POSTAL Book Package 2023

Mechanical Engineering

Conventional Practice Sets

Refrigeration and Air Conditioning

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1 CHAPTER Introduction and Basic Concepts

Practice Questions : Level-I

Q.1 A reversed Carnot cycle refrigerator maintains a temperature of – 5°C. The ambient air temperature is 35°C. The heat gained by the refrigerator at a continuous rate is 2.5 kJ/s. What is the power required to run the heat pump?

Solution:

Given data: $T_2 = -5°C = (-5 + 273)\text{ K} = 268\text{ K}$; $T_1 = 35°C = (35 + 273)\text{ K} = 308\text{ K}$

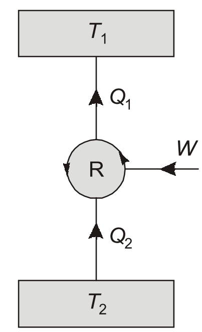
$Q_2 = 2.5\text{ kJ/s} = 2.5\text{ kW} = 2500\text{ W}$

$$(\text{COP})_R = \frac{T_2}{T_1 - T_2} = \frac{268}{308 - 268} = 6.7$$

Also,
$$(\text{COP})_R = \frac{Q_2}{W}$$

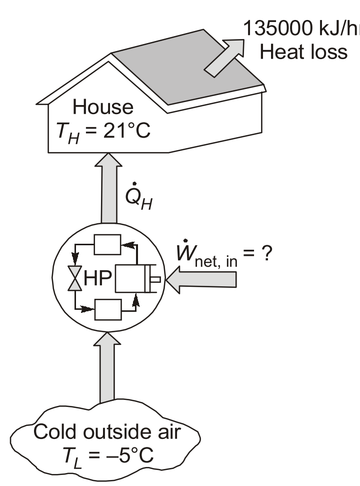
$\therefore$
$$6.7 = \frac{2500}{W}$$

or
$$W = \frac{2500}{6.7} = 373.13\text{ W}$$



Refrigerator

Q.2 A heat pump is to be used to heat a house during the winter as shown in figure. The house is to be maintained at 21°C at all times. The house is estimated to be losing heat at a rate of 135000 kJ/hour when the outside temperature drops to –5°C. Determine the maximum power required to drive this heat pump:



Solution:

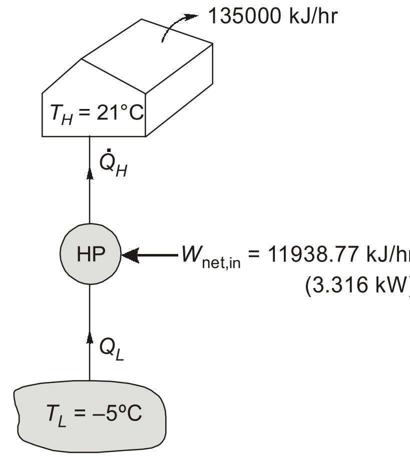
Given data: Temperature at which hour to be maintained, $T_H = 21°C = 294\text{ K}$

Rate of loss of heat from hours, $Q_{H\,loss} = 135000\text{ kJ/hr}$

Outside temperature, $T_L = -5°C = 268\text{ K}$

To maintain the house at 21°C, heat supplied to house Q_H should be equal to rate of heat loss $Q_{H\,\text{loss}}$ from the house.

Hence, $Q_{H\,\text{loss}} = Q_H = 135000$ kJ/hr



$$\text{COP of heat pump} = \frac{T_H}{T_H - T_L} = \frac{Q_H}{W_{\text{net,in}}}$$

$$\text{COP} = \frac{(294)}{(294)-(268)} = \frac{294}{26} = 11.3077$$

$$\text{COP} = 11.3077 = \frac{Q_H}{W_{\text{net,in}}}$$

$$W_{\text{net, in}} = \frac{Q_H}{COP} = \frac{135000}{11.3077}$$

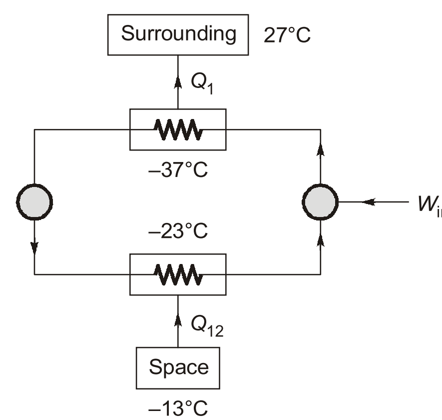
$$= 11938.77 \text{ kJ/m} = \frac{11938.77}{3600} = 3.316 \text{ kW}$$

