UNIT 6 CHILLING

Structure

6.0 OBJECTIVES

After reading this unit, you should be able to:

- describe chilling and refrigeration cycle;
- explain chilling injury and refrigerated requirements of fruits and vegetables; and
- define evaporative cooling.

6.1 INTRODUCTION

You know that fruits and vegetables are highly perishable and more liable to spoilage than food grains. This is basically because they contain high moisture content. The spoilage of such perishable crops can be delayed by controlling the post harvest environmental conditions of temperature, humidity and atmospheric concentration of gases. Chilling is one such method of regulating temperature. More precisely, chilling mean the use of low temperature without inducing ice formation in foods. The chilling process may be considered complete when the mean temperature of the product has approximately reached the intended value for storage or processing.

The chilling operation is divided into 3 basic types based on its main purpose.

i) Chilling for preservation.

ii) Chilling for development of desired biological and biochemical processes.

iii) Chilling to facilitate some processing treatments, by temporarily changing certain physico-chemical properties.

Chilling for preservation is aimed to extend the shelf-life or keeping quality of a living produce, e.g., fruits and vegetables. This is mainly due to reduction of metabolic activity at low temperature. Chilling may also be used to extend the storage life of products such as pasteurized and sterilized canned foods.

Chilling for development of desired biological and biochemical processes includes fermentation of beer and wine, meat ageing, and processing of many dairy products such as cheeses, etc.

Temporarily changing certain physico-chemical properties to facilitate some processing treatments is used in the processing of bakery products, chocolate, butter, margarine etc. However, this is beyond the scope of the present unit and we would restrict ourselves to chilling for preservation only. In the present unit, we will focus only on the first purpose, i.e., chilling for preservation.

Refrigeration is the most common method of chilling or low temperature storage of fruits and vegetables. Refrigerated storage helps to retard the spoilage in perishable crops in the following manner:

- aging due to ripening, softening, textural and colour changes;
- undesirable metabolic changes and respiratory heat production;
- moisture loss and the wilting;
- spoilage due to invasion by bacteria, fungi, and yeasts; and
- undesirable growth, such as sprouting of potatoes.

One of the most important functions of refrigeration is to control the respiration of crops. Respiration generates heat as sugars, fats, and proteins in the cells of the crop are oxidized. The loss of these stored food reserves through respiration means decreased food value, loss of flavour, loss of saleable weight, and more rapid deterioration. The respiration rate of a product strongly determines its transit and post-harvest life. The higher the storage temperature, the higher will be the respiration rate. Apart from temperature, humidity and concentration of gases are also important. Before observing their effect let us first understand how refrigerator works.

6.2 REFRIGERATION

The refrigerator cycle is based on the principle of making cold which is done by removing heat from the system. If you are science student then you must have surely studied carnot's engine. Refrigeration is in fact the reverse of carnot's engine. The refrigeration cycle uses a fluid, called a refrigerant, to move heat from one place to another. The key to understanding how it works is recognizing that at the same pressure, the refrigerant boils at a much lower temperature than water. For example, the refrigerant commonly used in home refrigerators boils between 40 and 50°F (4.4 – 10°C) as compared to water's boiling point of 212°F (100°C). In the original home refrigerators ammonia was the common refrigerant used. Pure ammonia gas is highly toxic to people and would pose a threat if the refrigerator were to leak, so all home refrigerators don't use pure ammonia. You might have heard of refrigerants known as **CFCs** (chlorofluorocarbons). These were originally developed by Du Pont in the 1930s as a non-toxic replacement for ammonia. CFC-12 (dichlorodifluoromethane) has about the same boiling point as ammonia. However, CFC-12 is not toxic to humans, so it is safe to use in your kitchen. However, many large industrial refrigerators still use ammonia. In the 1970s, it was discovered that the CFCs then in use are harmful to the ozone layer, so as of the 1990s, all new refrigerators and air conditioners use refrigerants that are less harmful to the ozone layer. Freon is the common refrigerant used today. Now we need to study the refrigeration cycle.

