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DEPARTMENT OF FOOD TECHNOLOGY

COURSE CODE & NAME: 19FTT301 & Refrigeration & Cold Chain Management

III YEAR / V SEMESTER

UNIT : IV LOW TEMPERATURE STORAGE SYSTEMS

TOPIC 4 : Calculation of refrigeration load in cold store

Introduction

1. It is necessary to select the capacity of refrigeration plant for the cold storage to maintain required storage temperature in the cold storage.
2. Under capacity plant, may load to higher temperature of cold storage than required while over capacity may lead to higher initial cost of the refrigeration system.
3. The capacity of the refrigeration plant should be such that it can take care of all the heat load of the cold storage.
4. It is also necessary to reduce cold storage load in order to reduce the energy cost for the operation of refrigeration plant.

The various factors contributing the total load of the cold storage are discussed below

Wall Gain Load

Air Change Load

Product Load

Miscellaneous Load

Total heat load

Wall Gain Load

- The heat flow rate by conduction through the walls ceiling & floor of the cold storage from outside to inside is called wall gain load.
- The value of U depends on the materials used in construction and insulation used in the construction of wall as well as on the thickness of these materials. If either U or 12â'†T'> are different for different walls, then it is necessary to calculate Q_w of each wall/ceiling/floor separately taking corresponding values of U and 12â'†T'>.

The overall heat transfer co-efficient is given by

Where, h_o = Convection heat transfer Co-efficient on the outer surface

h_i = Convection heat transfer Co-efficient on the inner surface

x_1, x_2…..= thickness of different layers of wall including insulation

k_1, k_2,….= conductivities of different layers of wall including insulation

Air Change Load

This is the amount of heat carried by the air when cold storage door is opened and part of cold air is replaced by outside warmer air. The air change load depends on the number of air changes occurring in the cold storage, enthalpy of outside air and inside air. The measurement of amount of air changed due to door opening is difficult and hence air change factor is used to estimate the amount of air changed.

Air change load, $Q_a = m (h_o - h_i)$

Where, m= mass of air entering, kg d. a. /h

h_o = Enthalpy of outside air, kJ/kg dry air

h_i = Enthalpy of inside air, kJ/kg dry air

Mass of air can be estimated by multiplying volume of cold storage with air change factor. The volume of the air is converted into amount of dry air in the volume taking specific volume of the outside air.

Product Load

It is necessary to cool the product from initial temperature to the storage temperature. The amount of heat to be removed from the product to lower the temperature of the product from initial temperature to storage temperature is called product load. It is also necessary to estimate the heat load for cooling of the packaging material along with the product as specific heat of product and material is different. For example, plastic crates are to be cooled from room temperature to the storage temperature.

Product load, $Q_p = m_p \times C_1 \times (t_1 - t_2)$

Where m_p = Mass flow rate of the product in the cold storage, kg/h

C_1 = Specific heat of the product kJ/kg K

T_1 = Initial temperature of the cold storage

T_2 = Final storage temperature of the product.

Similarly, heat load of packaging materials transferred in the cold store along with the product is estimated as above taking the mass of packaging material, its specific heat and temperature difference. This load is added in the actual product load.

For frozen foods

$Q_p = m_p \text{ x } C_1 (t_1 + t_f) + m_p h_{fg} + m_p \text{ x } C_2 (t_f - t_2)$

Where t_f = Freezing temperature

h_{fg} = Latent heat of freezing

Heat produced due to respiration of the fruits and vegetables are required to be considered for such types of cold storages.

$Q_r = m_p$ (kg/h) x Respirate rate (kJ/kg)

Miscellaneous Load

The miscellaneous load consists of primarily of heat given off by light and electric motors present in the cold storage.

Cooling load for electric appliances in terms of kJ is given by

Q_c = kW × 3600 kJ/h

Heat Load from occupants is calculated based on the data available for heat loss from human body.

It is necessary to refer standard data if heat loss from human body under different temperature conditions. For example, a person at rest at 20 ^{o}C, total heat loss from the body is about 400 kJ/h (Q_l= 160 kJ/h and Qs = 240 kJ/h)

Air changes per hour for cold storage due to infiltration & door openings

Volume of Cold Storage, m^2	Air Changes/h (Air Change Factor)
10	1.23
20	1.95
30	0.65
40	0.57
50	0.50
60	0.45
70	0.42
80	0.37
100	0.35
150	0.27
200	0.23
250	0.21
500	0.14
1000	0.10

Total heat load

$$Q_t = Q_w + Qa + Q_p + Q_m$$

It is common practice to add 10-15% of total load as safety factor. After adding safety factor, the cooling load is multiplied by 24 hours and divided by the desired operating time in hours to find capacity of the plant required for the cold storage.

What is a cold room?

- A cold room is used to store perishable goods such as meat and vegetables to slow down their deterioration and preserve them as fresh as possible for as long as possible.

- Heat accelerates their deterioration so the products are cooled down by removing the heat.

- To remove the heat we use a refrigeration system as this allows accurate and automatic control of the temperature to preserve the goods for as long as possible.

