CHAPTER 1

Introduction

In this chapter a brief description of traditional and modern storage methods for fruits and vegetables is presented with an intension of exposing the reader to the Science and Engineering involved in the storage of fruits and vegetables. Proper marketing of perishable commodities such as fruits and vegetables often requires some storage to balance day-to-day fluctuations between harvest and sale or for long term storage to extend marketing beyond the end of harvest season. Storage of fresh fruits and vegetables prolongs their usefulness and in some cases, improves their quality, it also controls a market glut. The principal goal of storage is to control the rate of transpiration, respiration, disease, and insect infestation and to preserve the commodity in its most usable form for the consumer. Storage life can be prolonged by harvesting at proper maturity, control of post harvest diseases, chemical treatments, irradiation, refrigeration, controlled and modified atmospheres and by several other treatments. The main goals of storage are to:

1. Slow the biological activity of fruits and vegetables without chilling injury,
2. Slow the growth of microorganisms,
3. Reduce transpirational losses and otherwise the following undesirable processes may occur in certain fruits and vegetables.
    - (i) Sprouting – potatoes, onions, ginger, garlic.
    - (ii) Elongation – asparagus, carrots, beets, kohlrabi.
    - (iii) Rotting – due to increased humidity which may result in rapid decay, shriveling, and exhaustion of food reserves.
    - (iv) Greening – exposure of potatoes to light during storage may produce green tissue and synthesis of toxic glycol alkaloids such as solanine and chaconine.
    - (v) Toughening – green beans, sweet corn may toughen due to prolonged storage at relatively high temperatures.

Factors need to be considered for success of produce storage:

1. ***Temperature*:** Temperature in a storage room should normally be maintained at the desired level for commodities being stored. Delay in cold storage reduces marketability of fruits and vegetables. Temperatures below the optimum range for a given fruit or a vegetable will cause freezing or chilling injuries. Temperatures above, depending upon produce will reduce storage life. A wide temperature fluctuation can result in rapid weight and water loss depending upon maturity of produce. The refrigeration temperature within the recommended range is a result of several important design factors. The refrigeration system must be sized to handle the maximum expected heat load. An undersized system will allow the air temperature to rise during peak heat load condition. An oversized system is unnecessarily expensive. The system should be designed so that the temperature of the air leaving the refrigeration coils is close to the desired temperature. This will prevent large temperature fluctuations as the refrigeration cycles turn ON and OFF. Temperature variation within the room is minimized by incorporating adequate amounts of insulating material in the walls and by maintaining adequate levels of air circulation in the room. When the room is filled, the containers should be stacked to allow an air passage along at least one side of each container. Thermostats are placed at a height of 1.5 m from the floor for ease in checking locations. A calibrated thermometer should be used to periodically check the thermostat.
2. ***Relative Humidity*:** For most perishable fresh fruits and vegetables, the relative humidity should be maintained between 90 to 95%. The relative humidity below this range will result in a moisture loss from the produce (Table 1.1). Thus the produce will be shriveled and limp. Refrigeration equipment must be especially designed to maintain a higher relative humidity. The environmental factors of temperature, relative humidity and vapour pressure deficit are important in the storage life of fruits and vegetables. A 5 to 10% loss in weight of produce results in shriveling, which makes the produce look stale and unattractive to sell. By using high relative humidity during storage, care must be taken to prevent the growth of surface microorganisms.
3. ***Atmospheric Composition*:** The atmospheric composition in a storage room is controlled by addition of gases allowing the commodity to produce or consume gases or by physically or chemically removing undesirable gases from the storage room. Gases such as carbon monoxide (CO), carbon dioxide(CO_2), ethylene (C_2H_4), and nitrogen (N_2) can be added to a facility from a bottled supply (or dry ice in the case of CO_2) or produced by on-site generators. As the perishable fruits and vegetables undergo respiration, they consume O_2 and release CO_2. This effect can be successfully used to control the desired concentration of these gases in storage. High concentration of undesirable gases are removed by scrubbing devices. For example, CO_2 can be absorbed in water or lime. C_2H_4 and other

volatiles can be removed by potassium permanganate, catalytic oxidation or by UV light; O_2 can be removed by using it in a combustion process or by a molecular sieve. In certain cases external concentrations of gases are desirable and the accumulated gases can be adjusted by ventilation.

