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Design of Cold Storage Structure For Thousand Tonne Potatoes

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Abstract

Refrigeration has been the principal known method of successful storage of fresh fruits and vegetables to retain their freshness and flavour. When fruits and vegetables are harvested, they are cutoff from their source of water and nutrition and soon start to deteriorate. They lose weight, texture, flavor, nutritive value and appeal. Both time and temperature are important factors in post-harvest product deterioration .Cooling the harvested product control the rate of quality loss by slowing the rate of respiration. The warmer the temperature, the faster the deterioration and the shorter the storage life; conversely, the cooler the temperature, the slower the deterioration and the longer the storage life. The more quickly the product is cooled, the longer it will remain marketable.

This paper deals with different aspects of design of cold storage and includes all standard refrigeration principles and heat load factors which are normally considered in a cold storage design. This design is hypothetically intended to serve as a guide for future fabrication and erection.

Keyword: refrigeration, refrigeration principle, heat load, design

1. Introduction

Storage is the art of keeping the quality of agricultural materials and preventing them from deterioration for specific period of time, beyond their normal shelf life. Cold storage Control ripening retards aging, softening, texture and color change, retards moisture loss, wilting, microbial activity, spoilage, sprouting and undesirable growth.

Availability of proper cold storages are important for preserving perishable commodities like milk, meat, eggs, vegetables, fruits, ornamental flowers and other floricultural goods. These cold storages give perishable food items a longer shelf life by preventing them from rotting due to humidity, high temperature and micro-organisms. This results in a decrease in loss due to spoilage.

Potatoes are an important staple food crop and have a wide range of seasonal adaptability. It is a cool season crop and is moderately frost – tolerant. Temperature during the growing season has long been recognized as one of the most important factors influencing yield. Young plants grow best at a temperature of 24°C; later growth is favored at 18°C. Tuber production reaches a maximum at 20°C, decreases with rise in temperature, and at about 30°C tuber production stops entirely. Short days are beneficial for tuber production. Required temperature, relative humidity and storage period for early crop, seed potato and table potato are given in table-1

Table-1 storage conditions of potato

Fresh Potato	**Temperature**	**Storage Period**	**Relative Humidity**
Early Crop	4 – 10°C	0 – 3 months	95%
Seed Potato	3°C	5 – 10 months	90 – 95%
Table Potato	4°C	5 – 10 months	90 – 95%

2. Principles of Refrigeration

The cold storage like every other refrigerating systems of the same magnitude employs the vapour compression method of mechanical refrigeration. Fig.1 presents the T-s diagram of the vapour compression cycle, while the Fig.2 illustrates the processes of the refrigeration employed in the cold room, respectively [2].

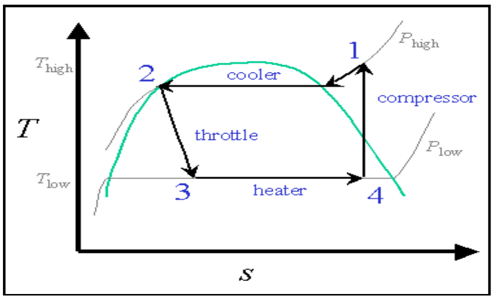

Fig.1. T-s diagram of the vapour compression cycle

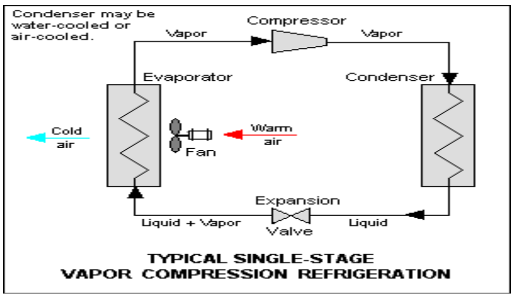

Fig. 2. Processes of the refrigeration

3. Design Procedure

3.1 Heat load factors normally considered in a cold storage design

- Wall, floor and ceiling heat gains from solar radiation due to conduction
- Load due to ingression of air by frequent door openings and during fresh air charge.

