UPPSC-AE 2021

Uttar Pradesh Public Service Commission

Combined State Engineering Services Examination

Assistant Engineer

Mechanical Engineering

Environmental Control

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

MADE EASY Publications

Environmental Control

Contents

CHAPTER 1 Introduction: Refrigerating Machine and Reversed Carnot Cycle

1.1 Introduction

A refrigerating machine is a device which will either cool or maintain a body at a temperature below that of the surrounding. Hence, heat must be made to flow from a body at a low temperature to the surroundings at high temperature.

However, this is not possible on its own. We see in nature that heat spontaneously flows from a high temperature body to a low temperature body.

- There are essentially two categories of thermal plants
  - (i) Thermal power plants/work producing plants.
  - (ii) Refrigeration or heat pump plants/work consuming plants.
- Work producing plants or heat engine lead to the conversion of heat to work.
- The objective of work consuming plant is to lead to the flow of heat from a low temperature body to a high temperature body.
- Unit of Refrigerating Capacity is TR (Tonne Refrigeration)

  1 TR = Rate of removal of heat from 1 ton of water to freeze it into ice in 24 hr at 0°C = 50.4 kcal/min

  Specific heat of water = 4.18 kJ/kgK; Specific heat of ice = 2.11 kJ/kgK;

  Specific heat of vapour = 1.99 kJ/kgK; 1 kcal = 4.18 kJ;

  Latent heat of water in fusion = 335 kJ/kg (at 0°C);

  Latent heat of water in vapourization = 2260 kJ/kg (at 100°C)

1.2 A Refrigerating machine - The second law interpretation

- A refrigerating machine is a device which will either cool or maintain a body at a temperature below that of the surroudings.
- The cooled space is to be maintained at 15°C. The refrigerating machine takes the air at 25°C, and due to evaporation of refrigerant, heat is taken from the air which is cooled to 15°C and returned back to cooled space. During compression, the temperature rises to 65°C while outside temperature is 45°. Hence heat is transferred to outside air while the refrigerant is condensed and temperature of outside air is raised. This condensed/liquid refrigerant is expended by a throttling device and temperature lowers again to 5°C.

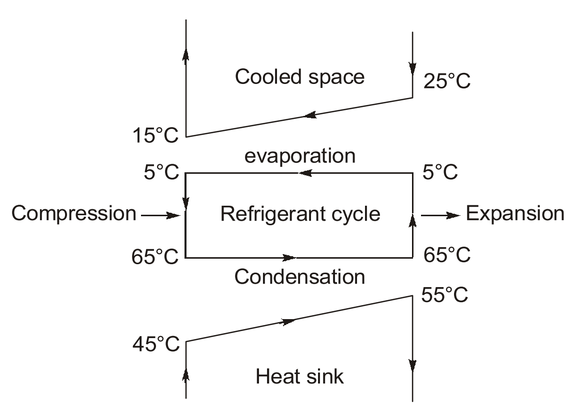


Fig: Schematic Diagram of Refrigerating/AC machine with temperature

Units in Refrigeration

- 1 cal = 4.1868 Joule (J)
- 1 horse power = 746 Watt (W)
- 1 unit of power = 1 kWH = 3600 kJ = 860 K cal
- 1 TR (ton refrigeration) = 50 K cal/min = 3.5167 kW = 211 kJ/min.

Properties of Air

- Specific heat at constant pressure: $C_P = 1.005$ kJ/kgK
- Specific heat at constant volume: $C_V = 0.718$ kJ/kgK
- Characteristic gas constant: $R = 0.287$ kJ/kgK
- Specific heat ratio: $\gamma = 1.4$
- Molecular weight: $M = 28.966$

Example - 1.1 In a 3 ton capacity water cooler, water enters at 30°C and leaves at 15°C steadily, what is the water flow rate per hour?

(a) 60 kg (b) 100 kg
(c) 602 kg (d) 2520 kg

Solution: (c)

In steady state, heat absorb from water is equal to the capacity of water cooler.

$$3 \text{ ton} = 3 \times 3.5 \text{ kJ/s} = 3 \times 3.5 \times 3600 \text{ kJ/hr} = 37800 \text{ kJ/hr}$$

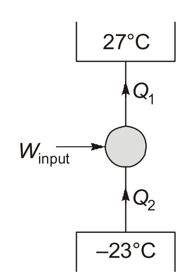
Now,
$$37800 = \dot{m} C_p \Delta T$$

$$\Rightarrow \quad \dot{m} = \frac{37800}{4.18 \times 15} = 602.87 \text{ kg/hr}$$

Example - 1.2 A refrigerator operates between the temperature –23°C and 27°C. If one TR = 3.5 kW, the minimum power required per TR to operate the refrigerator is __________.