4. ***Air movement*****:** Air movement must be sufficient enough to remove respiration heat. It is essential that all parts of the room are subjected to a uniform flow of air. This is accomplished by proper placement of blowers or ducts and stacking of fruits and vegetables to permit free air flow.

The successful operation of a large refrigeration system requires an efficient control system. Microcomputers are presently used to allow precise controls for large warehouse refrigeration systems. The defrosting cycle should be set to accomplish the process automatically.

Table 1.1 Weight losses in various fruits during storage as affected by humidity, temperature and air movement

Fruit	**Temp. °C**	**Air movement changes/h**	**RH %**	**Weight loss, percent of original weight after (d = days)**			
				30d	**60d**	**90d**	**120d**
Pears	0	3-4	65	2.9	5.8	7.7	10.7
	0	3-4	80	2.5	4.8	6.5	8.3
	0	3-4	98	2.0	3.5	4.6	5.5
	5	4	65	5.6	9.9	14.0	19.7
	0	3-4	80	3.5	6.2	8.5	11.3
	0	3-4	98	2.6	4.2	5.0	6.4
	5	8-9	65	8.4	15.5	22.5	29.3
	0	8-9	80	5.2	9.5	13.8	18.3
	0	8-9	98	3.0	4.5	6.0	7.8
Apples	3.9	4	65	2.5	4.7	6.9	9.3
	3.9	4	75	2.1	4.0	6.0	8.3
	3.9	4	100	1.2	1.8	2.7	--
				2d	**4d**	**8d**	**10d**
Strawberries	0	4	65	4.7	7.3	12.4	15.0
	0	4	80	4.4	7.0	11.6	13.3
	0	4	90	4.4	6.8	11.3	14.0
	0	9	65	4.7	8.4	15.7	20.4
	0	9	80	4.4	6.3	11.1	13.8
	0	9	90	4.2	6.6	11.2	13.9

Ref: Ryall, A.L and Pentzer, W.T., Handling, Transportation, and Storage of Fruits and Vegetables, Vol.2, Fruits and Nuts, AVI Publishing, Westport, CT, 1982 with permission.

5. ***Light and other factors*****:** Exposure of potato tubers to light in grocery stores can synthesize glycoalkaloids (solanine and chalkonine) which are toxic to humans.

Likewise, other factors such as herbicides, fungicides, pesticides and growth regulators may affect the produce and may have harmful affects on humans.

1.1 Storage Operations

The increase of fruit and vegetable production, owing to large acreage and high-yielding cultivars, requires sufficient storage space. Accordingly, storage operations have evolved into skilled methods of efficiency with a wide range of variations depending upon the existing facilities, including nature and the variety and quantity of produce to be stored.

Storage operations may be either temporary, short-term or long-term. Temporary storage operations are needed for highly perishable produce which requires immediate marketing. It may be installed with or without refrigeration. Temporary storage is extremely important for roadside stands, gardens, markets, railway stations, shipping yards and retail stores. The mid-term storage operation is aimed at checking the market glut without product deterioration. This may extend from 1 to 6 weeks depending upon the need, kind and maturity of the produce. Mango, banana, papaya, cabbage, eggplant, tomatoes, cauliflower and French bean are transferred to short-term storage rooms, when their quality is still good, and held there until a reasonable market price is attained. Fruits and vegetables like apples, oranges, pomelo, pears, spuash, potatoes, sweet potatoes, carrots, onions, garlic, and pumpkins require long-term storage. Its operations are mainly influenced by economic factors. The produce is stored during their periods of production and sold continuously during the rest of the year when producers and dealers can obtain reasonably high prices.

Storage operations may be classified as either natural or artificial. The natural storage operation keeps the produce in situ without any treatment, whereas artificial storage may be further classified into four types: (1) mechanical or structural, (2) controlled atmosphere, (3) chemical and (4) radiation.

In case of natural storage, the main purpose is to let the fruits or vegetables mature and ripen on plants as long as possible; on the other hand, artificial storage operations attempt to provide conditions to prolong the produce quality.

1.1.1 Traditional Storage Methods

(i) ***Natural storage*****:** Vegetables such as potato, yam, sweet potato, and garlic are kept underground for several months. They are harvested prior to the rainy season for a better market price. This storage does not involve extra expenditure and building for storage.