- Product load from incoming goods and heat of respiration from stored product
- Heat from workers working in the room
- Cooler fan load, light load, aging of equipment
- Miscellaneous loads, if any

3.2 Heat load calculations

Cold storage for capacity 1000 tons requires room volume approximately 4000 m^3 because nearly 50-60 % of the total volume is utilized for storage purpose. For this purpose one room of size 18m X 15m X 10m (2700 m^3) is considered.

3.2.1** Structural heat gain:** It constitutes the heat transmission into the cold store through wall, ceiling and floor.

(a) Heat transmission through walls: **-** considering walls consisting of 1.5 cm thick plaster, 37 cm thick brick, 1.5 cm thick plaster, 10 cm thick thermocol, and 1.5 cm thick plaster, from outer to inner surfaces respectively.

$$Q = UA\,\Delta t$$

$$U = \frac{1}{\frac{1}{h_{out}} + \frac{x_1}{K_1} + \frac{x_2}{K_2} + \cdots + \frac{x_n}{K_n} + \frac{1}{h_{in}}} \qquad \text{———— Equation (1)}$$

$$U = \frac{1}{\frac{1}{4} + \frac{0.37}{0.25} + \frac{0.15 \times 3}{0.65} + \frac{0.1}{0.028} + \frac{1}{15}} = 0.183\ \text{kcal}/\text{m}^2\ \text{h}\ °\text{C}$$

The storage temperature for potato is kept 5°C and outside temperature is taken 45°C. Heat flow per m^2/hour = U (tout – tin) = 0.183 (45-5) = 7.32 kcal/hour, Wall area = 660 m^2,

Heat flow through walls = 660 X 7.32 = 4831.2 kcal/hour = 1.61 TR

(b) Heat transmission through ceiling: **-** considering ceiling consisting of 3mm thick asbestos sheet and 10 cm thick thermocol. From equation (1)-

$$U = \frac{1}{\frac{1}{4} + \frac{0.1}{0.028} + \frac{0.003}{2.7} + \frac{1}{15}} = 0.25\ \text{kcal}/\text{m}^2\text{hr}°\text{C}$$

Heat flow per m^2/hour = 10 kcal/hr, wall area = 270 m^2, Heat flow through walls = 0.9 TR

(c) Heat transmission through floor: **-** Considering floor consisting of 6cm thick sand, 10cm thick rubble filling, 8cm thick cement concrete, 10 cm thick thermocol and 1 cm thick cement plaster. From equation (1)

$$U = \frac{1}{\frac{1}{4} + \frac{0.06}{0.6} + \frac{0.1}{9.2} + \frac{0.08}{0.7} + \frac{0.1}{0.028} + \frac{0.01}{0.65} + \frac{1}{15}} = 0.25\ \text{kcal}/\text{m}^2\text{h}°\text{C}$$

Heat flow per m^2/hour = 9.6 kcal/hour, Heat flow through walls = 2592 kcal/hour = 0.864 TR *(d) Heat transmission through door*: - Door is made up of M.S. sheet with thermocol insulation are taken. Size of the door is 1.25m X 2.5 m. Average air changes per hour for 2700 m^3storage room due to door opening and infiltration is 0.06.

Heat gain, Q = room volume × air changes per hour × air density × enthalpy change

= 2700 × 0.06 × 0.85 × (40-3) = 5094.9 kcal/hr = 1.7 TR

***3.2.2** Equipment load :-* (From lighting, evaporators etc.) Here it is assumed that 10 KW is required for this purpose so the equipment loads= 10×860/3000 =2.86 TR

***3.2.3** Cooling down to freezing point*: - Here c_p above freezing point for potato is taken 0.82. Two months are taken for harvesting and during this period 1000 Tonne potatoes are to be stored, hence daily loading rate will be 20 Tons / day. It is assumed that potato is cooled for 24 hours

$$\text{Initial cooling} = \frac{20 \times 1000 \times 0.82(45-5)}{24 \times 3000} = 9.11\text{TR}$$

