

Heat load calculation

9.5.1.Example - 1

1. 20 kg of water at 25°C is raised to 80 °C Calculate the heat required. Take the specific heat of water = 4.19KJ/kgok

Solution:

Weight of the water $m = 20$ kg

Initial temperature $T_1 = 25^\circ\text{C}$

Final temperature $T_2 = 80^\circ\text{C}$

specific heat of water $c = 4.19\text{KJ/kgok}$

$$Q \text{ or } H = m c \Delta T$$

$$= m c (T_2 - T_1)$$

$$= 20 \times 4.19 \times (80 - 25)$$

$$= 4609 \text{ KJ}$$

2. At a flow rate of $0.2\text{m}^3/\text{sec}$. If the water is cooled from 39°C to 2°C . Calculate the heat energy removed.

Solution:

Mass flow rate of water = $0.2 \times 1000 = 200$ kg/sec.

$$\Delta T = T_2 - T_1 = 2 - 39 = -37^\circ\text{C}$$

$$Q \text{ or } H = m c \Delta T$$

$$= 200 \times 4.19 \times (-37)$$

$$= -31006 \text{ KJ/Sec.}$$

Here T_2 is less than T_1 . The answer obtained is negative indicating the heat is rejected.

3. 10kg of water at 0°C is frozen into ice at 0°C Calculate the heat removed. Take latent heat of fusion of water under atmospheric pressure is 335KJ/kg.

$$QL = m \times hf$$

$$= 10 \times 335$$

$$= 3350 \text{ kj}$$

(Latent heat of fusion of water under atmospheric pressure is 335kj/kg)

4. Calculate the quantity of heat required to melt 12lb of ice at 32°F into water at 32°F . The latent heat of fusion of water under atmospheric pressure is 144 Btu per pound

$$QL = m \times hf$$

$$= 12 \times 144$$

$$= 1728 \text{ Btu}$$

Note: Since 12lb of ice absorb 1728 Btu in melting into water, it follows that 12lb of water at 32°F will reject 1728 Btu in returning to the solid state.

5. A refrigerating machine preserve food at -7°C temperature at the room temperature of 23°C find C.O.P.

$$T_1 = -7 + 273 = 266^\circ\text{K}$$

$$T_2 = 23 + 273 = 296^\circ\text{K}$$

$$T_1$$

$$\begin{aligned}
 (\text{C.O.P.})_R &= \frac{266}{T_2 - T_1} \\
 &= \frac{266}{296 - 266} = 8.86
 \end{aligned}$$

6. A machine working on a Carnot cycle operates between 305K and 260K. Determine C.O.P. when it is operated as

1. a refrigerating machine
2. Heat pump
3. heat engine

$$T_1 = 260^\circ\text{K}$$

$$T_2 = 305^\circ\text{K}$$

1. C.O.P. of a refrigerating machine

$$\begin{aligned}
 (\text{C.O.P.})_R &= \frac{T_1}{T_2 - T_1} = 5.78
 \end{aligned}$$

2. C.O.P. of a heat pump

$$\begin{aligned}
 (\text{C.O.P.})_P &= \frac{T_2}{T_2 - T_1} = 6.78
 \end{aligned}$$

3. C.O.P. of a heat engine

$$\begin{aligned}
 (\text{C.O.P.})_E &= \frac{T_2 - T_1}{T_2} = 0.147
 \end{aligned}$$

9.5.2.Example - 2

A Carnot refrigeration cycle absorbs heat at 270K and rejects it at 300 K.

Calculate the coefficient of performance of this refrigeration cycle

If the cycle is absorbing 1130 KJ/min at 270K how many KJ of work is required per second.

If the Carnot heat pump operates between the same temperature on the above refrigeration cycle, what is the coefficient of pump.

How many KJ/min will the heat pump deliver at 300 K if it absorbs 1130 KJ/min at 270 K.