Every refrigerator is made up of at least four key parts:

i) Compressor
ii) Heat-exchanging pipes (also known as a condenser)

iii) Expansion valve
iv) Refrigerant

Let's look at the process to see how boiling and condensing a refrigerant can move heat. The process is the same whether it is operating a refrigerator, an air conditioner or a heat pump. This example illustrates a closed-loop system (Figure 6.1).

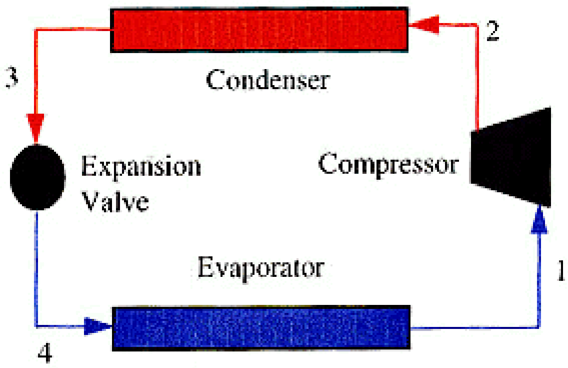


Figure 6.1: Vapour compression refrigeration cycle

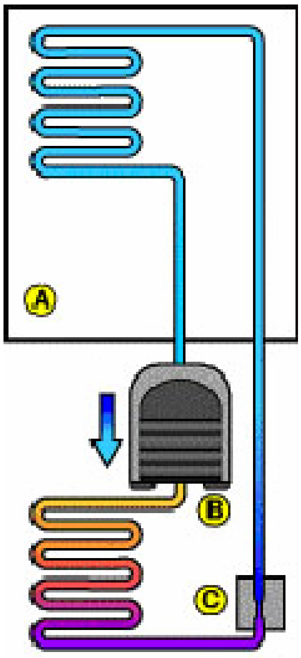
The above diagram shows the simplified, stepwise process of the refrigeration cycle, where the associated parts of the refrigerator fit into it. These four parts will now be explained in detail. Lets begin with evaporator first. As the name implies, refrigerant in the evaporator "evaporates". Upon entering the evaporator, the liquid refrigerant's temperature is between 40 and 50°F and without changing its temperature, it absorbs heat as it changes state from a liquid to a vapour. The heat comes from the warm moist room air blown across the evaporator coil. As it passes over the cool coil, it gives up some of its heat and moisture may condense from it. The cooler drier room air is re-circulated by a blower into the space to be cooled.

The vapour refrigerant now moves into the compressor, which is basically a pump that raises the pressure so it will move through the system. Once it passes through the compressor, the refrigerant is said to be on the "high" side of the system. Like anything that is put under pressure, the increased pressure from the compressor causes the temperature of the refrigerant to rise. As it leaves the compressor, the refrigerant is a hot vapour, roughly 120 to 140°F.

It now flows into the refrigerant-to-water heat exchanger, operating as the condenser during cooling. Again, as the name suggests, the refrigerant condenses here into liquid form. As it condenses, it gives up heat to the loop, which is circulated by a pump. The loop water is able to pick up heat from the coils because it is still cooler than the 120 degree coils.

As the refrigerant leaves the condenser, it is cooler, but still under pressure provided by the compressor. It then reaches the expansion valve. The expansion valve allows the high pressure refrigerant to "flash" through becoming a lower pressure cooled liquid. This pressure drop causes expansion followed by evaporation. Evaporation further causes heat absorption making refrigerant cool. The cycle is complete as the cool liquid refrigerant re-enters the evaporator to pick up room heat. In winter, the reversing valve switches the indoor coil to operate as the condenser and the heat exchanger as the evaporator.

In summary, the indoor coil and refrigerant-to-water heat exchanger where the refrigerant changes phase by absorbing or releasing heat through boiling and condensing. The compressor and expansion valve facilitate the pressure changes, increased by the compressor and reduced by the expansion valve. See a detailed Figure 6.2.



