Potato Storage Technology and Store Design Aspects

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ABSTRACT

The quality of potato, and its storage life, is reduced by the loss of moisture, decay and physiological breakdown. These deteriorations are directly related to storage temperature, relative humidity, air circulation and gas composition. In an attempt to attain the desired storage condition in an enclosure, many systems have been developed over the years depending on the geographic location, volume produced, consumer demand and the marketing strategies. Potatoes being a living organism require an effective management for storage. Quality of the potatoes cannot improve during storage. Bruise prevention is an important part of keeping quality of potatoes with minimum weight loss and storage diseases. Many attempts have been made by researchers to investigate the suitability of various storage systems over the years for safe storage of agricultural commodities. Conventional refrigerated room, ventilated cold room, bulk storage facilities, jacketed storage and various types of controlled atmosphere (CA) storage like Marcellin and Atmolysair have been used. In this paper, attempts have been made to integrate the application of scientific storage techniques, design factors and management fundamentals into storage systems, to minimize the storage losses.

Keywords: Potato, Storage Technology, Irradiation, store design

1. INTRODUCTION

The potato is the most important food crop in the world after wheat, rice and maize. Over one billion people consume worldwide and potatoes are part of the diet of half a billion people in the developing counties. Potato ranks 4th in the world and third in India with respect to food production. In the year 1999- 2000, India produced 25 million tonnes of potatoes from an area of 1.34 million hectares with an average yield of 18.6 t/ha.

Potato is a staple food in the colder regions of the world, while in other parts of the world it is generally used as a vegetable. In India 73% potatoes are consumed in different forms such as cooked, roasted, French-fried, chipped etc. Cooking often reduces mineral and vitamin constituents. In case of processed products it is possible to add missing or low ingredients in order to enhance overall nutritional value of the product (Shekhawat, 2001).

The potato (*Solanum tuberosum L.*) is a semi-perishable commodity. Appropriate and efficient post harvest technology and marketing are critical to the entire production-consumption system of potato because of its bulkiness and perishability. Unlike in temperate regions, in India the potato is harvested in the beginning of summer. Due to inadequate cold storage facilities to hold the produce for longer periods, prices plunge at harvest time and large quantities are spoiled before they could be disposed off. Consumers are also unable to develop a habit of consuming more potatoes because potato stocks disappear from the market within a few months of harvest and in later part of the year relative prices of potato are high. Per capita consumption of potatoes in India is 18.3 kg a year as against the world average of 52.7 kg, in spite of increase in production in recent years (FAO, 1991).

Egypt is one of the largest producers and exporters of potatoes in Africa. Potato is the second most important vegetable crop after tomato (El-Tobgy, 1974). In 1996, Egypt produced 2.6 million metric tonnes of potatoes and exported 411,000 metric tonnes valued at nearly US $80 million to Europe and the Arab countries. Small farmers grow 65% of these potatoes. In year 2000 Egypt produced 1.784 metric tonnes from an area of 83000 Ha with average yield of 21.49 t Ha^{-1} (FAO, 2000).

2. STORAGE OF POTATO

The purpose of storage is to maintain tubers in their most edible and marketable condition and to provide a uniform flow of tubers to market and processing plants throughout the year. Four variables to determine storage losses are the potato variety, pre-storage conditions, storage conditions and storage duration. It must be realized that storage losses cannot be avoided even by optimal storage. Good storage can merely limit storage losses in good product over relatively long periods of storage. Storage losses are often specified as weight losses and losses in the quality of potatoes, although the two cannot always be distinguished.

Storage losses are mainly caused by the processes like respiration, sprouting, evaporation of water from the tubers, spread of diseases, changes in the chemical composition and physical properties of the tuber and damage by extreme temperatures. These processes are influenced by storage conditions. All the losses mentioned above depend on the storage conditions and therefore can be limited by maintaining favourable conditions in the store. However, the storability of potatoes is already determined before the beginning of storage, by such factors as cultivar, growing techniques, type of soil, weather conditions during growth, diseases before harvesting, maturity of potatoes at the time of harvesting, damage to tubers during lifting, transport and filling of the store (Rastovesky, 1987 and Burton et al., 1992).

The four main outlets for stored potatoes are: seed potatoes, household consumption, the processing industry and potatoes as raw material for the production of starch or alcohol. Choice of storage method must be considered by the requirements for each purpose, but for all uses wound healing is essential immediately after harvest.

Good storage should prevent excessive loss of moisture, development of rots, and excessive sprout growth. It should also prevent accumulation of high concentration sugars in potatoes, which results in dark-coloured processed products. Temperature, humidity, CO_2 and air movement are the most important factors during storage (Harbenburg et al., 1986 and Maldegem, 1999).

Varns et al. (1985) investigated the potato losses during the first three months of storage for processing. It was observed the sampling of three respondent groups includes a local storage region, the processing industry, and the federal inspection service (USDA). Questionnaires indicated that 64 to 150 thousand metric tons were annually lost during early storage from the total crop stored for processing. This constitutes a range of 5.6- 13.2 million dollars lost in production costs.

Rastovsky (1987) has reported the approx. values of storability of potatoes at different temperatures (Table 1) and ideal storage temperature for potato as per different uses (Table 2). In addition to this, the atmospheric humidity must, in general, be as high as possible, in the range of 85 to 90 per cent. The warehouse potatoes must be treated with sprout inhibitors at storage temperatures above 4°C.

Table 1. Storability of potatoes at different temperatures.

Average storage temperature, °C	Storability, months	Average storage temperature, °C	Storability, months
5	6	20	2-3
10	3-4	25	2
15	2-3	30	1

Table 2. Recommended storage temperature for potatoes for different usage.

Purpose	Storage temperature, °C
Fresh consumption	2-4
Chipping	4-5
French frying	7-10
Granulation (mashed potatoes)	5-7

2.1 Traditional Storage Practices

Storage methods, which were in vogue in the warm plains of India till recently, are described by many authors and are as follows. i) Storage in cool dry rooms with proper ventilation on the floor or on bamboo racks and ii) Storage in pits. The former was generally followed in the plains for seed potatoes during the period from Feb.- March to Sept.-Oct. Storage in pits was adopted in the erstwhile Bombay state from Feb.- March till the onset of monsoon season in June (Kishore, 1979).