$$T_1 = 270\text{K}$$

$$T_2 = 300\text{K}$$

1. (C.O.P) of camot refrigeration cycle

$$(C.O.P.)_R = \frac{T_1}{T_2 - T_1} = \frac{270}{300 - 270} = 9$$

2. Work required per second

W_R = Work required per second

Heat absorbed at 270K (i.e. T_1) $Q_1 = 1130\text{KJ} = 18.83 \text{ KJ/s}$

$$\text{We know that } (C.O.P.)_R = \frac{Q_1}{W_R}$$

$$W_R = \frac{Q_1}{(C.O.P.)_R}$$
$$W_R = \frac{18.83}{9}$$

Therefore $W_R = 2.1 \text{ KJ/S}$

3. C.O.P. of heat pump

$$(C.O.P.)_P = \frac{T_2}{T_2 - T_1} = 10$$

4. Heat delivered by heat pump at 300 K

Q_2 = Heat delivered by heat pump at 300 K

Heat absorbed at 270 K

$$Q_1 = 1130 \text{ KJ/min.}$$

$$(C.O.P.)_P = \frac{Q_2}{Q_2 - Q_1} \text{ or } 10 = \frac{Q_2}{Q_2 - 1130}$$

$$Q_2 = 1256 \text{ KJ/min}$$

9.5.3.Example – 3

A cold storage is to be maintained at -5°C while the surrounding are at 35°C . The heat leakage from the surrounding into the cold storage is estimated to be 29 KW (2490kcal/hr). The actual C.O.P. of the refrigeration plant is one third of an ideal plant working between the same temperature. Find the power required to drive the plant?

$$\text{Given } T_1 = -5^{\circ}\text{C} = -5 + 273 = 268 \text{ K}$$

$$T_2 = 35^{\circ}\text{C} = 35 + 273 = 308\text{K}$$

$$Q_1 = 29 \text{ KW}$$

$$(\text{C.O.P.})_{\text{actual}} = \frac{1}{3}(\text{C.O.P.})_{\text{ideal}}$$

Let $WR = \text{Work or Power required to drive the plant}$

We know that the coefficient of performance of an ideal refrigeration plant

$$(\text{C.O.P.})_{\text{ideal}} = \frac{T_1}{T_2 - T_1} = \frac{268}{308 - 268} = 6.7$$

Therefore Actual coefficient of performance

$$(\text{C.O.P.})_{\text{actual}} = \frac{1}{3} (\text{C.O.P.})_{\text{ideal}} = \frac{1}{3} \times 6.7 = 2.233$$

$$\text{We know that } (\text{C.O.P.})_{\text{actual}} = \frac{Q_1}{WR}$$

$$WR = \frac{29}{(\text{C.O.P.})_{\text{actual}}} = \frac{29}{2.233} = 12.987\text{KW}$$

9.5.4.Example - 4

8. 1.5 KW per tonne of refrigeration is required to maintain the temperature of -40°C in the refrigerator. If the refrigeration cycle works on camot cycle, determine the following.

1. C.O.P. of the cycle
2. Temperature of the sink
3. Heat rejected to the sink per tonne of refrigeration
4. Heat supplied and E.P.R. If the cycle is used as a heat pump.

Given $W_R = 1.5 \text{ KW}$, $Q_1 = 1 \text{ TR}$
 $T_1 = -40^{\circ}\text{C} = -40 + 273 = 233\text{K}$

1. C.O.P. of the cycle

Since 1.5 KW per tonne of refrigeration is required to maintain the temperature in the refrigerator, therefore amount of work required to be done

$W_R = 1.5\text{KW} = 1.5 \text{ KJ/sec} = 90 \text{ KJ/min}$ and heat extracted from the cold body

$Q_1 = 1 \text{ TR} = 210 \text{ KJ/min}$

We know that $(\text{C.O.P.})_R = \frac{Q_1}{W_R} = \frac{210}{90} = 2.33$

2. Temperature of the sink

$T_2 = \text{Temp. of the sink}$

We know that $(\text{C.O.P.})_R = \frac{T_1}{T_2 - T_1}$ or
$$2.33 = \frac{233}{T_2 - 233}$$
$$T_2 = 333 \text{ K} = 60^{\circ}\text{C}$$

3. Heat rejected to the sink per tonne of refrigerator

We know that heat rejected to the sink

$Q_2 = Q_1 + W_R = 210 + 90 = 300 \text{ KJ/min}$

9.5.5.Example – 5

9. Five hundred kgs of fruits are supplied to a cold storage at 20 °C. The cold storage is maintained at -5 °C and the fruits get cooled to the storage temperature in 10 hours. The latent heat of freezing is 105 KJ/kg and specific heat of fruit is 1.256 KJ/kgk. Find the refrigeration capacity of the plant.