Cold Room Heat Sources

Transmission load

Typically 5-15% is through transmission loads. This is the thermal energy transferred through the roof, walls and floor into the cold room. Heat always flows from hot to cold and the interior of the cold room is obviously a lot colder than its surroundings, so heat is always trying to enter the space because of that difference in temperature. If the cold store is exposed to direct sunlight then the heat transfer will be higher so an additional correction will need to be applied to allow for this.

Product Load

Then we have Product loads which account for typically 55-75% of the cooling load. This accounts for the heat that is introduced into the cold room when new products enter. Its also the energy required to cool, freeze and further cool after freezing. If you’re just cooling the products then you only need to consider the sensible heat load. If you’re freezing the product then you need to account for the latent heat also as a phase change occurs.

Internal load

The next thing to consider is the internal loads which account for around 10-20%. This is the heat given off by people working in the cold room, the lighting and equipment such as fork lifts trucks etc. So for this you'll need to consider what equipment will be used by the staff members in order to move the products in and out of the store, how much heat will they and the equipment give off and the daily duration.

Equipment Load

Then we need to consider the refrigeration equipment in the room which will account for around 1-10% of the total cooling load. For this we want to know the rating of the fan motors and estimate how long they will run for each day, then we want to also account for any heat transferred into the space from defrosting the evaporator.

Infiltration heat load

The last thing we need to consider is infiltration which again adds 1-10% to the cooling load. This occurs when the door opens so there is a transfer of heat into the space through the air. The other consideration is ventilation. Fruit and vegetables give off carbon dioxide so some stores will require a ventilation fan, this air needs to be cooled down so you must account for this if it's used.

The latent heat load per kg of dry air infiltered into the room = $H_a - H_c$

The sensible heat load per kg of dry air infilterated into the room = $H_c - H_b$

Based on the total heat load the tonnes of refrigeration can be calculated by:

1 tonne of refrigeration = 3000 k cal/hr

= 3489 watt

Problem : Eight tonnes of apple having specific heat of 0.80 k cal/Kg-°C is to be cooled from 25 to 14°C in 24 hours. The heat of respiration per 24 hour is 745 k cal/t. Three men will work for 4 hours and lighting load is estimated to be 100 watt. Air infilteration load is assumed as 980 k cal in 24 hours.

The cold storage measures 6 × 6 × 3 m on the inside and is constructed of bricks laid in cement mortar. Wall thickness is 40 cm and there is 10 cm thick cork insulation on the inside of the four walls. The cement plaster is 1 cm thick. The heat transfer coefficient for the ceiling is 20% more than that for the walls. The outside temperature is 30°C and the inside is maintained at 5°C. Calculate the plant capacity needed in tonnes of refrigeration.

Thermal conductivity of brick = 0.45 k cal/hr/m-°C

Thermal conducivity of cork = 0.025 k cal/hr/m-°C

Thermal conductivity of cement plaster = 0.25 k cal/hr/m-°C

Heat of respiration for men = 170 k cal/hr

There is no heat transfer through the floor

Solution :

(i) Heat load for cooling the apples

$= 8000 \times 0.8\ (25 - 14) = 70400$ k cal/24 hr

(ii) Heat of respiration from apples

$= 745 \times 8 = 5960$ k cal/24 hr

(iii) Heat load due to air infilteration

= 980 k cal/24 hr

(iv) Heat load due to lights

$= \frac{100 \times 24 \times 3.6}{4.1868} = 2060$ k cal/24 hr.

(v) Heat load because of workers

$= 3 \times 170 \times 4 = 2040$ k cal/24 hr.

(vi) Heat load due to conduction of 4 walls

$Q = U A \Delta T$

The overall heat transfer coefficient, U, can be calculated by the following equation

$$\frac{1}{U} = \frac{1}{U_B} + \frac{1}{U_P} + \frac{1}{U_C}$$

where U_B, U_P and U_C and heat transfer coefficients for brick, plaster and cork respectively. In general—

$U = \frac{K}{...} = \frac{\text{thermal conductivity}}{\text{thickness of layer}}$

∴ Heat transfer through walls $= 0.203 \times 72 \times (30 - 5) \times 24$

$= 8769.3$ k cal/24 hr

(vii) Heat transfer through ceiling

$Q = U A \Delta T$

$= 0.203 \times 1.2 \times 6 \times 6 \times (30 - 5) \times 24$

$= 5261.76$ k cal/24 hr.

∴ Total heat load $= 70400 + 5960 + 980 + 2060 + 2040 + 8769.3 + 5261.76$

$= 95471.06$ k cal/24 hr.

Since 1 t of refrigeration = 3000 k cal/hr

Hence, plant capacity $= \frac{95471.06}{3000 \times 24}$

$= 1.326$ tonnes

Problem : 110 kg of lean poultry is first cooled from 20 to 4° C, thereafter it is further cooled and frozen to −20°C. Specific heat of poultry is 3.21 kJ/kg°C and below freezing point is 1.71 kJ/kg°C. Freezing point of poultry is −2.8°C and the latent heat of fusion is 246.8 kJ/kg. Calculate the total heat load.