In Egypt, the bulk of potato storage takes place in traditional structures or nawallas made of mud bricks. Nawallas are typically privately owned and are concentrated in the northern governorates with lower average temperatures. Walls are typically from 2.5 to 3.5 m high and 30 to 60 cm thick. Storage period is normally for 5 months, May to September. Roofs consist of bamboo matting, rice straw, and mud supported by wood or bamboo frames. Seed potatoes are dusted with SEVIN and CAPTAN (brand names) and arranged in piles 1.5 to 4 m across and 0.8 to 1.0 m high. The piles are sorted every two weeks and infested, diseased, or damaged tubers discarded. Rats and Tuber moth are major problems.

Temperatures within the nawallas are not much lower than the ambient temperatures in the shade outside, although within the heaps temperatures may as much as 10˚C lower. Losses from tuber moth infestation, dehydration, excessive sprouting, and other causes average about 20-30%, although losses of up to 70% have been reported. The need for improving storage facilities and practices for warehouse as well as seed potatoes has been noted by several authors (Geddes and Monninkhoff, 1984).

2.2 Scientific Storage Systems

2.2.1 Evaporatively Cooled Storage

Evaporative cooling is nature's very own method. The ancient Egyptians used a primitive form of evaporative cooling, dating back to about 2500 BC. Evaporation of water produces a considerable cooling effect and the faster the evaporation the greater is the cooling. Evaporative cooling (EC) occurs when air that is not already saturated with water vapour is blown across any wet surface. Thus evaporative coolers consisted of a wet porous bed through which air is drawn and cooled and humidified by evaporation of the water (Khader, 1999).

The farm level storage system, which is less capital intensive and extends the shelf life of fruits and vegetables sufficiently to realize better prices after the storage period was very much needed. EC storage was thus considered to meet the much-desired need and hence studies were initiated on this aspect in the early eighties at CFTRI, Mysore, CPRS, Jalandhar and IARI, New Delhi (Rama and Narasimham, 1991).

An open cycle 3-ton air conditioner has been designed to suit the hot humid climate by Gupta and Gandhidason (1979). The method is based on dehumidification of air by using a liquid absorbent followed by adiabatic evaporative cooling.

Roy and Khurdiya (1982) constructed 4 types of evaporatively cooled chambers for storage of vegetables. The first chamber was made of cheap quality porous bricks and riverbed sand, which was latter known as Zero energy cool chamber. The other three chambers were ordinary earthen pots placed in three tanks: the first one made of bricks, the second one an ordinary wooden box and the last, an ordinary fruit basket. The gap in all the cases was filled with sand. The sand and the gunny bags covering the top of the chambers were kept saturated with water. The cool chambers maintained a temperature between 23-26.5˚C and relative humidity (RH) between 94-97% as against the ambient temperature between 24.2-39.1˚C and RH 9-36% during the months of May-June. Chamber 1, i.e. the Zero energy cool chamber, performed best with the enclosed air temperature remaining between 23-25.2˚C.

Roy (1984) reported that a 6 tonne cool chamber was constructed, where the side wall was constructed with two layers of bricks leaving approx. 7.5 cm gap in between them. This gap was filled with riverbed sand. The floor was made of wooden planks. Below the floor, a 33 cm deep tank was constructed with 4 air ducts made of bricks opening at the center and submerged under wet sand. The sand in the wall and surrounding the ducts were saturated with a drip system. The top of the chamber was insulated and incorporated with an exhaust fan. The air while passing through saturated duct and walls cooled sufficiently and took away heat from the produce. Sprinkling of water twice daily was enough to maintain the desired temperature and humidity.

Chouksey (1985) reported the design aspects of a solar-cum-wind aspirator ventilated evaporative cooling structure of 20-ton capacity for potatoes and other semi perishables, which was constructed at the Central Potato Research Station (CPRS), Jalandhar. The structure maintained a temperature of 21-25˚C with 80-90% RH at ventilation rate of 24m^3/min when the outside temperature and RH were 40-42˚C and 30-35%, respectively.

Anonymous (1985) and Roy and Khurdiya (1986) reported the detailed method of construction of a Zero energy cool chamber. A chamber for storage of about 100 kg horticultural produce was constructed with two layers of bricks as side walls leaving approx. 7.5 cm gap in between them. This gap was filled with riverbed sand. The top of the storage space was covered with khaskhas/ gunny cloth in a bamboo-framed structure. There was no provision for mechanical ventilation. The sidewall and top cover were kept completely wet during the period of storage. It was observed that the cool chamber had a temperature of less than 28˚C during summer, when the maximum outside temperature was 44˚C. The average minimum temperature of the cool chamber was either less than or near the outside average minimum temperature, excepting in winter, when it maintained a few degrees centigrade more than the outside average minimum temperature.

Habibunnisa et al. (1988) fabricated a metallic EC chamber measuring 45 x45 x 45 cm (approx. 0.1 m^3) with a 2 mm GI sheet with the top side open. The four sides of metallic chamber were covered with a cloth, the top ends of which were immersed in water placed in the top tray. For allowing evaporation, the cloth surrounding the metallic chamber was made to remain wet continuously by downward gravitational flow of water. A wire mesh basket of size 30 x30 x 30 cm filled with fruits was kept inside the chamber, leaving adequate space all around the basket for circulation of the air. The EC storage increased the shelf life of apple by 6 times and Coorg mandarins by 4 times.

Rama et al. (1990) studied the relative performance of two models of EC storage structures with regard to their efficiency in maintaining the temperature close to the ambient wet bulb temperature and high RH The first structure was the same as that used by Habibunnisa et al. (1988). The second one resembled the first one except that the outer metallic wall was replaced by a weld wire mesh (2.5 x 2.5 cm) with evaporative sides covered with wet gunny cloth to help in free movement of evaporatively cooled air. The top tray used in this system (to serve as the water reservoir to wet the gunny cloth) was devoid of vents. The inside temperature for both the systems were almost similar and close to the ambient wet bulb temperature and the relative humidities were 90 ±5%, respectively. The lower RH of the system 2 was attributed to the free air circulation through the structure.