(ii) ***Artificial storage*****:** Pits or trenches are dug underground for storing beets, potatoes, onions, carrots, turnips, cabbages, parsnips, and sweet potatoes where they are covered with straw and soil until there is a market demand (Fig. 1.1).

(iii) ***Ventilated storage*****:** Cellars are underground rooms with slanting roofs covered with sods and soils. The structure may be built into the hillside and covered with additional soil. Cellars are provided with heaters and dry atmospheres during winter months. Potatoes, turnips, carrots and beets are stored with high relative humidity at 35 to 40 ^{o}F (1.7-4.4^{o}C). Where snow is prevalent, a good cellar will provide satisfactory storage for hard vegetables and fruits. Above ground warehouses may be used to store produce. In cold weather the produce is covered with blankets to protect from cold temperatures. Ventilation is essential for good storage. Potatoes, onions, garlic bulbs, crucifer, leafy vegetables and fruits are stored successfully.

This storage structure has several advantages over other types.

1. Special construction is not needed
2. produce is easily handled
3. grading, storing, packaging of fruits and vegetables is facilitated
4. air may be humidified and
5. fans can be controlled manually or automatically with a thermostat.

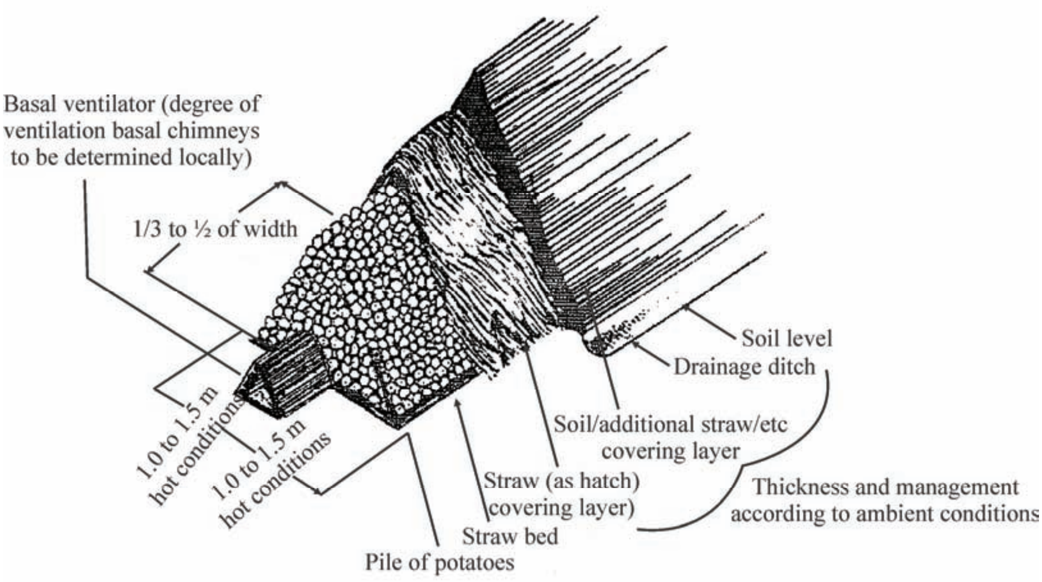

Fig. 1.1 Farm storage of potatoes (*Source:* CIP, 1981)

(iv) ***Storage with Ice refrigeration*****:** An advance on the above-ground warehouses was the use of ice as a refrigerant. Lower temperatures obtained enable longer storage of meat and perishable fruits and vegetables. Ice can be obtained in winter from frozen lakes and ponds and stored in ice houses. The melting of 1 kg of ice absorbs 325 kilo joules of heat. However, removal of melted ice water is a disadvantage. The introduction of a small ice box was a great advance on the domestic level, and for small-scale commercial storage of fruits and vegetables.