Given: $m = 500 \text{ kg}$ $T_2 = 20 \text{ }^\circ\text{C} = 20 + 273 = 293 \text{ K}$

$T_1 = 5 \text{ }^\circ\text{C} = -5 + 26 = 268 \text{ K}$

$h_{fg} = 105 \text{ KJ/kg}$ ($F = 1.256 \text{ KJ/kgk}$)

We know that heat removed from the fruits in 10 hours

$$\begin{aligned} Q_1 &= mCF (T_2 - T_1) \\ &= 500 \times 1.256 (293 - 268) \\ &= 15700 \text{ KJ} \end{aligned}$$

And total latent heat of freezing

$$Q_2 = m.h_{fg} = 500 \times 105 = 52500 \text{ KJ}$$

Therefore total heat removed in 10 hours

$$\begin{aligned} Q &= Q_1 + Q_2 = 15,700 + 52,500 = 68200 \text{ KJ} \text{ and Total heat removed in one minute} \\ &= \frac{68200}{10 \times 60} = 113.7 \text{ KJ/min} \end{aligned}$$

$$\text{Therefore Refrigeration capacity of the plant} = \frac{113.7}{210} = 0.541 \text{ RT}$$

(Total heat removed i.e. capacity of heat removed in terms of RT)

9.5.6.Example – 6

10. A cold storage plant is required to store 20 tons of fish. The fish is supplied at a temperature of 30 °C. The specific heat of fish above freezing point is 2.93 KJ/kgk. The specific heat of fish below freezing point is 1.26 KJ/kg k. The fish is stored in cold storage which is maintained at -8 °C. The freezing point of fish is -4 °C. The latent heat of fish is 235 KJ/kg. If the plant requires 75KW to drive it find

1. The capacity of the plant (RT).
2. Time taken to achieve cooling. Assume actual C.O.P. of the plant is 0.3 of the carnot C.O.P.

Given $m = 20t = 20,000 \text{ kg}$, $T_2 = 30 \text{ }^\circ\text{C} = 30+273=303 \text{ K}$

$CAF = 2.93\text{KJ/kg k}$, $CBF = 1.26 \text{ KJ/Kg k}$

$T_1 = -8 \text{ }^\circ\text{C} = -8+273=265\text{k}$

$T_3 = -4 \text{ }^\circ\text{C} = -4+273=269\text{k}$

$hfg(\text{fish}) = 235 \text{ KJ/kg}$ $P = 75\text{KW} = 75\text{KJ/s}$

1) Capacity of the plant We know that Carnot C.O.P. = $\frac{T_1}{T_2-T_1} = 6.97$

Therefore C.O.P. = $0.3 \times 6.97 = 2.091$

And heat removed by the plant /minute C.O.P. = $\frac{Q}{W_R}$

= Actual C.O.P. x work required

= $2.091 \times 75 = 156.8\text{KJ/sec} \times 60 = 9408 \text{ KJ/min}$

Heat removed by temp(Q)

Therefore capacity of the plant = $\frac{9408}{210}$
 = 44.8 RT (Therefore IRT = 210 KJ/min)

2) Time taken to achieve cooling We know that heat removed from ;the fish above freezing point

$Q_1 = m \times CAF (T_2-T_3) = 20,000 \times 2.93 (303 - 209)$

= $1.992 \times 10^6 \text{ KJ} = 2.22 \times 10^6 \text{ KJ}$

Similarly Heat removed from the fish below freezing point

$Q_2 = m \times CBF (T_3-T_1)$

= $20,000 \times 1.26 (269-265)$

= $0.101 \times 10^6\text{KJ}$ and total latent heat of fish

$Q_3 = m \times hfg (\text{fish}) = 20,000 \times 235 = 4.7 \times 10^6 \text{ KJ}$

Therefore total heat removed by the plant = $Q_1 + Q_2 + Q_3$

= $1.992 \times 10^6 + 0.101 \times 10^6 + 4.7 \times 10^6$

= $6.793 \times 10^6\text{KJ}$

Total heat removed by the plant

And time taken to achieve cooling = $\frac{\text{Total heat removed by the plant}}{\text{Heat removed by the plant per minute}}$
 = $\frac{6.793 \times 10^6}{9408} = 722\text{min} = 12.03 \text{ hour}$

1) Calculate the heat leakage through a 20cm brick wall having an area of 20 square meter if the inside temperature is 10 °C and outside temperature is 70 °C.

Heat leakage = $\frac{KA (t_1 - t_2)}{T}$

$K = 0.26 \text{ Kcal/hrm } ^\circ\text{C}$

$A = 20 \text{ sq.m.}$

$T = 20 \text{ cm} = 0.2 \text{ meter}$

Heat leakage = $\frac{KA(t_1 - t_2)}{T}$

= $\frac{0.26 \times 20 (60)}{0.2}$

= 1560 kcal/hr