Sharma and Kachru (1990) used evaporatively cooled sand stores, where a 5 cm thick potato layer was placed on floor in between two sand layers each of 20 cm thickness. In order to allow evaporative cooling, 2.1 m^3 of water was sprinkled daily to wet the sand. It was observed that under low atmospheric RH conditions, wet sand was suitable for storing potatoes for up to 90 days as compared to 60 days in jute bags and still less in other storage methods like bamboo baskets and heaps.

Umbarkar et al. (1998) constructed an EC structure of 2 tonne capacity based on the results of their previous studies (Umbarkar et al., 1991). The walls of the structure were constructed with 10 cm thick brick batt pad sandwiched between two 10 cm thickness brick perforated walls. To add to the structural strength, 8 mm diameter mild steel reinforcement anchored the latter with each other. Holes of 50 x 40 mm were provided between two successive brick layers for air circulation throughout the height of the structure. A thatched roof with bamboo mat and dry grass was provided as cover at the top. At the bottom of storage stacks, a free board of 10 cm was left for bleed off water from walls. The temperature in the chamber varied between 23-26.5˚C as against ambient temperature variations between 25-44˚C on a test day. The RH. in the structure was 85-97%. The water requirement was 325 litres per day.

Dash (1999) developed a mathematical model for analysis of time dependent thermal environment in evaporatively cooled storage structures. Simulation studies indicated that the RH inside the EC structure would remain close to 100%, throughout the year and maximum advantage of evaporative cooling could be obtained under low ambient RH conditions. The structural orientation had a negligible effect on the inside thermal environment of the EC structures. The cumulative heat units was lowered by 8.1, 8.23, 3.2 and 4.8% by shading the structure during the month of January, April, July and October, respectively. The cost of storing one kg of potato in a 1.0m^3 EC structure for about 100-120 days storage period were Rs. 1.14 and Rs. 1.17 (1US $ = 46 Indian Rupees) in the pad and brick structures, respectively. In a 25m^3 structure (for 8 tonnes potato), the cost of storage was Rs 0.97/kg.

2.2.2 Cold Storage

The cold storage is serving mankind by preventing the spoilage of perishable commodities and making them available off-season and in places where they are harvested. This also serves the dual purposes: the growers of the perishable produce need not require to sell out their produce in hurry at throwaway price and protect the nation from shortage of commodities due to spoilage of food during off season.

A solar cold store could help the farmer in rural areas to store seasonal agricultural produce for several months. Winter-grown vegetables like onions and potatoes are usually stored for 2-5 month before being supplied to the market.

In India studies by Mann and Joshi (1925) on the preservation of potatoes with minimum wastage emphasized the need for cold storage. The storage of potatoes in cold stores was started commercially at Karachi in 1932. The Meerut cold store was started in 1938 and others followed (Singh, 1974). Cold storage facilities in India are shown in Table 3. More than 85% of the potato production in India takes place during winter season till March and they must be stored for warehouse purposes to meet the demand from May to October. This period is characterized by high ambient temperature and low RH, which accelerate the deterioration. A report indicated that due to inadequate cold storage space; only 41% of the total output (19.2 million tones) of potatoes (1995-96) could be kept in refrigerated storage facilities (Dahya et al., 1997).

About 3.4 m^3 of volume is required per tonne of potato to be preserved while for onions this value is about 5.7 m^3/t. Thus, one can calculate the total volume of storage space as soon as the amount of storage product is known (Prasad, 1999).

The earlier cold storage were cubical in shape in order to minimize the surface area for a given volume, i.e.,

$$a = b = H = V^{1/3} \qquad (1)$$

Where a, b, H and V are width, breadth, height and volume of storage space. In doing so the height of large cold storage becomes too big, causing material handling, stacking and similar other problems. A comparative study of the single and multi-storeyed cold store buildings has been made with respect to space and installation (Heinze, 1973). It has been found that the single-storeyed buildings turn out to be a better choice. However, the multi-storeyed cold storages with mechanized arrangements are preferred for the multi-variety systems, especially in cities where the floor area is extremely expensive.

Table 3. Commodity-wise distribution of cold storage facility in India.

Commodity	Capacity (Million tonnes)	Percentage of Total
Potatoes	7.67	87.76
Multipurpose	0.75	8.56
Other fruits and Vegetables	0.17	1.98
Fish and Marine Products	0.06	0.75
Others	0.08	0.95
Total	8.73	100.00

Source: Floriculture Today (1998)

Sometimes cold storage size is based on floor area, i.e., about 100 kg m^{-2}. However, there does not exist a unique specification agreed upon and used internationally. Despite lots of discussions differences on specification on the cold storages exist.

To name a few, the cold storage is specified on the gross volume or net volume or the capacity to store commodity or tonnage of the refrigeration system (Prasad, 1999).

Giri and Bovne (1978) designed a one-ton solar powered cold storage plant. They proposed the guideline for the development of 10-20 ton capacity refrigeration plants for rural applications.

Once produce is placed in the cold store, the heat from the produce is transmitted to the air, which transfers this heat to the evaporator, which in turn removes it in the normal mechanical refrigeration cycle. The cooling of the air and hence the cooling of produce is speeded up by the presence of electric fans mounted across the evaporator coils and may be supplemented by circulatory fans placed in the room and directed across the produce.

The time it takes for the produce to reach the optimum storage temperature (sometimes called the pull-down time) will be limited by the overall refrigeration capacity of the equipment and the speed of the air passing over the evaporator and over the produce assuming there are no barriers to air circulation around the produce.

In the refrigeration industry, the unit used is ton refrigeration (TR). It is equivalent to the rate of heat transfer needed to produce 1 ton (1000 kg) of ice at 0˚C (273.16 K) from water at 0˚C (273.16 K) in one day.

$$1\,TR = \frac{\left[\left(1000\ kg\ d^{-1}\right)x\left(80\ k\,cal\ kg^{-1}\right)\right]}{24\ h\ d^{-1}\ x\ 60\ min\ h^{-1}} = 55.56\ k\ cal\ min^{-1}$$

Rapid air movement over produce enhances water loss and so in most refrigerated stores for long-term storage, air circulation is moderated to keep water loss to a minimum over the storage period. Produce temperature reduction under these conditions will be slow and the rate of respiration will only be slowly reduced.