1.2 Modern Storage Methods

1.2.1 Storage with Mechanical Refrigeration

Refrigerated storage makes possible the marketing of perishable fruits and vegetables beyond their harvest season. Most of the fruits and vegetables are available year-round to consumers. This is due to the refrigerated storage. Most storage facilities use mechanical refrigeration to control the desired temperature. This system utilizes the fact that a liquid absorbs heat as it changes to gas. A common mechanical refrigeration system uses a refrigerant such as ammonia or Freon where vapour can be easily recaptured by a compressor. Heat exchange methods of heat transfer play an important part in the refrigeration of fruits and vegetables in maintaining the desired temperature in a refrigerator or a refrigerated warehouse. The refrigerant passes through an expansion valve where its pressure drops and liquid evaporates at temperatures low enough to be effective in removing heat from the storage area. Heat needed for evaporation comes from the fruits and vegetables to be cooled. The evaporator is located in the storage room. The gas is re-pressurized by the compressor and then passed through a condenser where it is cooled to a liquid. The condenser is located outside the storage area and it rejects heat. Refrigerant is stored in the receiver and is metered out as needed to produce an essential or a desired cooling temperature.

The capacity of a refrigeration system is based upon adding all the heat inputs to a storage area. Heat inputs include:

(i) Heat conducted through walls, floor, and ceiling.

(ii) Field and respiration heat of fruits and vegetables.

(iii) Heat from air infiltration.

(iv) Heat from equipment such as lights, fans, forklifts, and personnel moving in and out.

Mechanical refrigeration is of two types:

(i) Vapour compression,

(ii) Vapour absorption.

The basic equipment for vapour compressions mechanical refrigeration consists of compressor, condenser, expansion valve, and evaporator. The refrigerant (ammonia or Freon) is compressed, cooled by passing through an air-or water-cooled condenser, and then expanded through an expansion valve into evaporator coils. During evaporation and expansion phase, heat is absorbed from fruits, vegetables, and the area to be cooled.

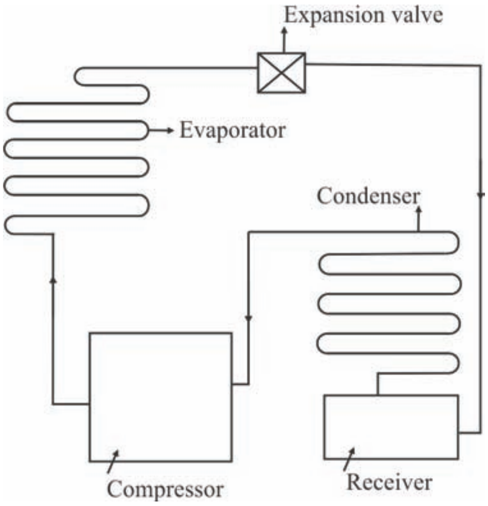

Fig. 1.2 Simplified schematic drawing of refrigeration cycle

The absorbed heat is returned for eventual elimination in the condenser. All modern room-refrigeration system provide forced-air circulation. This system uses prefabricated units containing both evaporator coils and blowers for air circulation. They provide excellent storage environment. Substantial heat must be removed quickly from the produce in storage; it is apparent that greater refrigeration capacity and air velocity must be available. Fig. 1.2 and 1.3 shows the schematic diagram of vapour compression refrigeration system and its cyclic representation on a psychrometric chart respectively. The psychrometric chart gives the graphical representation of various thermodynamic properties of air. If any two measurable properties of air are known, the other properties such as enthalpy, vapour pressure and specific volume etc. can be directly read from the chart. It facilitates the easy and quick estimation of various design parameters for air conditioning equipment. The success of mechanical refrigeration storage depends upon controlled temperature, relative humidity, and air movement.

Temperature

Temperature control depends upon a tight, well-insulated structure and sufficient refrigeration capacity. It also depends on the amount and nature of the evaporator-coil surface, its freedom from condensed ice, and the rate of air flowing over the coils. These factors control the total efficiency of refrigeration.

Relative Humidity

Relative humidity is the percentage of saturated water vapor at a given temperature. Relative humidity (%) can be determined from psychrometric chart (Fig. 1.3) on the basis of wet-bulb and dry-bulb temperatures. As the temperature of air increases so does its water-holding capacity. Accordingly, air with 90% RH at 70°F (21°C) contains much more water vapour than air of the same relative humidity at 40°F (4°C). As the relative humidity of air decreases, so does its vapor pressure and as vapor pressure decreases, the capacity of the air for removing water from moist produce increases. Thus it is important to maintain a high vapour pressure. If drying is to be avoided, a small vapor pressure differential between stored produce and storage air must be obtained. Effective ways of accomplishing this is by rapid equalization of produce and air temperature, maintenance of high relative humidity in the storage room air as the produce will tolerate and no more air movement than is required for even temperature distribution in the refrigerated room.