A -- Inside of refrigeration
B -- Compressor
C -- Expansion valve

Figure 6.2: Back panel of a refrigerator

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What is chilling?

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2. Where does actual phase change take place in the refrigerator?

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3. What are the common refrigerants used in the refrigerator?

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6.3 DETERMINATION OF REFRIGERATION LOAD

If we want to cool the product then heat must be removed and brought to a specific low temperature. The heat removed is described in terms of refrigeration load. In other words, refrigeration load can be defined as that quantity of heat which must be removed in order to reduce the temperature of the products from its initial temperature to the temperature consistent with good frozen food storage. It is calculated in terms of heat unit as British Thermal Units (Btu), calories (cal) or joules (J). This has, of course, been replaced by International System of Units (SI) which employs joules and gram as units of heat and weight (One Btu = 252 calories = 1055 joules = 1.055 KJ).

One Btu or British Thermal Unit is defined as the quantity of heat which will raise or lower the temperature of one pound of water by 1°F through the range of 32°F to 212°F at normal atmospheric pressure.

A calorie is the amount of heat which will raise or lower the temperature of one gram of water by 1°C from 14.5 to 15.5°C at normal atmospheric pressure.

The specific heat of any substance is the ratio of its heat capacity to that of water. In either case, the specific heat of water is taken as one. Thus, in British system, specific heat is

$$= -\frac{\text{Heat required to raise/lower the temperature of unit mass of water by } 1\,^{\circ}\text{C}}{\text{Heat required to raise/lower the temperature of unit mass of water by } 1\,^{\circ}\text{C}}$$

(Since heat capacity of water = 1).

Or, Specific heat at any temperature = Heat required to raise or lower the temperature of unit mass of water by 1°C or in other words, amount of heat in calories required to raise or lower the temperature of one gram of the substance by 1°C.

Generally heat is of two types – Sensible heat and latent heat.

Sensible heat may be defined as the heat we readily perceive by the sense of touch and which produces a temperature rise or fall as heat is added or removed from a substance. Always remember that specific heat is different in the liquid state and in the frozen state. So, it may be different before and after freezing.

Latent heat is the quantity of heat required to change the state or condition under which a substance exists, without changing its temperature, e.g., a definite quantity of heat must be removed from water at 0°C (32°F) to change it to ice at 0°C. This is known as latent heat of fusion or crystallization.

Similarly, in going from water to steam at 100°C, it is the latent heat of evaporation. In freezing, we are interested in the latent heat of fusion, and this in the case of water is 144 Btu/1b. It is quantitatively different from 144 Btu/lb for substances other than water.

Calculation Refrigeration Load

After you have known the terms, let us see how to calculate refrigeration load. To calculate this we need to understand that to freeze a food it is necessary to bring down its temperature to freezing point. This involves the following:

i) The number of Btu required to cool the product from its initial temperature to its freezing point, or say H_1.

ii) The number of Btu required to change the food from the liquid state to the frozen state at its freezing point, or say H_2.

iii) The number of Btu required to lower the frozen food from its freezing point to the desired storage temperature, or say H_3.

Using this concept, we can calculate refrigeration load using the following equations:

$$H_1 = (S_L) \times (W) \times (T_i - T_f) \qquad (1)$$

$$H_2 = (H_f f) \times W \qquad (2)$$

$$H_3 = (S_S) \times W \times (T_f - T_s) \qquad (3)$$

$$H_{fs} = H_1 + H_2 + H_3$$

Where,

S_L = Specific heat of food above its freezing point

H_f = Latent heat of fusion

S_S = Specific heat of food below its freezing point

H_{fs} = Total heat (Btu) requirement

W = Weight in pounds

T_i-T_f = Difference between the initial temperature and the freezing point (°F).

T_f-T_S = Difference between the freezing point and the desired storage temperature (°F).

