Potatoes moving on a conveyor in a cold storage

Potato Cold Storage Load Calculations per NHB Standard 01:2010

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Introduction

NHB Standard 01:2010 gives a summary of cooling load calculation (on page 40) for

1. 5-A: Loading and temperature pull down to 15°C per chamber.
2. 5-B: During pull down to +3°C at the rate of 0.5°C per day – fully loaded per chamber.
3. 5-C: During holding period at +3°C – fully loaded per chamber.

Pages 38 and 39 of the Standard give the assumptions for a 5000MT potato cold storage and suggest typical chamber layout.

The refrigeration load is maximum during loading and pull down to 15°C for 1000 bags/day of potatoes, each weighing 50 kg, totaling 50 tons/day per chamber (4% of 1250 tons), and the cooling load indicated is 85.32 kW or 24.37 TR per chamber. Detailed calculations arriving at these values are not given in the Standard.

The subsidy format given on page 29 of the Standard demands the load calculation summary during pull down and holding period for each new cold storage planned, and the customer or contractor needs to engage a refrigeration consultant to calculate cooling loads in order to fill up the form.

This article has, therefore, been prepared giving detailed load calculations to make it easy for the contractor or end user to calculate the cooling load himself. This would also help to calculate the refrigeration load for any other commodity with different conditions and parameters like room size, storage capacity and insulation type for positive temperature cold storages.

For presenting the load calculations, the assumptions mentioned on page 38 of the Standard have been considered.

Assumptions

1. Product: Potatoes
2. Location: Uttar Pradesh
3. Outside temperature: +45°C maximum DB, +30°C WB (113°F/86°F)
4. Product loading temperature: 20°C-25°C maximum
5. Weight of each bag: 50 kg (110 lbs)
6. Total storage capacity: 5000 metric ton
7. Each room storage: 1250 ton (1250x3.4 = 4250m^3)
8. Chamber size (each): 21m Lx16m Wx13.7m H (volume = 4603 m^3, floor area = 226 sq m)
9. Loading rate: 4% of total capacity/day = 1250x0.4 = 50 ton or 50000 kg/day
10. Pull down time: 15°C in 24 hrs
11. Compressor running hours: 20 hrs/day during pull down
12. Ventilation requirements: 2 to 6 air changes per day (page 4-2-h)

About the Author

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13. Insulation: PUF (32 kg/m^3 density, K value = 0.023 W/m.^{0}K = 0.16 Btu.in/h.ft^2.^{0}F (ASHRAE Refrigeration Handbook 2014, page 24.1, *Table 1*). (Though the Standard mentions PUF density of 32 kg/cm^2, it is recomended that a minimum of 38 kg/cm^2 be used.)
14. Thickness (walls, roof, floor): 100 mm (NHB Standard 01:2010, page 10)
15. Specific heat of potato above freezing: 3.433 kJ/kg.°K (NHB Standard 01: 2010, page 51)
16. Heat of respiration: 18mW/kg (ASHRAE Refrigeration Handbook 2014, page 19.22) or 18kW/ton (NHB Standard 01:2010, page 51)
17. Loading density: 3.4 m^3/metric ton = 120 cu ft/ton (NHB Standard 01:2010, page 44)
18. Safety factor of 10% has been considered, whereas diversity factor has not been considered

Load Calculations

For positive temperature cold storages, the major heat load contributors are:

- Heat gain through walls, roof and flooring
- Product load comprising of load due to the difference in product loading temperature and storage temperature
- Respiration load, as the product continues to breathe during storage for a considerable period
- Outside air load due to ventilation requirements and infiltration
- Equipment load such as air cooler fan heat gain and forklifts
- Loads contributed by human beings operating inside the room
- Lighting load

We shall now consider each factor for this typical NHB presented data on page 40, and how the values have been arrived at.