***3.2.4** Heat evolved in storage:* - The heat evolved in storage of potatoes at 5°C = 450 kcal/ton/day.

$$\text{Heat evolved} = \frac{1000 \times 450}{24 \times 3000} = 6.25\text{TR}$$

***3.2.5** Heat of respiration:* - Assuming respiration rate 10 KW/ ton (taking average value).

Heat of respiration= 1000×10×860/3000=2.86TR

***3.2.6** Human occupancy:* - Assuming number of occupants working in cold storage be 3 and working for 10 hours in a day. The amount of heat dissipated by them is 430 kcal/hour (each). Hence heat load due to human occupancy is given by-

$$= \frac{3 \times 430 \times 10}{24} = 537.5\ \text{kcal/hr} = 0.1719\text{TR}$$

Hence, Total TR =5.074 + 2.86 + 9.11 + 6.25 + 2.86 + 0.1719 = 26.3259 TR.
Assuming 10-15 % more of calculated TR to be the heat load.
Therefore, Total TR = 30 TR.

4. Design of Component Of Cold Storage

For ammonia used as refrigerant

4.1 Ideal vapour compression cycle

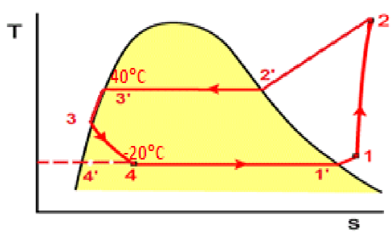

Figure 3. *Actual Temperature- entropy*

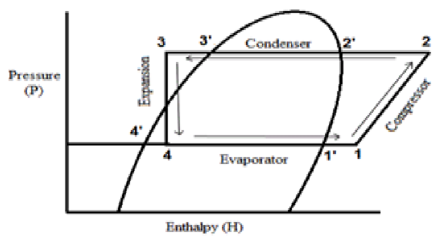

Figure 4. *Actual Pressure – enthalpy diagram*

The following values and parameters specified below were selected from the psychrometric chart of the refrigerant, ammonia for the operating pressure range of 1.902 bars to 15.54 bars

Table-2 Saturated properties of ammonia

Temperature (°C)	Pressure (bar)	Specific Volume (m^3/kg)	Specific Enthalpy		Specific Entropy	
			saturated liquid (kcal/kg)	saturated vapor (kcal/kg)	saturated liquid (kcal/kg K)	saturated vapor (kcal/kg K)
-20	1.902	0.5093	21.38	338.09	0.0876	1.338
40	15.54	0.0833	88.54	350.78	0.3238	1.1611

S_4'= 0.0876 Kcal/kg K, S_1'= 1.338 Kcal/kg K, S_3'=0.3238 Kcal/kg K, S_2'=1.1611 Kcal/kg K
h_2' = 350.78 kcal/kg, h_3'= 88.54 kcal/kg, h_1'= 338.09 kcal/kg, h_4'= 21.38 kcal/kg
Refrigerant is superheated by 5°C; therefore temperature T_1 will be -15°C (or 258 K). Since entropy at point 2 will be same as entropy at point 1, therefore equating both the equations-

$$S_2 = S_2' + Cp \ln(T_2/T_2') \qquad \text{Equation (2)}$$
$$S_1 = S_1' + Cp \ln(T_1/T_1') \qquad \text{Equation (3)}$$

Cp for ammonia = 0.66 Kcal/Kg K
Equation (2) = Equation (3)
S_2 = 1.1611 + 0.66 ln(T_2/313), S_1 = 1.338 + 0.66 ln(258/253)
Temperature of refrigerant leaving the compressor, T_2= 420 K,, ∴ S_2= 1.1611 +0.66 ln(420/313) = 1.4 kcal/kg K

4.2 Calculation of COP

$$\text{COP} = \frac{\text{refrigerating effect}}{\text{work done}} = \frac{h_1 - h_4}{h_2 - h_1}$$