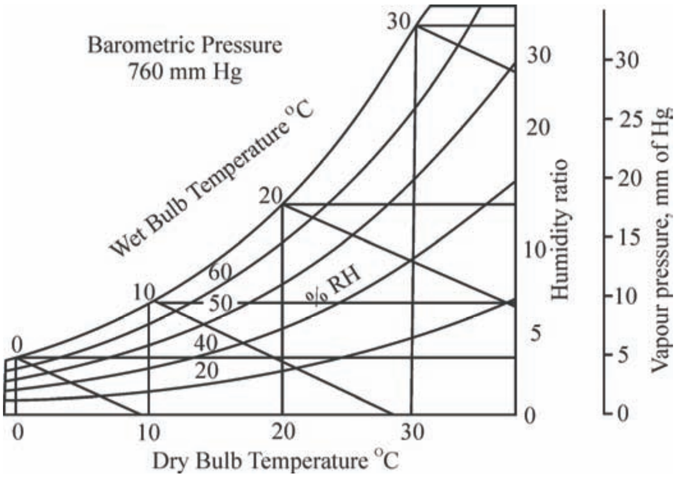

Fig. 1.3 Psychrometric chart

1.3 Controlled Atmosphere Storage

Controlled atmosphere storage (CAS) process is most important innovation in fruit and vegetable storage since the introduction of mechanical refrigeration. To reduce fruit losses during refrigerated storage, it is important to utilize to maximum advantage all the potentialities of this method in order to suppress the vital activity of phytopathogenic micro organisms which are always present on the fruit surfaces, to retard the processes connected with most harvest ripening of fruits and to delay the senescence and collapse of fruit tissues. But in most cases by maintaining a definite regime of temperature and humidity alone is not sufficient for prolonging the period for which fruits can be preserved and for reducing fruit losses. A definite gas composition of the atmosphere, strictly differentiated for each type of fruit and for different varieties of the same fruit is also necessary.

The first studies regarding fruit preservations in gaseous medium were carried out in an atmosphere consisting of more CO_2 and less O_2 than normally present in air. Carbon dioxide played the dominant role, and this is why the method is also called the “Carbon dioxide preservation method”. It was found that CO_2 concentration in the regime not only reduce the vital activities of the fruit and also because of its strong antiseptic nature.

Many investigations have shown that the basic advantage of fruit preservation in a controlled atmosphere are as follows.

(i) The so called low-temperature diseases are prevented during refrigeration.

(ii) Infestation of fruits by other physiological diseases frequently encountered when fruits are preserved in refrigerators in conventional fruit storages is reduced.

(iii) The taste and aroma fruits are preserved better.

(iv) The consistency of fruits is maintained for longer periods.

(v) The fruit losses in the controlled atmosphere are half to one third, while the period of preservation is significantly higher than when kept in an uncontrolled atmosphere.

Various aspects of the controlled atmosphere storage are given in part 3 of this book.

1.4 Modified Atmosphere Packaging

Storage of fruits in packings of polymer materials with selective permeability for gases is what it is called modified atmosphere storage. This technique was found to enhance the shelf life of produce stored in the polymeric pouches, bags and containers. Such storage is done in conventional cold storage chambers and therefore does not involve large capital outlay necessary for the construction and equipping of special hermetically sealed chambers with controlled atmosphere.

Advances in the design and manufacture of polymeric films with wide range of gas permeability have stimulated interest in creating and maintaining modified atmosphere within the flexible film packages.

The gas composition in the packings can be changed partially by the type of material selected, capacity of the packing, variety of fruit and the temperature of storage. In the selection of material, their gas-vapour permeability is of decisive importance, and this depends on the type and thickness of the material.

To understand this method of storage in more detail, it is necessary to know about characteristics of gas exchange during the storage of fruits in packages with selective permeability. For maintaining the desired atmosphere within a package, absorbers, adsorbers of O_2, CO_2, C_2H_4 and water vapour provide additional benefit.

Selection of suitable packaging materials for fruits basing on their selective permeability to the gases and the basic principles governing such selections are discussed in part 4 of this book.

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