2.2.3 Vapour Compression Cooling

Any liquid, when it evaporates, takes a certain amount of outside heat to change from liquid into vapour form without any increase in its temperature. This amount of heat depends upon the characteristics of the liquid and it is known as the latent heat. It is the utilization and removal of this heat, which causes cold and more the latent heat of evaporation of a liquid the better it is to use as a media for producing cold. To produce cold by mechanical means i.e. by refrigeration, the above principle is used. Vapour compression system is referred to as mechanical refrigeration by different authors.

2.2.4 Forced Draught Cooling

In this system, the produce is stacked in the manner like in a cold store with a high refrigeration capacity. A sheet of canvas or other material is placed over the stacked produce and a powerful electric fan sucks cold air rapidly from the room through the packed produce.

Although the rapid air movement creates more water loss from the produce, cooling is much more rapid than otherwise and the respiration rate is reduced very quickly. As soon as the produce has been cooled down to close to the optimum storage temperature, it can be transferred to an ordinary cold store for the rest of its storage life. There are many different types of forced-draught cooling systems and most depend upon the produce being in appropriate containers – often fiberboard cartons. Ships and containers adapted especially for refrigeration and carriage of fresh produce use a variation of this system.

2.2.5 Ice-bank Cooling

This is a relatively recent development in which heat is removed by melting a large block of ice, which has been built up over a period of days by a small refrigeration unit. The heat is removed from air in the store by passing it through sprays of ice-cold melt water in a chamber separate from the store. In this way cool air of very high relative humidity can rapidly cool the store and the produce.

Temperature of ventilating air is reduced at the rate of –17.5°C per day until holding conditions is reached. This is first done by measuring the return air temperature (although measuring the bulb temperatures at the top of the pile will be more accurate). If the return air temperature is within -16.7°C of the set temperature, it will be necessary to lower the set temperature at the rate mentioned above. The best time to measure the return air is during early morning hours because the pile would have gone through an extended period of cooling through the night. Ventilation should always be provided during cool down. Once the conditions inside the storage are stabilized, daily ventilation carried out should be long enough to maintain a –17.2 to –16.7°C differential between the bottom and the top of the pile. Increasingly, fans are being run in shorter cycles (at the rate of 2 to 4 hours per run with a break of at least 2 hours). The shorter cycles tends to reduce extreme pile temperature difference between the top and the bottom. The point to remember is that if the fans are stopped for long periods, the pile tends to get warmer; therefore, it will require more time to cool down. This recommendation is fairly new and therefore storage managers are advised to check the efficiency of the air system before making any changes.

2.2.6 CO_2 Control System

In a storage room equipment with a CO_2-control system, the desired Co_2 levels are maintained by controlling the airflow to the scrubber or by regulating the outflow into the storage area. There are four main reagents, which are commercially used for CO_2 absorption. They are: water, Hydrated lime, activated charcoal, and molecular sieve. In these systems, the O_2 levels are usually maintained by introducing outside air into the storage room.

2.2.7 Irradiation

During the past three decades, ionizing radiation has come into use as a means of food preservation. This method has been recognized as the only new method of food preservation since the invention of food canning by Nicolas Appert in 1890. The radiation treatment consists of exposing a product to electromagnetic radiations or accelerated electrons. These radiations interact with the product matter including chemical changes, ionization and excitation, which alter the normal life process of living cells. Ionizing radiation can kill bacteria, delay ripening, inhibit sprouting or impair insect reproduction without heating or using chemical treatments.

Low-dose irradiation of potatoes produced no detrimental effects on potato flavour (Pederson, 1956). Panalaskas and Pellefier (1960) found that specified level of gamma radiation did not cause consistent variations in the ascorbic acid content of potatoes. Mikaelson and Roer (1956) reported that the vitamin C content decreased in both the irradiated and non-irradiated potatoes during the first 7 months of storage at 5°C but was restored after this period, and that the ascorbic acid levels of the irradiated potato samples were higher than those under control. Tatsumi et al. (1972) reported their experiments on mechanism of browning. The results showed that the O-diphenol content increased in irradiated potato tubers (Table 4) and the rate of increase was greater in the cortex and vascular bundles than in the pith. The ascorbic acid content decreased with increasing levels of irradiation dose, the rate of decrease being greater in the cortex and vascular bundles than in the pith. According to Wills et al., (1981) irradiation of potato and onion is more expensive than treatment with chemical sprout inhibitors like CIPC and MH.

Table 4. Ascorbic acid and O-dephenol contents after irradiation.

Doses (krad)	Irradiated 1 day after harvest*			Irradiated 3 months after harvest*		
	Cortex	Vascular bundle	Pith	Cortex	Vascular bundle	Pith
Ascorbic acid						
0	18.2	18.5	19.3	9.3	9.8	7.6
10	11.3	12.5	15.5	8.9	8.3	6.7
20	15.4	11.0	11.7	7.2	7.1	7.3
40	9.9	10.4	10.1	7.6	7.6	7.3
O-dephenol						
0	3.2	3.4	2.0	5.7	3.6	1.2
10	8.4	7.2	4.4	6.0	5.7	0.6
20	10.8	7.6	4.8	5.4	6.6	0.9
40	11.7	8.4	4.6	3.9	6.0	0.0

* mg/100g fresh weight of potato tubers

source; Tatsumi et al. (1972)

3. POTATO STORAGE DESIGN PARAMETERS

To achieve the best results in efficiency and economy, cold storages should be designed and constructed properly. The first step, while installing a cold storage plant, is the selection of proper site. The cold storage building is an expensive structure and must be considered as a permanent building. Therefore, the site should be selected, keeping in view the long range planning of production operations, and plant expansion.