Let's take one example:

What is Btu requirement to lower the temperature of 1000 lbs of peas from 70°F to 30°F, and finally to storage given at temperature at 0°F. Given S_L =0.8, H_f = 108, S_S = 0.43.

Here we first have to calculate H_1.

From equation (1)

$$H_1 = (S_L) \times (W) \times (T_i - T_f)$$

$$= 0.8 \times 1000 \times (70 - 30)$$

$$= 0.8 \times 1000 \times 40$$

$$= 32000 \text{ Btu.}$$

Now, calculate H_2.

From equation (2)

$$H_2 = H_f \times W$$

$$= 108 \times 1000$$

$$= 108000$$

Finally, calculate H_3.

From equation (3)

$$H_3 = (H_f) \times (W) \times (T_f - T_s)$$

$$= 0.43 \times 1000 \times (30\text{-}0)$$

$$= 12900$$

$$H_{fs} = H_1 + H_2 + H_3$$

$$= 32000 + 10800 + 12900$$

$$= 152900 \text{ Btu.}$$

Refrigeration load is usually reported in terms of refrigeration. So values should be changed to tonnes by dividing Btu by 288000:

$$\frac{152000}{288000} = 0.527 \text{ tonnes}$$

One ton (2000 1b) of refrigeration is the number of Btu required to convert 1 ton of water at 32°F to 1 ton of ice at 32°F in 24 hrs. Since latent heat of fusion for water = 144 btu/lb, a ton of refrigeration = 144 × 2000 = 288,000 Btu/24 hrs.

6.4 REFRIGERATED STORAGE OF FRUITS AND VEGETABLES

The principal refrigeration requirements of fruits and vegetables are controlled low temperature, air circulation and humidity.

Relative humidity (RH): Most food stores are best at refrigeration temperatures when the relative humidity of air is between 80 and 95 per cent. This is generally related to moisture content of foods. Celery, spinach and several other crisp leafy vegetables require 90-95% RH.

Controlled low temperature: Fruits and vegetables are highly perishable because they respire and produce heat at varying rates. They, therefore, need to be stored at low temperatures. Refrigeration is the gentlest method of extending the shelf life of fruits and vegetables. By and large, it has relatively few adverse effects upon taste, texture, nutritive value and overall changes in food, provided simple rules are followed. Domestic refrigerators usually run at 4.4°–7.2°C (40-45°F). Properly designed refrigerators, refrigerated storage rooms and warehouses provide sufficient refrigeration capacity and insulation to maintain the room within about 1°C. Proper insulation is must to maintain the optimum storage temperature. Refrigeration system must be of appropriate size to handle maximum expected heat load as an undersized system will allow temperature to rise during peak heat load conditions. Different fruits and vegetables evolve different heat during respiration. (Table 6.1) As you can see from the table green beans, broccoli, sweet corn, green peas, spinach and strawberry evolve high heat during respiration. These products are difficult to store.

Table 6.1: Heat evolved from respiration of fruits and vegetables

Commodity	Btu per tonne per 24 hrs	
	32°F (0°C)	40°F (4.4°C)
Apples	300-800	590-840
Beans, green	5,500-6,160	9,160-11,390
Broccoli	7,450	11,000-17,600
Carrots	2,130	3,470
Corn (sweet)	6,500	9,390
Onions	600-1,100	1,260-1,980
Oranges	420-1,030	1,300-1,500
Peach	850-1,370	1,440-2,030
Peas	669-880	-
Peas (green)	8,160	13,220
Potatoes	440-880	1,100-1,760
Spinach	4,240-4,860	7,850-11,210
Strawberry	2,730-3,800	3,660-6,750
Tomatoes (ripe)	1,020	1,250

Based on their respiration rate, the storage requirement and shelf-life of fruits and vegetables is also different, e.g., broccoli, a highly respiring vegetable at a storage temperature of 32^{o}F has a shelf-life of 7-10 days in comparison to 6-8 months for onions at same temperature. While temperature is the primary concern in the storage of fruits and vegetables, relative humidity is also important. The relative humidity of the storage unit directly influences water loss in produce. Water loss can severely degrade quality-for instance, wilted greens may require excessive trimming, and grapes may shatter loose from clusters if their stems dry out. Water loss means saleable weight loss and reduced profit.