Solution : The heat loads are:-

(i) To cool from 20 to 4°C

$= 110 \times 3.21\ (20 - 4) = 5649.6$ kJ

(ii) To cool from 4°C to freezing point in freezer

$= 110 \times 3.21\ [4 - (-2.8)] = 2401.08$ kJ

(iii) For freezing the poultry

$= 110 \times 246.8 = 27148$ kJ

(iv) To cool from freezing point to storage temperature

$= 110 \times 1.71\ [(-2.8) - (-20)] = 3235.32$ kJ

∴ Total heat load $= 5649.6 + 2401.08 + 27148 + 3235.32$

$= 38434$ kJ

Problem : Find the refrigeration load expressed in tons of refrigeration which is caused by heat loss from the four side walls of a small cold room 2.4 m × 3.0m × 2.4m. The walls are made of 20 cm brick, 20 cm cork board and 1.25 cm cement. Inside wall temperature is −30 °C and outside wall temperature is 21 °C. Add a suitable safety factor for losses through joints etc. Respective thermal conductivities of brick, cork and cement plaster are 0.6 W/m °C, 0.04 W/m °C and 0.8 W/m °C. ... (ARS 1991)

Solution :

Heat load due to conduction of walls

$Q = U A \Delta T$

The overall heat transfer coefficient, U, can be calculated by the following equation.

$$\frac{1}{U} = \frac{1}{U_B} + \frac{1}{U_C} + \frac{1}{U_P}$$

$$= 0.333 + 5 + 0.0156$$

or,

$$U = 0.187 \ W/m^2-°C$$

$$Q = 0.187[(2 \times 2.4 \times 2.4) + (2 \times 3 \times 2.4)] \times [21-(-30)]$$

$$= 247.2 \ W$$

Taking safety factor as '2' to cover the loss of heat through duct and joints.

$$\text{Total heat load} = 247.2 \times 2$$

$$= 494.4 \ W$$

Since 3489 W = 1 ton of refrigeration

$$\therefore \quad \text{Ton of refrigeration} = \frac{494.4}{3489}$$

$$= 0.14$$

Problem : A cold storage plant is required to store 25 tonnes apples. The following data are given.

Initial temperature of apples = 30°C
Refrigerated storage temperature = 2°C
Specific heat of apple above freezing point = 0.87 k cal/kg°C

If the cooling is achieved within 8 hours, determine the following:

(i) Capacity of the refrigeration plant
(ii) C.O.P. of carnot cycle between the temperature range
(iii) If the actual C.O.P. is 25% of the Carnot C.O.P., find out the horsepower required to run the plant.

Solution :

Heat removed from 1 kg of apples in 8 hours

$= 0.87\,(30-2) = 24.36\ k\,cal/kg$

Heat removed per minute by the plant

$= \frac{24.36 \times 25 \times 1000}{8 \times 60} = 1268.75\ k\,cal$

Capacity of the plant

$= \frac{1268.75}{50} = 25.375\ tons$

$$C.O.P.\text{ of Carnot cycle} = \frac{T_a}{T_b - T_a} = \frac{(273+2)}{(273+30)-(273+2)} = 9.82$$

Actual C.O.P. $= 9.82 \times 0.25 = 2.455$

$\therefore \quad 2.455 = \frac{\text{refrigeration/min}}{\text{work done/min}} = \frac{1268.75}{W}$

or $\quad W = 516.80\ k\,cal/min$

$\therefore$ Horse power required $= \frac{516.80}{10.54} = 49.06\ hp.$

Problem : In a cold storage plant 50 tonnes of pears are to be stored at −1°C. The initial temperature of the pears is 27°C. If the cooling is achieved within 12 hours, determine the following:

(i) Capacity of the plant in tons of refrigeration.
(ii) C.O.P. of Carnot cycle between this temperature range.
(iii) horse power required to run the plant, assume the actual C.O.P. be 30% of the Carnot C.O.P.

The specific heat of pears above and below freezing points are 0.89 and 0.43 k cal/kg°C respectively. Consider the freezing point of pears is 0°C and the latent heat of fusion as 60 k cal/kg.

Solution :

Heat removed from 1 kg of pears in 12 hours

$= 0.89\,[30-(-0)] + 60 + 0.43\,[0-(-1)]$

$= 87.13\ k\,cal$

Heat removed by the plant per minute

$= \frac{87.13 \times 50 \times 1000}{12 \times 60} = 6050.69\ k\,cal$

(a) Capacity of the plant $= \frac{6050.69}{50} = 121.01\ ton$

(b) COP of Carnot cycle $= \frac{T_a}{T_b - T_a} = \frac{272}{300-272} = 9.714$

(c) Actual COP $= 9.714 \times 0.3 = 2.914$

or, $\quad 2.914 = \frac{6050.69}{W}$

$\therefore \quad W = \frac{6059.69}{2.914} = 2076.42\ k\,cal/min.$

$\therefore$ horsepower required $= \frac{2076.42}{10.54} = 197\ hp.$

THANK YOU…