Transmission Load through Walls/Roof/Floor per day

Q = U x A X TD

= 0.023/0.1 x 2 x (21x16+2x21x13.7+16x13.7) x (45-15)

= 0.23 x1663.4x30

= 11477.46 W, say **11.5 kW**

Where 'U' is overall heat transfer coefficient in W/m^2.K = K/x,

'K' is thermal conductivity of insulation used in W/m.K and 'x' is insulation thickness in m,

'A' is the external area of each room in m^2 (for the sake of simplicity, no partition wall has been considered and each room is treated as a separate cold room),

'TD' is the temperature difference between ambient condition and cold room temperature in K,

The correct method is to calculate individual wall loads depending on the direction each wall is facing w.r.t. the sun, and separate temperatures for roof and flooring. However, to simplify the calculations, we assume that all the six surfaces are exposed to 'TD'. This would not make much difference to the load calculation, as the insulation has a greater influence compared to other factors.

Product Load

= 4% of 1250 ton x sp.ht. x TD

= 50000 x 3.433 kJ/kg.°K x (25-15)

=1716500 ÷ (24x3600) = 19.87 kW

It is assumed that the product is loaded at 25^{0}C and cooled to 15^{0}C in 24 hours.

Respiration Load

Assuming that the remaining (1250-50 = 1200 ton or 1200000 kg) potatoes are already in store, and refrigeration load on the last day of loading is considered, the respiration load would be:

Respiration load = 1200000x0.018 = 21600W = 21.6 kW

Total product load would be 19.87+21.6 = 41.47 kW, **say 42 kW**

Infiltration Load

Based on 4 air changes/day, outside enthalpy 99.173kJ/kg at 45^{0}C DB and 30^{0}C WB, inside enthalpy 13.62 kJ/kg at 3^{0}C and 90% RH, Δh = 85.553. (These values have been taken from Psychrometric property tables for moist air.)

Amount of ventilation air for 4603 (volume of room, m^3) x 4 air changes ÷ (24x3.6) = 213 litre/second.

And using the standard formula for total heat load as 1.2 x l/s x (Δh),

= 1.2x213x85.53/1000 = 21.86 kW. With 70% recovery, it would be **15.3 kW**

Internal Load due to Fan Motors

Assuming 4 coolers per room, each with 2 fans of 0.75 kW, total motor power is 6 kW. Power contributed to heat load at the rate of 993W per motor = 8x0.933 = 7.94 kW

Lighting Load

At 10 W/sq m during loading = 336 sq ft floor area x10 W/1000 = 3.6 kW

Occupancy Load

Assuming 4 persons working inside the cold room during loading, each person would be contributing 250 W. Total occupancy load = 250 Wx4 = 1 kW

Total Internal Load = 7.94+ 3.6 + 1 = **12.54 kW**

Total Load = Transmission+ product + infiltration + fan motor + lighting + occupancy

= 11.5+42+15.3+12.54 = 81.34 kW x 1.1 safety factor = **89.474 kW** per chamber

Table 1: Refrigeration load summary per chamber, each of 1250 ton storage capacity

S. No.	Description	Refrigeration Load, kW/24 hr as Per NHB Standard 01:2010, pg 40	Calculated as Above
1	Transmission load	12.12	11.5
2	Product load	43.16	42
3	Internal load	5.25	4.6
4	Infiltration and ventilation air load	16.14	15.3
5	Equipment load	8.65	7.94
6	Total load	85.32 (24.37 TR)	81.34x1.1 safety factor = 89.474 kW

Considering the compressor running time of 20 hours, the total capacity required would be 89.474x24/20 = 107.36 kW per room. The Standard is for 5000 tons with 4 rooms. Hence, total plant capacity required during loading is 429.47 kW.

Refrigeration system capacity recommended in NHB Standard 01:2010 at +2^{0}C SST and 38^{0}C SCT is 234.85x2 = 469.7 kW (page 42-6-ii).

Since it is a normal practice in India to hold potatoes for considerable duration in storage, and the holding load mentioned in the Standard (page 41) is 32.93kWx4 = 131.72 kW, I recommend selecting one compressor to meet the holding load and a second compressor to meet the initial loading and pull down load of 297.75 kW (429.47-131.72 = 297.75) instead of selecting two compressors of equal capacity. Running one base compressor at full load and the second with variable capacity depending on the load, with capacity control arrangement of either cylinder unloading or VFD, would give better power savings compared to two compressors of equal capacity.