Most fruit and vegetable crops retain better quality at high relative humidity (80 to 95%), but at this humidity, disease growth is encouraged. The cool temperatures in storage rooms help to reduce disease growth, but sanitation and other preventative methods are also required. Maintaining high relative humidity in storage is complicated by the fact that refrigeration removes moisture. Humidification devices such as spinning disc aspirators may be used.

Air circulation: Air must be well circulated in the cold storage rooms. This will help more heat away from food surface to cooling coil. Air, that is, circulated within a cold storage must not be too moist or too dry. If it is high in humidity, moisture will condense on surface of cold foods and moulds will grow on these surfaces. On the other hand, if air is too dry, it will cause excessive drying out. Most food stores are best at refrigeration temperatures when the relative humidity of air is between 80-95% for prolonging the storage period. Foods can be protected from losing excessive moisture by using several packaging methods. This forms a barrier for migration of moisture from food to storage temperature.

6.5 CHILLING INJURY OF FRUITS AND VEGETABLES

Low temperature storage may have some deleterious effects also. One such effect is called as chilling injury. Chilling injury has variable symptoms as ripening failure in climacteric fruits, different forms of external or internal discolouration, pre-disposition to microorganism infection, etc. The exact mechanism by which chilling injury affects the crop has still not been determined. It has been shown to be concerned with loss of membrane integrity and ion leakage and changes in enzyme activity.

General symptoms of chilling injury

i) Surface and internal discolouration, e.g., internal browning in apples and brown vascular streaks in banana.

ii) Surface pitting, e.g., in tomato, papaya, mango, limes and lemons.

iii) Development of off-flavour.

iv) Failure to ripen in some climacteric fruits.

v) Incidence of surface mould growth or decay.

The chilling injury depends on storage temperature and varies with crop, e.g., chilling injury symptoms develop in banana around 12.6°C. However, some varieties may be resistant to chilling injury at this temperature. In mango, generally chilling injury occurs at 10-15°C depending upon variety.

Based on sensitivity to chilling injury, the crops are classified as

- Chilling sensitive, and
- Non-chilling sensitive.

Chilling sensitive

Fruits: banana, mango, avocado, papaya, pineapple, citrus, plantains, pomegranate, sapota, guava, olive, etc.

Vegetables: snap beans, cucumber, muskmelon, watermelon, okra, potato, tomato, spinach, sweet potato, summer squash, etc.

Non-chilling sensitive

Fruits: apple, apricot, cherry, fig, peach, pea, plum, strawberry, etc.

Vegetables: asparagus, lima beans, beet root, cabbage, broccoli and carrots.

Mechanism of chilling injury

The general mechanism of chilling injury involves following changes:

i) *Abnormal respiratory response:* This generally involves a sudden upsurge in respiratory rate and respiratory quotient leading to uneven ripening.

ii) *Changes in lipids:* Chilling injury involves irreversible disorganization of cellular membranes like mitochondrial and vacuolar membranes. A phase transition occurs in the cytoplasm and it changes from soil to gel stage. When gel formation occurs, the cytoplasm becomes viscous and its movement is restricted.

iii) *Increased membrane permeability:* This is evident by high percentage of electrolytes leached out of the cell. This further leads to increased rigidity of protoplasm and resistance to flow.