3.1 Storage Building Structures

The basic functions of storage buildings are i) retention of the stored product; ii) protection of the commodity against weather; and iii) to provide a micro-environment in which temperature, air circulation, relative humidity and atmospheric composition can be easily controlled. The storage building should be constructed on a well-drained soil, at a location that meets all the requirements of the owner. Provisions for parking, receiving, shipping, storage for empty containers, waste disposal, and future expansion should be made. Building floor plans are to be designed according to the nature and the amount of the product to be stored and handled, the space availability, the type of operation planned and costs involved. A flow diagram that shows the path of all traffic as the product is received, stored, handled and shipped is most suited at this stage of planning. Figure 1 show the important components of storage.

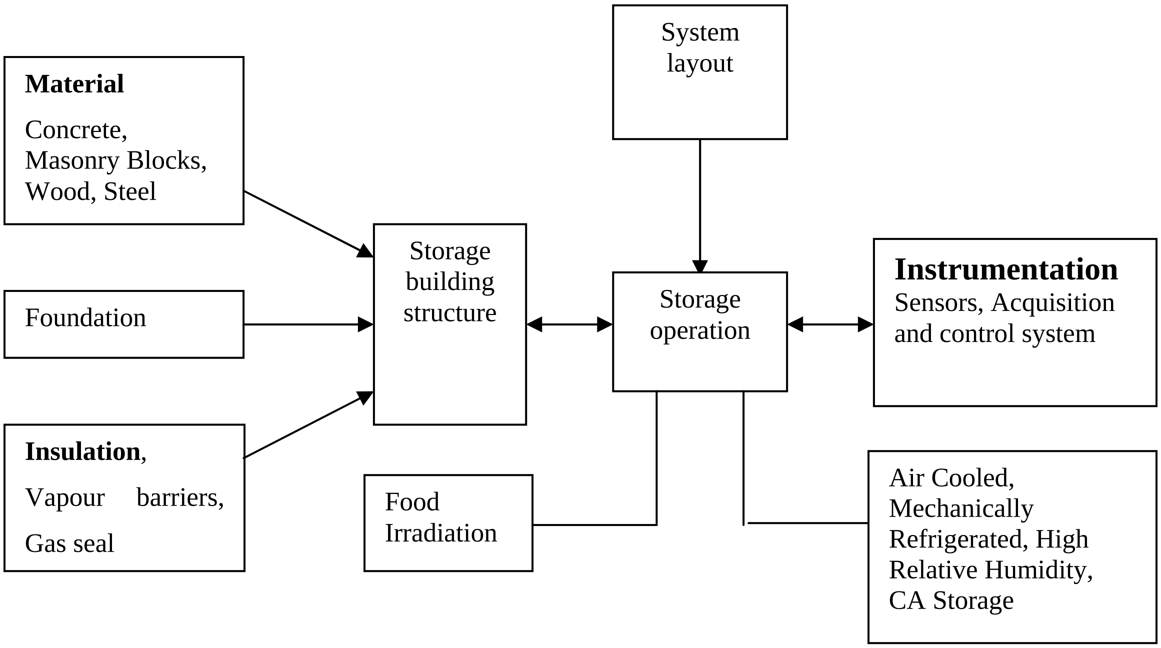

Fig. 1. Flow chart showing the various components of storage.

3.2 Static Load on Storage Building

There are three load factors to consider when designing a potato storage building (Brook et al., 1995). (i) Wind and snow loads for the local geographic area. Most building contractors know the wind and snow load factors required for their area. Another source is ASAE Engineering Practice EP 288, Agricultural Building Snow and Wind Load (ASAE, 1994). (ii) Maximum floor load, primarily due to loaded field trucks. Another source is ASAE Engineering Practice EP 378, floor and suspended loads on agricultural structures due to use (ASAE, 1994). (iii) Static Loading of Potatoes on the Sidewalls of the Building. For vertical walls, these static loads should be based on design information in ASAE Engineering Practice EP 446, Lateral Pressure of Irish Potatoes Stored in Bulk (ASAE, 1994). The values of lateral forces from potatoes can be calculated with the following expression:

$$L = 17.8 + 8.52\,H - 0.18\,H^2 \qquad (2)$$

Where: L = lateral force, lb/ft^2 and

H = the depth of potatoes in the bin, ft (Schaper and Herrick, 1968).

However, the angle of repose of clean potatoes is about 37° relative to a horizontal surface, and the storage capacity of the building will be reduced at the natural angle of repose. Measurements of pressures on the walls of reinforced concrete bins 122 m long and 18 m wide from potatoes piled 6.1 m deep showed lateral pressures upto 11.5 Pa at 1.22 m above the floor (Powell at al., 1980).

Since high pressure damages the tubers, causing bruising, the pressure must be limited by restricting the stack height to 3 to 4 m depending on the quality of the potatoes. With a stacking height of 3 m, therefore, 2 tonnes of potatoes per m^2 can be stored, increasing to 2.87 tonnes/m^2 for a height of 4 m (Rastovski, 1987).

3.3 Insulation

A correct insulation helps the store operator to maintain the right environmental conditions for the storage of potatoes.

In any insulation calculations it is the inside and outside temperatures which are used, as the actual surface temperature is not normally known. When heat goes from inside to outside, it first goes into the structure, then through the structure and then goes out of the structure. These inside and outside surfaces actually provide a resistance to heat flow and the value of coefficient of heat transfer (U) should be taken into account. This surface resistance can be important particularly in a poorly insulated structure.

$$U = \frac{1}{Total\ sum\ of\ the\ thermal\ resis\tan ces} \qquad (3)$$

Where: U = thermal transmittance, and

$$Thermal\ Resistance = \frac{Thickness\ of\ material}{Thermal\ conductivity\ of\ material} = \frac{x}{k} \qquad (4)$$

Therefore for calculation of the heat loss or heat gain of a building, it is the ‘U’ values of the walls, roof and ceiling, which are required. As mentioned before, the heat transmission through a structure depends on three factors: the thermal transmittance (the ‘U’ value), the surface area of the structure (A) and the temperature difference between inside and outside (T_o - T_i). This can be expressed as an equation:

$$Q = U\,A\,(T_o - T_i) \qquad (5)$$

When considering an economic level of insulation, the following factors must be taken into account:

- The annual cost of insulating material used.
- The annual capital cost of the plant.
- The loss in value of the produce stored as a result of moisture removed by the cooling system.
- The temperature being maintained within the structure.