Minimum power required to drive heat pump, $W_{\text{net, in}} = 3.316$ kW

Q.3 A refrigerator has working temperatures in the evaporator and condenser as –23°C and 37°C respectively. The environment temperature is 27°C. The required refrigeration temperature is –13°C. What is the maximum COP possible? If the actual COP of the refrigerator is 0.65 of the maximum, calculate the required power input for a refrigerating effect of 5 kW.

Solution:

Given data: T_e = –23°C = 250 K, T_c = 37°C = 310 K, $T_{\text{surrounding}}$ = 27°C = 300 K



$$\text{Maximum COP} = \frac{T_e}{T_c - T_e} = \frac{250}{310-250}$$

$$(\text{COP})_{\text{max}} = 4.166$$

Now it is given that, $(\text{COP})_{\text{actual}} = 0.65(\text{COP})_{\text{max}}$

$$= 0.65 \times 4.166 = 2.708$$

⇒COP is defined as refrigerating effect/power

⇒ $$\text{COP} = \frac{5}{\text{Power}} = 2.708$$

⇒ $$\text{Power required} = \frac{5}{2.70} = 1.846 \text{ kW}$$

Q.4 A thermoelectric refrigerator is powered by a car battery and has a COP of 0.1. The refrigerator cools a 0.35×10^{-3} m³ canned drink from 20°C to 4°C in 30 minutes. The properties of canned drink are same as that of water at room temperature, i.e., ρ = 1000 kg/m³ and c = 4.18 kJ/kg K. Neglecting the heat transfer through the walls of the refrigerator, determine the average electric power consumed by the thermoelectric refrigerator.

Solution:

Given data: COP = 0.1; Volume = 0.35×10^{-3} m³; ΔT = 20 – 4 = 16°C;
t = 30 minutes; ρ = 1000 kg/m³; c_p = 4.18 kJ/kg-K

$$\text{Refrigeration capacity} = \frac{mc_p\Delta T}{t} \qquad (m = \rho V)$$

$$= \frac{10^3 \times 0.35 \times 10^{-3} \times 4.18 \times 16}{30 \times 60} = 0.013 \text{ kW}$$

$$\text{COP} = \frac{\text{Refrigeration capacity}}{\text{Power input}}$$

$$\text{Power input} = \frac{0.013}{0.1} = 0.13 \text{ kW}$$

Q.5 A cold storage plant is required to store 20 tonnes 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/kgK. 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 75 kW to drive it, find:

1. The capacity of the plant
2. Time taken to achieve cooling

Assume actual COP of the plant as 0.3 of the Carnot COP.

Solution:

(i)
$$\text{Carnot COP} = \frac{T_1}{T_2 - T_1} = \frac{265}{303 - 265} = 6.97$$

$$\therefore \quad \text{Actual COP} = 0.3 \times 6.97 = 2.091$$

$$\text{Heat removed by the plant} = \text{Actual COP} \times \text{Work required}$$

$$= 2.091 \times 75 = 156.8 \text{ kW} = 156.8 \times 60 \text{ kJ/min} = 9408 \text{ kJ/min}$$

$$\therefore \quad \text{Capacity of the plant} = \frac{9408}{210} = 44.8 \text{ TR}$$

(ii) Heat removed from the fish above freezing point

$$Q_1 = m \times c_{AF}(T_2 - T_3)$$

$$= 20 \times 1000 \times 2.93(303 - 269) = 1.992 \times 10^6 \text{ kJ}$$

Similarly, heat removed from the fish below freezing point,

$$Q_2 = m \times c_{BF}(T_3 - T_1) = 20 \times 1000 \times 1.26 \times (269 - 265)$$

$$= 0.101 \times 10^6 \text{ kJ}$$

$$\text{Total latent heat of fish, } Q_3 = m \times (h_{fg})_{\text{fish}}$$

$$= 20 \times 1000 \times 235 = 4.7 \times 10^6 \text{ kJ}$$

$\therefore$ Total heat removed by the plant

$$= Q_1 + Q_2 + Q_3 = (1.992 + 0.101 + 4.7) \times 106 = 6.793 \times 10^6 \text{ kJ}$$