Approaches to control chilling injury in fruits and vegetables

If the tolerance to chilling in the chilling resistant tissues can be increased or if the development of chilling injury symptoms can be delayed, the storage life can be increased. The following approaches are generally recommended to control chilling injury in fruits and vegetables:

i) Temperature conditioning
ii) Intermittent warming
iii) Controlled atmosphere storage
iv) Application of growth regulators
v) Packaging, waxing and other coatings

i) *Temperature conditioning:* A cool temperature conditioning just prior to critical chilling range increases the tolerance of commodities to chilling during subsequent low temperature storage and delays the development of injury symptoms. A cool conditioning at 10°C for 10 days before storing at 4°C in peppers reduces chilling injury symptoms. Sometimes a double step-wise temperature conditioning may be more effective than single step conditions. A hot conditioning may be useful in some cases, e.g., pre-storage heating at 30°C for 17-22 hrs decrease injury.

ii) *Intermittent warming:* Interrupting low temperature storage with one or more short periods of warm temperature increases storage life of some chilling sensitive crops. Intermittent warming treatment must be given before chilling injury becomes irreversible. If applied too late, results are not seen. Intermittent warming is hypothesized to remove toxic or inhibiting substances that accumulate during chilling.

iii) *Controlled atmosphere storage:* Most products respond favourably to decrease in oxygen level and increase in carbon dioxide concentration. Pre-storage treatment of grapefruit with high carbon dioxide is effective during inhibiting pitting during cold storage.

iv) *Application of plant growth regulators:* Application of some plant growth regulators such as ABA, Triazoles and ethylene decreases chilling injury symptoms.

v) *Packaging, waxing and other coatings:* Packaging in plastic films and coatings help to maintain relative humidity and modify gas concentration and prevent chilling injury symptoms.

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Define chilling injury.

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2. Why should you not store banana in refrigerator?

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3. What are the common symptoms of chilling injury?

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4. List some measures to control chilling injury.

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6.6 EVAPORATIVE COOL STORAGE SYSTEM

On-farm cooling facilities are a valuable asset for any produce operation. A grower who has on farm cooling facility for storing produce has greater market flexibility because the need to market immediately after harvest is eliminated. The challenge, especially for small-scale producers, is the set-up cost. Refrigerated storage systems are although best but expensive in terms of capital investment. Innovative farmers and researchers have thus created a number of low-cost structures. One such low cost structure is evaporative cool storage which was developed by scientists at Indian Agricultural Research Institute.

Principle

Evaporative cool storage is also called as zero energy cool chamber. It is based on the simple principle of evaporative cooling. Evaporative cooling occurs when air, that is not already saturated with water vapour, is blown across any wet surface. An evaporative cooler consists of a wet porous bed through which air is drawn, cooled and humidified by evaporation of water. The faster the evaporation, the greater is the cooling. Can you now think and tell why it is called a zero energy cool chamber? It is so called because it does not require any electricity or power to operate and all the materials required to make the cool chamber are available easily and cheaply. It can be installed at any site by even unskilled person as it does not require any specialized skill or raw material. This simple storage structure has many advantages. Let's see what are they?

- No mechanical or electrical energy is needed.
- Allows small farmers to store produce for a few days; so growers are not forced to sell at low prices, and incur losses.
- Ideal for use in packing stations and markets.
- Reduces losses and pays for itself in a short time.
- Can also be used for mushroom cultivation, sericulture and storage of bio-fertilizers.
- Raw materials required are re-usable.
- The fruits and vegetables stored do not suffer chilling injury.

Let us find out how to construct a zero-energy cool chamber at farm level. We need simple raw materials like

i) Bricks, riverbed sand, bamboo, khaskhas (or any plant material of similar nature), gunny bags/cloth, etc.

ii) A source of water like a tap, a tubewell, a well, a pond, or a canal. The water can be drawn from the source to the cool chamber with the help of a flexible tube/pipe or any suitable container.

iii) Design and construction*:* The floor of the storage space is made with a single layer of bricks. The side walls are made with a double layer of bricks leaving approximately 3" space between the bricks. The cavity between the bricks is filled with riverbed sand. About 400 bricks are required to make a chamber of the dimensions as given in Fig. 6.3. The top of the storage space is covered with khaskhas /gunny cloth in a bamboo frame structure.