- The period of operation and the ambient temperatures occurring during this period. The costs of fuel used to heat or cool the structure and its efficiency of utilization.

3.4 Vapor Barrier

Vapor barriers are important for a high humidity potato storage. The most adequate methods of excluding moisture from the insulation materials are by sealing the insulation using the methods that may exclude moisture from the insulation (Raghavan and Gariepy, 1984). Methods that may exclude moisture from the insulation and produce adequate air tightness at the same time are the sprayed-on polyurethane insulation and the prefabricated insulated steel panels.

3.5 Ceiling

A good ceiling is important in any potato storage, especially those with a truss roof. Space above the ceiling will provide good venting for the ceiling insulation. The reduced space between the potatoes and the ceiling will result in less temperature stratification. The ceiling will be warmer to reduce the likelihood of moisture condensation. Painting the inside of the ceiling black, causes the ceiling to stay warmer than a light colored surface. Using a material similar to an asphalt mastic will help reduce moisture transfer through the ceiling while creating rough surface with less chance for condensation. The attic space (created by the ceiling) needs a ventilation area of approximately 1/50th of the ceiling surface area (Brook et al., 1995).

Condensation occurs on a surface when its temperature drops below the dewpoint of the air with which it is in contact. Therefore condensation occurs when relatively warm moist air meets a cold surface. Condensation should be avoided in potato storage for three reasons (Bishop et al., 1980):

1. The condensing surfaces remove moisture from the air, which is largely replaced, by moisture from the crop; therefore every litre of condensation is a direct loss of one kg of crop.
2. The loss of moisture by a crop can affect its appearance and therefore its marketability.
3. If condensation occurs on the ceiling water can drip back into the crop, making it more susceptible to disease development.

The formation of condensation can be prevented by providing a proper insulation of the walls and roof.

3.6 Fans and Airflow

The uniform distribution of ventilation air in potato storage is necessary for useful long-term storage. Uniform air distribution equalizes bin temperatures, maintains the desired environmental conditions and ensures an even distribution of sprout inhibitors. Good air distribution is provided by proper ventilation duct design.

Recirculation is the term applied to continuous ventilation with store air, in the case of bulk storage being introduced through ducts under the potatoes and the air intake usually in the roof space above potatoes. If the store is sealed, depending for temperature control upon heat leakage through the structure, the air is rapidly humidified by its passage through the potatoes- the volume of the air in a filled bulk store could be some 2 $m^3.t^{-1}$, capable of holding at a temperature of, say 7°C, only about 15 g of water vapour per tonne stored. There will be some of this water by condensation on cold parts of the structure and by air leakage from the store; there may also be dilution when it is necessary to introduce outside air, for cooling purposes, but nevertheless the store air can often be maintained with a very low WVPD, of the order of 0.5 mbar. In such a case, recirculation is equivalent to continuous ventilation with air with an inlet WVPD of 0.5 mbar. At the rate of 30 $m^3.t^{-1}.h^{-1}$ this would give an operative WVPD in the stack of about 0.9 mbar and an evaporative loss of perhaps 0.15% $week^{-1}$ (Harris, 1992).

Weight loss variations, sprouting problems or disease problems can often be traced to an improperly designed or unbalanced airflow system. Airflow recommendations vary by geographical region due to differences experienced during the harvest season. When installing the fan, a velocity shelf must be used and the fan mounted horizontally with the airflow moving along the shelf about 3 to 4 m before moving into the air plenum.

Some potato storage systems may utilize one or two other airflow components:

i) Over-pile circulation. It is often used when there is no ceiling in the storage, or when the roof insulation is inadequate to prevent condensation. Fans are mounted above the pile to force air movement over the potatoes. Use one or more fans, each supplying an airflow of 0.3 $m^3\ min^{-1}\ m^{-2}$ of pile surface area.

ii) Powered exhaust fans: These are used in situations where the bin is not scaled sufficiently to hold the above pile pressure required to force open the exhaust louver. In these situations, use an exhaust fan that is sized to 25-30% of ventilation capacity must be used. The exhaust fan should operate only when fresh air is required.

Neale and Messer (1976) studied the resistance of root and bulb vegetables to airflow. The pressure required to ventilate small stacks of potatoes, red beet, onions and carrots increases by velocity (0.04 and 0.3 m/s) to the power of 1.8. The pressure drop in a stack of potatoes has been described as:

$$P = k\ v^{1.8} \qquad (6)$$

Where:

P = pressure drop in mm W.G.,
v = the velocity of the air in m/s and
k = constant.

3.7 Air Tightness: It is important not to let air of a different temperature or relative humidity into the store or this nullifies the effect of the insulation. Therefore care must be taken to ensure that all cracks are sealed and that door is a good fit and never left open when it is not necessary. A separate personnel door should be fitted in the commercial large-scale storehouse so that the main doors do not have to be opened when the potato is inspected.

3.8 Choice of Colour: A white surface will absorb 50 per cent of the radiation incident on it whereas a grey surface will absorb 85 per cent of the same radiation.

3.9 Shading: Diffused sunlight has less radiation and so any way that the building or part of it can be shaded will cut down the solar heat gain.

3.10 Thickness: The rate at which the solar radiation transmitted depends not only on the insulation value of the walls and roof but also the thickness, and there may be time lag between the peak incident radiation and the maximum effect on the building. Therefore this ‘flywheel’ effect means that although the maximum radiation on a roof occurs at midday the effect may not be felt in the building until late afternoon.

3.11 Orientation: The best way to place a potato store is east- west with the long dimensions facing north- south. This is so that the rising and setting sun are shining against the shorter walls.

4. HEAT BALANCE IN A POTATO STORE (COOLING LOAD)

Before one goes into the design aspect of various components of the refrigeration system, it is imperative to know the cooling load of the confined space for which refrigeration system is needed.