Conclusion

Depending upon individual requirements, the assumptions to carry out heat load calculations would change, but the methodology and formulae would remain the same. The user would now be confident to carry out heat load calculations. It is, however, recommended that the person using the above formulas is reasonably competent and familiar with the basics of refrigeration.

The temptation to present calculations in a ready to use excel format has been purposely avoided as it is my experience that the use of software is dangerous unless one knows the methodology of calculating with formulae. Once this is mastered, in order to reduce the calculation time one may use software or an excel spreadsheet. Not knowing the basics and using ready to use tools can lead to serious errors, which the user would remain ignorant of till a problem occurs.

Post-Harvest Ripening of Banana and Other Fruits

continued from page 14

Table 1: Fruit pulp temperature (°C)

	Days in the ripening room								
Ripening Schedule	**First**	**Second**	**Third**	**Fourth**	**Fifth**	**Sixth**	**Seventh**	**Eighth**	**Ninth**
4 days	18 ethylene	18	16.5	15.5	Store at 14.5				
5 days	16.5 ethylene	16.5	16.5	16.5	16.5	Store at 14.5			
6 days	16.5 ethylene	16.5	15.5	15.5	15.5	14.5	Store at 14.5		
7 days	15.5 ethylene	15.5	15.5	15.5	15.5	14.5	14.5	Store at 14.5	
8 days	14.5 ethylene	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5

determined visually or with a pair of calipers. Individual fingers should be between light three-quarter and full three-quarter size. Over-sized fruit ripens rapidly and should be handled with great care because the peel can easily split during handling, while under-sized fruit will not ripen normally.

After determining the maturity, pallets are placed in the ripening room and the air circulation system turned on. The fruit is heated or cooled to the desired ripening temperature (14˚C-18˚C; do not exceed 20˚C pulp temperature during the ripening cycle). Temperature controls the rate of ripening and high temperatures will result in 'green' ripening, i.e. softening of the pulp without de-greening of the peel. As soon as the pulp has reached the set temperature, ethylene is introduced into the ripening room with an ethylene generator or bottled ethylene to maintain the levels at 100 ppm for a duration of 24 hours. After ethylene treatment, the room should be vented to get rid of excess ethylene and CO_2. Thereafter, the rooms should be vented at least twice per day for 20 minutes or continuously with exhaust fans to keep the CO_2 levels below 1%. CO_2 levels above 1% will inhibit the ripening process.

The fruit should be kept at the required temperature until it has reached the desired stage of ripeness (firmness). Pulp temperatures must be recorded throughout the room on a daily basis and the relative humidity should be kept at 90-95% throughout the ripening cycle. Once the fruit has reached the desired ripeness, it should be cooled down to 14˚C to slow down ripening, and placed in a cold store at 14˚C. Ripened fruit are less prone to chilling injury than unripe fruit. Further ripening after storage can be controlled by time and temperature. The higher the pulp temperature, the shorter is the time required to reach eat ripeness. The pulp temperature should never be allowed to rise above 20˚C during ripening. Please see *Table 1*.

Uneven Ripening

Uneven ripening in a box, pallet or load is a common problem encountered in fruit that is ripened after harvesting. The most common causes of uneven ripening are improper ripening techniques, insufficient ethylene levels, incorrect exposure time, incorrect ripening temperature, RH below 90%, temperatures above 21˚C during ripening, improper air circulation, excessive holding periods before the start of the ripening cycle, variable fruit age, variable fruit maturity, wide variations in pulp temperature upon arrival at the ripening room, exposure to temperatures below 12˚C prior to ripening and exposure to extreme high temperatures prior to ripening (heat damage).

Conclusion

Fruit ripening chambers are proliferating throughout the country as the fruit handler community has realized the importance of deploying a scientific method for ripening in a cold room, exercising control over temperature, RH and gas levels of ethylene, CO_2 and oxygen. A revolution has taken place in this sector during last the five years, as ripening chambers have reached even the smallest villages and farms. Refrigeration engineers play an important role in setting up these facilities.

This sector has a vast potential for rural employment generation. National Horticulture Board (NHB) offers handsome incentives for setting up ripening and cold preservation chambers for all fruits and vegetables and other agricultural produce.