$h_3 = h_3' - Cp\ (T_3' - T_3)$ = 88.54 – 0.66 (313-310) = 86.56 kcal/kg = h_4

$h_1 = h_1' + Cp\ (T_1 - T_1')$ = 338.09 + 0.66 (258-253) = 341.39 Kcal/kg

$h_2 = h_2' + Cp\ (T_2 - T_2')$ = 350.78 + 0.66 (420 – 313) = 421.4 Kcal/kg

$$\text{COP}_{\text{actual}} = \frac{h_1 - h_4}{h_2 - h_1} = \frac{341.39 - 86.56}{421.4 - 341.39} = 3.2$$

$$\text{Horse power required} = \frac{\text{capacity in TR} \times 3000}{\text{COP} \times 630}$$

Taking 20% more of the calculated HP = 50 + 0.2 X 50 = 60 HP**.** 6 set of compressors 10 HP each should be used, including one standby.

$$\text{Refrigerating effect} = (h_1 - h_4) = (341.39 - 86.56) = 254.84\ \text{kcal/kg}$$

$$\text{Mass flow rate(MFR)} = \frac{\text{TR} \times 50}{\text{refrigerating effect}} = \frac{30 \times 50}{254.84}$$

4.3 Design of compressor

Specific volume of ammonia at point 1 or while entering the compressor = 0.5093 m^3/kg (from table)

∴ Volume flow rate of refrigerant = MFR X specific volume = 400 X 0.5093 = 203.72 m^3/hr

Assuming volumetric efficiency to be 80%,

$$\text{Actual displacement} = \frac{\text{theoretical displacement}}{\text{volumetric efficiency}} = \frac{203.72}{0.8} = 254.65 m^3/hr$$

This volume is to be divided into 6 sets of compressor each having 2 cylinders and running at a speed of 450 rpm.

$$\text{For one set displacement will be} = \frac{254.65}{6} = 42.44 m^3/hr$$

$$\text{Displacement} = \text{number of cylinder} \times \pi d^2 \times \text{length of stroke} \times \text{RPM of compressor} \times 60$$

$$\text{Assuming, lengthof stroke/dia of stroke} = 1.5$$

$$42.44 = 2 \times \frac{3.14}{4} \times d^2 \times 1.5d \times 450 \times 60$$

Therefore, Diameter of cylinder piston = 0.087 m or 8.7 cm ≅ 10 cm (standard size which can be obtained in market), Stroke Length of piston = 15 cm (since 1.5 D).

4.4 Design of condenser

Condenser design depends on the amount of heat removed by the condenser, thus the following calculation will represent the capacity of condenser:-

Quantity of heat removed (Q_2) = Heat load (Q_1) + work done by compressor in removing Q_1 (W)

= 30 X 3000 + 60 X 630 = 127800 kcal/hr

Assuming that water is entering at temperature 30°C and leaving at 40°C. Thus, for 10°C change of temperature amount of heat gain will be = 1 X 10 (since Cp for water = 1kcal/kg K) = 10 kcal/kg.

Therefore, amount of water required will be = 127800/10 = 12780 Kg/hr.

4.5 Design of throttling device

Throttling device must be capable of expanding 400 kg or 254.65 m^3 of refrigerant per hour and must operate in the pressure range of 1.902 bars to 15.54 bars.

4.6 Design of evaporator

Capacity of evaporator will be equal to the amount of refrigerating effect = 254.84 kcal/kg

In plant 6 set of compressors are used therefore, 6 set of evaporators should also be used i.e. one for each.

4.7 Design of cooling tower

Cooling towers are used to cool down the temperature of water coming out of the condenser, thus cooling tower of height 5m. For cooling, pump will be required for circulating water.

$$\text{Hp of pump} = \rho gQH = \frac{1000 \times 9.81 \times 12780 \times 1000 \times 5}{1000 \times 3600} = 173.95\ \text{W} = 0.234\ \text{Hp}$$

5. Conclusion

A good deal of experience is required to make a correct calculation of a cold store's refrigeration requirement and this should therefore only be done by a qualified person. The above calculation is not complete but it serves two purposes. It allows the reader to make a similar calculation for his own store and thereby obtain an approximate refrigeration requirement. It also helps the reader to appreciate the number of factors that have to be taken into account in calculating the heat load and also gives him some idea of their relative importance.

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