$$\therefore \quad \text{Time taken to achieve cooling} = \frac{\text{Total heat removed by the plant}}{\text{Heat removed by the plant per min}}$$

$$= \frac{6.793 \times 10^6}{9408} = 722 \text{ min} = 12.03 \text{ hr}$$

Practice Questions : Level-II

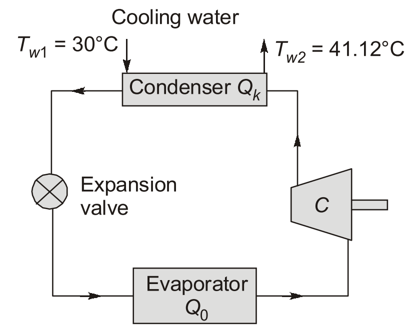
Q.6 A customer complained of poor cooling for an air-conditioning system of 100 TR capacity. The supplier carried out test on condenser which is water cooled and noted power input to the motor. The observations made are as under:

Cooling water flow rate	:	10 litre/s
Inlet water temperature	:	30°C
Outlet water temperature	:	41.12°C
Power input to motor	:	120 kW (94.92% efficiency)

Determine the actual refrigerating capacity and state whether the cooling capacity is lower, higher or as per specifications.

Solution:

Given data: Capacity = 100 TR; $T_{w1} = 30°C$, $T_{w2} = 41.12°C$



Water flow rate, $\dot{V} = 10$ litre/s $= 10 \times 10^{-3}$ m³/s,

Consider the refrigerating/AC system as shown

Heat rejection rate in condenser = rate of heat gain by water

$$\Rightarrow \quad Q_k = \dot{m}_w c_{p,w}(T_{w2} - T_{w1}) = \rho_w \dot{V} c_{p,w}(T_{w2} - T_{w1})$$

$$= 10^3 \times 10 \times 10^{-3} \times 4.18 \times (41.12 - 30)$$

$$= 464.81 \text{ kW}$$

Power input to motor = 120 kW

Actual power input to cycle = 120 × 0.9492 = 113.904 kW [As motor efficiency = 94.92%]

From 1st law of thermodynamics,

$$Q_k = Q_0 + W$$

$$\Rightarrow \quad Q_0 = Q_k - W = 464.81 - 113.904 = 350.906 \text{ kW}$$

$$\therefore \quad \text{Refrigeration capacity, } Q_0 = \frac{350.906}{3.5167} = 99.78 \text{ TR}$$

This is slightly lower than ideal or specified cooling capacity.

Q.7 An air conditioner working on the reversed Carnot cycle has the following data:

Capacity	2TR
Temperature of heat absorption in cooling heat exchanger	5°C
Temperature of heat rejection of condenser heat exchanger	60°C
Temperature of air entering heat rejection heat exchanger	45°C
Temperature of air leaving heat rejection heat exchanger	55°C

Overall heat transfer coefficient of heat rejection of heat exchanger between air and working substance in the cycle 900 kJ/hr-m²-K.

(a) Determine the mass flow rate of entering air, area of heat exchanger, COP and work input to the air conditioner.

(b) If instead of air, water is used for heat rejection and it enters the heat exchanger at 30°C and leaves at 40°C with overall heat transfer coefficient of heat rejection between water and working substance of 9000 kJ/hr-m²-K, determine the mass flow rate of entering water, area of heat exchanger, COP and work input.

Solution:

(a) Air as cooling medium

$$\text{COP} = \frac{T_2}{T_1 - T_2} = \frac{273 + 5}{(273 + 60) - (273 + 5)} = \frac{278}{55} = 5.0545$$

$$\text{Work input, } W = \frac{Q_A}{\text{COP}} = \frac{2 \times 210}{5.0545} = 83.09 \text{ kJ/min} = \frac{83.09}{60} \text{ kW} = 1.385 \text{ kW}$$

$$\text{Heat rejected, } Q_R = Q_A + W$$

$$= 2 \times 210 + 83.09 = 503.09 \text{ kJ/min}$$

$$\text{Mass flow rate of air} = \frac{Q_R}{c_p \Delta t} = \frac{503.09}{1 \times (55 - 45)} = 50.309 \text{ kg/min}$$

$$\text{Area of heat exchanger} = \frac{Q_R}{U \Delta t_m}$$