mechanical separation of butter. For the storage of butter, a temperature of 0 to 4°C is satisfactory. But for storage for 6 months or more, a temperature of – 23 to – 18°C must be used. This is the same as for some frozen products. Thus butter can be kept in freezer compartment of refrigerators for storing beyond a period of six months or more.

Ice-cream manufacture is another industry that makes great use of refrigeration. The ice-cream freezer has to whip in a certain amount of air in the mix, simultaneously with freezing. The product is 0 to 100 per cent frozen between the temperature range of – 2.5 to – 55°C approximately.

7.7.9 Breweries

The production of beers and ciders requires the fermentation of sugary fluids by the action of yeasts, and the cooling, filtration, clarification and storage of the resulting alcohol -water mixture.

The starting mix for beers is a warm brew of grain-based sugar and flavouring. This ‘wort’ leaves the hot brewing process and is cooled to a suitable brewing temperature around 10°C for lagers and 20°C for traditional bitters. This was originally carried out with Baudelot coolers, but now plate heat exchangers are mainly used, with chilled water as the coolant.

The process of fermentation gives off heat, and the tanks may need to be cooled with chilled water coils, with jackets, or by cooling the ‘cellar’ in which the tanks are located. When fermentation is complete, many beers are now pasteurized, in the same manner as milk. The beer is then cooled to just above freezing, filtered and left to ‘age’. Before final bottling, kegging or canning it will undergo a fine filtration to improve the clarity.

Refrigeration is required for the cold storage rooms and to provide chilled water for the plate heat exchangers. The ‘cellars’ are very wet areas, and the cooling plant should be designed to maintain as low a humidity as possible, to help preserve the building structure.

Beers at the point of sale are traditionally stored in cellars to keep them cool. Beers are in kegs or piped into bulk tanks. Artificial cooling of these areas is now usual, using packaged beer cellar coolers. Bulk-storage tanks may have inbuilt refrigeration plant. Drinks such as lager beers, which is normally drunk colder than other beers, are passed through a chilled water bath or double-pipe heat exchanger for final cooling.

Bottled beers and other drinks are kept on refrigerated trays, comprising a cooled base tray and an inbuilt refrigeration system.

In wine-making also, refrigeration is required in three stages, viz.,

(a) for the control of temperature during fermentation,

(b) for the removal of excess potassium tartrate by cold precipitation, and

(c) for storage.

The quality of wine is greatly affected by the temperature of fermentation which should not exceed 29°C for red wine and 15°C for white wine. The mini mum cooling requirement for fermentation is 31 kJ/kg of must. For grapes of high-sugar content, it can be up to 52 kJ/kg. Often chilled-water cooling coils are used in concrete fermentors.

For the cooling of wine for precipitating excess potassium bitartrate, the lowest possible temperatures above the freezing point of wine are used. The freezing points vary between – 13 and – 6°C.

The quality of wine also depends on the temperature and length of storage. Some wines require as low a temperature as 7°C for storage.

In carbonated-drink manufacturing plants, refrigeration is required to cool the water, syrup or finished product.

SAQ 1

(a) What are different steps in food preservation?

(b) Why and which food are frozen? What are the techniques of freezing?

(c) How would you calculate refrigeration load in freezers? Describe all source from which heat can leak inside a freezer.

(d) Describe ice in bunker technique for transport. Which ice is used? What are their methods?

(e) What do you understand by marine Refrigeration and how is it different from truck refrigeration?

(f) Write a note on comfort air conditioning bringing out all aspects.

7.8 SUMMARY

With the advancement of industrialization, people are living far away from the food production areas; and are thickly populated into the industrial areas. This dislocation of population requires proper means for food preservation and distribution without its spoilage. The food preservation technology has developed sufficiently to preserve the wide variety of foods for a considerable long time as near the point of freshness as possible.

7.9 ANSWERS TO SAQs

Refer the relevant preceding texts in the unit or other useful books on the topic listed in the section “Further Readings” to get the answers of the SAQs.

FURTHER READINGS

Manohar Prasad, *Refrigeration and Air Conditioning, second edition***,** New Age International Pvt. Ltd, New Delhi, 2002.

C. P. Arora, *Refrigeration and Air Conditioning, second edition*, Tata McGraw Hill, New Delhi, 2000.

P. N. Ananthanarayanan, *Basic Refrigeration and Air Conditioning*, Tata McGraw Hill, New Delhi, 1996.