The temperature at which the potatoes are placed in the store is usually higher than the required storage temperature. So the potatoes first have to be cooled to that temperature and then maintained at that temperature for the entire storage period. More heat than is being produced in the store has to be evacuated during the cooling period. Once the storage temperature is reached, heat evacuation must be equal to the heat production in the store if the required storage temperature is to be maintained. The refrigeration load for potato store is made up of six basic components (Bishop et al, 1980; Rastovski, 1987; ASHRAE, 1998; Prasad1999 and Arora 2000) as follows:

i) Sensible heat gain through walls, floor, and roof.
ii) Heat removed to cool from the initial temperature to some lower temperature (Heat content of the potatoes).
iii) Respiration of potatoes.
iv) Heat produced by fans.
v) Heat supplied by air renewal.
vi) Heat produced by equipment-related load.

5. POTATO STORAGE MANAGEMENT

It is important to remember that any management guideline is the result of an experience and typically assumes the storage of good quality potatoes in a normal year. A well-designed building, proper insulation and adequate refrigeration machinery of a cold storage cannot necessarily ensure good storage business results. It equally needs vigilant management, careful operation and maintenance of the plant as well. The cooperative societies putting up cold storages should select persons with requisite qualifications and experience to work as managers of their cold storages.

Management of stored potatoes can be divided into several stages as following (Brook et al., 1995).

iv) Equalization and drying phase- The time immediately after placing the potatoes in storage to allow the pile to achieve temperature equilibrium. In some wet years, tuber surface moisture may need to be dried. The ventilation fan should run continuously during the equalization phase, while the average potato pile temperature is allowed to settle within 2 degrees of the average pulp temperature upon entry into storage.
v) Wound healing phase- Lignification, suberization, and handling that occurred prior to storage. Successful curing of potatoes can be achieved by subjecting potatoes at 8-20°C and at 85% RH for 7 to 17 days. Care should be taken to avoid the condensation of water on the tubers during curing. The storage temperature during the curing period must not be allowed

to exceed 22°C, to prevent additional respiration losses and development of any fungus or bacterial diseases (Booth, 1974; Alam and Devnani, 1979; Kishore, 1979; Sparenberg, 1979; Meijers, 1981; and Sukumaran and Verma, 1993).

vi) Preconditioning phase- Preconditioning is used to eliminate pools of reducing sugars in potatoes. The storage environment is maintained similar to the wound healing phase, with the bulb temperature actively controlled at wound healing temperature.

vii) Cooling phase- The main ventilation fan should run continuously during the cooling phase of storage to help maintain a uniform pile temperature. Air blown through the potato should be no more than 1.6 °C cooler than the potatoes. Time periods when cooling air is available often exist only in the night, when manual control is difficult, so a control system capable of introducing fresh air into the storage as available is desirable.

viii) Holding phase- The goal of ventilation (recirculation and fresh air) is to maintain a uniform pile temperature within one degree from top to bottom of the pile.

ix) Reconditioning phase- The reconditioning phase is the practice of warming the potatoes from the holding temperature to obtain acceptable process colour if necessary, and to reduce the handling damage that might occur during unloading.

6. CONCLUSION

Following recommendations may be followed for better management of potato storage.

- Improvements to storage system layout should be achieved by considering the various aspects of marketing strategies and the existing facilities.
- The ideal atmosphere for optimum storage conditions should be maintained for the different cultivars (of potatoes) grown in different soils.
- Data acquisition and control systems should be devised and installed for improvement in management and maintenance of produce and integrated with the handling system.
- Irradiation technique that can significantly improve the storage life of commodities should be adopted.
- To avoid quick loading and overloading of storage chambers, it is best to keep tubers in pre-cooling chambers for one or two weeks before they are transferred to cold storage chambers. As different potato varieties are stored in the same chamber under identical storage conditions, this results in heavy storage losses. Therefore, need for identifying the suitable storage conditions, taking the variety into consideration, is of great and immediate importance.

7. REFERENCES

Alam, A. and R.S. Devnani. 1979. Equipment for production, handling and storage of potato. In Kishore, H.: Post harvest technology and utilization of potato. *Proceeding of International Symposium, The International Potato Center, Region VI, New Delhi and Central Potato Research Institute, Simla.*

Anonymous 1985. Zero energy cool chamber. Research bulletin No. 43, IARI. New Delhi.

Arora, C.P. 2000. *Refrigeration and air conditioning.* 2nd Edition. Tata McGraw-Hill publishing company limited, NewDelhi.

ASAE. 1994. ASAE Standards, 41st Edition. ASAE, St. Joseph, MI.

ASHRAE. 1998. *ASHRAE Handbook, Refrigeration*. American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. SI Edition.

Bishop C. F. H., BA (Oxon), W. F. Maunder, NDA NDAgrE, MRAC MIAgrE. 1980. *Potato mechanisation and storage*. Farming Press LTD.

Booth, R.H. 1974. Post-harvest deterioration of tropical root crops: losses and their control. Trop. Sci., **16**(1): 49-63.

Brook, R.C. R.J. Fick, and T.D. Forbush. 1995. Potato Storage design and management. Proceedings of the Symposium: Dynamics of the stored potato, a management approach. American Potato J., 72(8): 463-480.

Burton, W.G., van Es, A. and K.J. Hartmans. 1992. The physics and physiology of storage. *In*: *Harris, P.M. (eds) The potato crop*: The scientific bases for improvement. Chapman & Hall, London.

Central Potato Research Institute. 1999. Indian potato varieties for processing. Technical Bulletin No. **50**.

Chouksy, R.G. 1985. Design of passive ventilated and evaporatively cooled storage structures for potato and other semi perishables. In*: Proc. Silver jubilee convention of ISAE held at Bhopal*. pp 45-51.

Dahiya, P.S., S. Khatana, S.G. Ilangantileke. 1997. *Producer storage practices for potatoes in the Malwa region, Madhya Pradesh, India*. Social Science Department working paper No. 1997-10. Int. Potato Center (CIP), Lima, Peru.

Dash, S.K., 1999. Studies on evaporative cooled storage structures for horticultural produce. PhD thesis. Agril. Engineering, I.A.R.I., New Delhi 110012.181p.

Floriculture Today. 1998. Vol. **2**(12): pp-12.

Geddes, A.M.W. and G. Monninkhof. 1984. Report on a Tour of Egypt to Study Potato Production and Marketing. International Potato Center. Lima.