The cool chamber should be constructed under a shed with a lot of aeration. The cool chamber site should be close to the source of water.

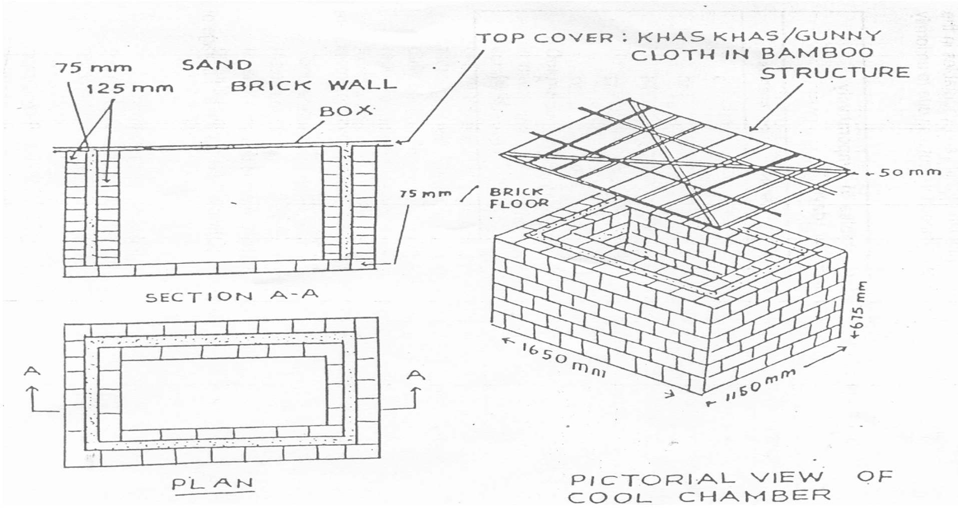

Figure 6.3: Pictorial view of cool chamber

iv) Operation: After construction, bricks of the walls and floor, the sand used in cavity and the top cover made of khaskhas /gunny cloth and bamboo are made completely wet by sprinkling water till they are saturated. It should be ensured before the actual storage of fruits and vegetables that the cool chambers are thoroughly wet. Once the cool chamber is completely wet, sprinkling of water is done once in the morning and once in the evening daily which is enough to maintain the required temperature and humidity. Alternatively, watering can be done by fixing a drip system with a source of water supply. The following precautions are to be observed for smooth functioning of cool chamber:

- Use clean unbroken bricks with good porosity.
- Sand should be clean and free of organic matter and clay.
- Keep the bricks and sand saturated with water.
- Prevent direct exposure to sun.
- Build in an elevated place to avoid water-logging.
- Try to site a place where breezes blow.

Temperature and relative humidity: It has been observed that the average maximum temperature of the cool chamber is considerably low compared to outside temperature throughout the year. During summer, when the maximum outside temperature is 44°C, the maximum cool chamber temperature is never recorded more than 28°C. Similarly, relative humidity of the cool chamber is maintained above 90 per cent practically throughout the year. The minimum relative humidity recorded in the cool chamber is 84 per cent even when the outside humidity is as low as 13 per cent. In general, it is noticed that there is a direct correlation between the outside relative humidity and the temperature difference between the cool chamber and outside. The maximum difference in temperature between cool chamber and outside is noted in the months of April, May and June. This could be attributed to low outside relative humidity during this period. The difference in temperature between the cool chamber and outside could be as high as 18-20°C when the outside humidity is extremely low.

The storage life of fresh fruits and vegetables is considerably increased by keeping them in cool chamber immediately after harvest. Its main advantage is that fruits and vegetables stored in cool chamber do not suffer chilling injury. Increased shelf life of fruits and vegetables in the cool chamber is not only because of low temperature but also due to uniformly high humidity (Table 6.2).