Giri, N. and K. Bovne. 1978. Solar ammonia-water absorption system for cold storage application. Sum: Mankinds future source of energy. Proceeding of the International Solar Energy Society Congress. New Delhi, India p: 1983.

Gupta, M. and P. Gandhidason. 1979. Open cycle 3 ton solar air conditioner: Concept design and cycle analysis. *Proceeding of National Solar Energy Convection, Bombay* p:1991.

Habibunnisa, E.A., E. Aror and P. Narasimham. 1988. Extension of storage life of the fungicidal waxol dip treated apples and orange under evaporarive cooling storage conditions. *J. Food Sci. Technol*., **25**(2): 75-77.

Harbenburg, R.E., A.E. Watada and C.Y Wang.. 1986. *The commercial storage of fruits, vegetables and florist and nursery stocks*. U.S. Department of Agriculture: 66-68.

Harris, P.M. 1992. *The potato crop*: *The scientific basis for improvement*. Chapman & Hall, London.

Heinze, K. 1973. *Refrigerated warehouse in high rack construction-comparison of cost of insulation and exploitation with those of single storeyed cold storages*. Progress in Refrigeration Science and technology, **III**: 399-408.

Khader,V. 1999. *Textbook on food storage and preservation*. Kalyani Pub. India.

Kishore, H. 1979. Storage Technology. In: *Post harvest technology and utilization of potato*. Proceeding of International Symposium. The International Potato Center, Region VI, New Delhi and Central Potato Research Institute, Simla.

Maldegem, JP V. 1999. *State of the art techniques for the potato storage*. Abstract, Global Conference on Potato, New Delhi, Dec 6-11.

Mann, H.H. and W.V. Joshi. 1925. Superintendent, Govt. Printing, Poona: 137 pp.

Meijers, C.P. 1981. Wound healing. *In*: *Rastovski, A, Van Es, A. (eds.) Storage of potatoes. Post-harvest behavior, store design, storage practice, handling*. Pudoc. Wageningen.

Mikaelsen, K and L. Roger. 1956. Improved storage ability of potatoes exposed to gamma radiation. Act Agric. Scand., **6**: 145.

Neale, M.A. and H.J.M. Messer. 1976. Resistance of root and bulb vegetables to airflow. J. Agric. Engng Res., **21**: 221-231.

Panalaskas, T. and O. Pellefier. 1960. The effect of storage on ascorbic acid content of gamma radiated potatoes. Food Res., **25**: 33.

Pederson, S. 1956. The effects of ionizing radiations on sprouts prevention and chemical composition of potato. Food Technol., **10**: 532.

Powell, A.E., C.A. Pettibone. and M.R. Torabi. 1980. Pressure exerted on the walls of large bins by stored potatoes. Transaction of the ASAE, **23**(3): 685-687.

Prasad, M. 1999. *Refrigeration and air conditioning*. New Age International (P) Limited, Publishers.

Raghavan, G.S.V. and Y. Gariepy. 1984. Structure and instrumentation aspects of storage systems. Acta Hort., **157**: 5-30.

Rama, M.V, H Krishnamurty and P. Narasimham. 1990. Evaporative cooling storage of potatoes in two model storage structures. J. Food Sci. Technol., **27**(1): 19-21.

Rama, M.V. and P. Narasimham. 1991. Evaporative cooling of potatoes in small naturally ventilated chambers. J. Food Sci. Technol., **28**(3): 145-148.

Rastovski, A. 1987. Storage losses. *In*: Rastovski, A, Van Es, A. (eds.) *Storage of potatoes. Post-harvest behavior, store design, storage practice, handling*. Pudoc. Wageningen.

Roy, S.K. 1984. Post harvest storage of fruits and vegetables in a specially designed built in space. In: *Proc. Intl. Workshop on Energy conservation in buildings*. CBRI, Roorkee, UP, India. pp 190-193.

Roy, K.S. and D.S. Khurdiya. 1982. Keep vegetables fresh in summer. Indian Hort. **27**(1): 5-6.

Roy, S.K. and D.S. Khurdiya. 1986. Studies on evaporatively cooled zero energy input cool chamber for storage of horticultural produce. Ind. Fd. Packer, **40**:26-31.

Schaper, L.A. and Jr. J.F. Herrick. 1968. Lateral pressures on walls of potato storage units. U.S. Department of Agriculture, Agricultural Research Service Report 52-32. , Washinton, D.C.

Sharma, S.K. and R.P. Kachru. 1990. Influence of storage period and storages on keeping qualities of potatoes. *In: Proc. Of the XXVI annual convention of ISAE*. HAU, Hissar 7-9 Feb., pp 84-90.

Sparenberg, H. 1979. Storage of potato. In Kishore, H.: Post harvest technology and utilization of potato. Proceeding of International Symposium, The International Potato Center, Region VI, New Delhi and Central Potato Research Institute, Simla.

Sukumaran, N.P. and S.C. Verma. 1993. Storage and processing. *In*: Chadha, K.L. and Grewal, J.S. *Potato*, Advances in Horticulture, **7**: 701-732.

Tatsumi, Y, K. Chachin and K. Ogata. 1972. Studies on the browning of potato tubers by gamma radiation. II. The relationship between the browning and the changes of O-diphenol ascorbic acid and activites of polyphenol oxidase and peroxidase in irradiated potato tubers. J. Food Sci. Technol., **19**: 508.

Umbarkar, S.P., R.S. Bonde and M.N. Kolase. 1991. Evaporatively cooled structures for orange (Citrus reticulata). Indian J. Agric. Eng., **1**(1): 26-32.

Umbarkar, S.P., P.A. borkar, P.S. Phirke, A.B. Kubde and P.B. Kale. 1998. Evaporatively cooled storage structure. Technical bulletin, No. 35. Dr. PDKV, Akola.

Varns, J.L., L.A. Schaper and D.A. Preston. 1985. Potatoes losses during the first three months of storage for processing. American Potato Journal **62**(2): 91-99.

Willis, R.H.H., T.H. Lee, D. Graham, M.C. Glasson and E.G. Hall. 1981. Postharvest: *An introduction to physiology and handling of fruits and vegetables*. South Wales University Press, Kenington, Australia.