Table 6.2: Shelf life of fruits and vegetables in evaporative cool chamber

Produce	Shelf life (days)		Cool chamber
	Time of storage	Outside	
Leafy vegetables	Summer	< 1	3
Leafy vegetables	Winter	3	8-10
Other vegetables	Summer	1-2	5-6
Other vegetables	Winter	4-5	10-12
Potato	Spring/Summer	40	97
Mango	Summer	4	8
Orange	Winter	8-10	50-60

Check Your Progress Exercise 3

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What is the principle of evaporative cooling?

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2. Why is it difficult to store vegetables like peas and broccoli?

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3. What is the optimum humidity requirement for storage of fruits and vegetables?

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6.7 LET US SUM UP

Fresh fruits and vegetables are perishable. They contain high moisture content and liberate heat during respiration. Storage at low temperature removes respiratory heat and extends the shelf life of fruits and vegetables. Refrigeration is best method for low temperature storage but is expensive and energy intensive. Zero-energy cool chamber is a viable option for low temperature storage of farm produce. It is relatively cheaper and can be constructed using locally available materials. During summer when the maximum outside temperature is 44°C, the maximum cool chamber temperature is never recorded more than 28°C. Similarly, relative humidity of the cool chamber is observed above 90 per cent throughout the year. Low temperature storage also has some drawbacks. Some crops are susceptible to chilling injury, a low temperature storage disorder, which manifests in number of ways like abnormal ripening, browning and pitting.

Temperature conditioning, intermittent warming and controlled atmosphere storage are some of the strategies to control chilling injury disorder.

6.8 KEY WORDS

Chilling injury : Chilling injury is a low-temperature physiological disorder or abnormality of crops where freezing is not a factor.

Specific heat : Specific heat of any substance is the heat required to raise or lower the temperature of unit mass of water by 1°C.

Latent heat : Latent heat is the quantity of heat required to change the state or condition under which a substance exists, without changing its temperature, e.g., a definite quantity of heat must be removed from water at 0°C (32°F) to change it to ice at 0°C.

Refrigeration load : It is defined as that quantity of heat which must be removed in order to reduce the temperature of the products from its initial temperature to the temperature consistent with good frozen food storage.

6.9 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

Your answers should include the following points:

1. Chilling is the low temperature treatment used to extend shelf life of fruits andvegetables. It does not involve ice formation.

2. Phase change in the refrigerator takes place at two places first at the evaporator and second at the condenser.

3. Common refrigerants used in the refrigerator are ammonia, CFC (Chloro fluoro carbon) and freon.

Check Your Progress Exercise 2

Your answers should include the following points:

1. Chilling injury is a low-temperature physiological disorder observed in some crops. The crops develop some abnormalities during freezing.

2. Banana is never stored in refrigerator because it suffers chilling injury at that storage temperature.

3. Surface and internal discoloration, e.g., internal browning in apples and brown vascular streaks in banana. Surface pitting, e.g., in tomato, papaya, mango limes and lemons. Development of off-flavour and failure to ripen in some climacteric fruits.

4. - Temperature conditioning
   - Intermittent warming
   - Controlled atmosphere storage
   - Application of growth regulators
   - Packaging , waxing and other coatings

Check Your Progress Exercise 3

Your answer should include the following points

1. When evaporation of water occurs cooling takes place producing cooling effect. The greater the evaporation the greater is the cooling effect.

2. It is difficult to store peas and broccoli because they are high respiring crops and produce large quantities of heat during respiration.

3. Optimum humidity requirement of most fruits and vegetables is 85-95%.

6.10 SOME USEFUL BOOKS

1. Thompson, A.K. (1996) Post harvest technology of fruits and vegetables. Blackwell Science Ltd., London.

2. Verma, L.R. and Joshi, V.K. (2002) Post harvest technology of fruits and vegetables, Vol. 2, Indus Publishing Co., New Delhi.

3. Potter, N. (2002) Food science, CBS Publishers and Distributor, New Delhi.