(a) 0.5 kW (b) 0.7 kW
(c) 0.9 kW (d) 1 kW

Solution: (b)



$$COP_R = \frac{T_L}{T_H - T_C} = \frac{250}{300 - 250}$$

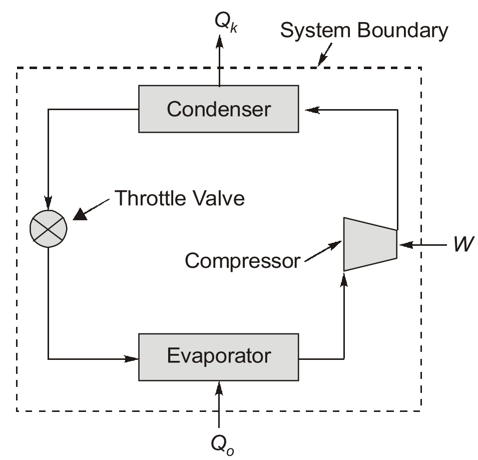
For minimum power requirement/TR

$$\frac{1 \times 3.5}{W_{min}} = \frac{250}{300 - 250}$$

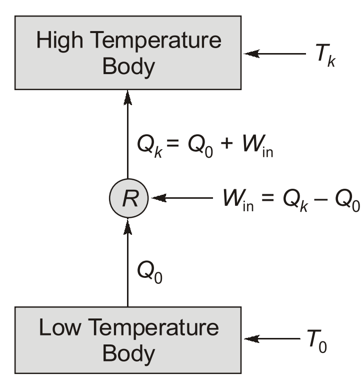
$$\Rightarrow \quad W_{min} = 0.7 \text{ kW}$$

1.3 Heat Pump/Refrigerating Machine

- It contains evaporator, compressor, condenser, expander.
- The processes involved in the cycle are as follows:
  - Heat Q_0 is absorbed in the evaporator by the evaporation of a liquid refrigerant at a low pressure P_0 and corresponding low saturation temperature T_0.
  - The evaporated refrigerant vapour is compressed to a high pressure P_k in the compressor consuming work W.
  - Heat Q_k is rejected from the condenser to the surrounding.



- When refrigerating machine is used for cooling the space, it is called refrigerator. When the machine is used for heating the space, it is called heat pump.
- Same machine can be used either for cooling or for heating. The main difference between the two is in their operating temperatures.
- A refrigerating machine operates between the ambient temperature and a low temperature. A heat pump operates between the ambient temperature and a high temperature.
- Another essential difference is in their useful functions. In a refrigerating machine the heat exchanger that absorbs heat is connected to the conditioned space. In a heat pump, the heat exchanger that rejects heat is connected to the conditional space.



1.4 Coefficient of Performance (COP) or Energy Ratios

It is defined as the ratio of desired effect to work input or it is defined as the ratio of refrigerant effect to the work input.

$$\text{COP} = \text{Energy Ratio} = \frac{\text{useful heat}}{\text{work}}$$

$$(\text{COP})_{\text{ref}} = \frac{Q_0}{W} = \frac{Q_0}{Q_k - Q_0}$$

$$(\text{COP})_{\text{pump}} = \frac{Q_k}{W} = \frac{Q_k}{Q_k - Q_0} = 1 + \frac{Q_0}{Q_k - Q_0}$$

$$\therefore \quad (\text{COP})_{\text{pump}} = 1 + (\text{COP})_{\text{ref}}$$

- If refrigerator/heat pump cycle is reversed, it becomes a heat engine.
- Thermal efficiency of heat engine

$$\eta_{\text{th}} = \frac{W}{Q_k} = \frac{Q_k - Q_0}{Q_k}$$

$$(COP)_{pump} = \frac{Q_k}{Q_k - Q_0} = \frac{1}{\eta_{th}}$$

$$(COP)_{ref} = \frac{1}{\eta_{th}} - 1 = \frac{1-\eta_{th}}{\eta_{th}}$$

NOTE

- COP of Different Vapour Compression System

Type of vapour Compression System	COP
Water cooled	3
Air cooled	2
Domestic Refrigerator	1
Vapour absorption system	<1

- Power consumption of a refrigerator/heat pump

$$1 \text{ H.P.} = \frac{\dot{W} \text{ (in kW)}}{0.746}$$

Refrigerating capacity,

$$(TR) = \frac{Q_0 \text{ (in kW)}}{3.5167}$$

$$\frac{HP}{TR} = \frac{\dot{W}}{0.746} \times \frac{3.5167}{\dot{Q}_0} = 4.71\frac{\dot{W}}{Q_0} = \frac{4.71}{(COP)_{Ref}}$$

where, $\dot{W}$ is power consumption (kW) ; Q_0 is refrigerating effect (kW).

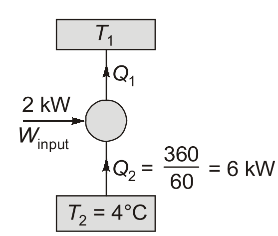
Example - 1.3 The food compartment of a refrigerator is maintained at 4°C by removing heat from it at a rate of 360 kJ/min. If the required power input to the refrigerator is 2 kW, the COP of the refrigerator is :

(a) 2.0 (b) 1/3
(c) 0.5 (d) 3.0

Solution: (d)

$$COP_R = \frac{Q_2}{W_{input}}$$

$$= \frac{6}{2} = 3$$



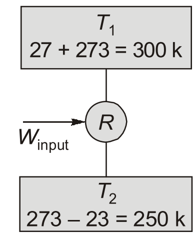
Example - 1.4 A refrigeration cycle operates between condenser temperature of +27°C and evaporator temperature of –23°C. What is the Carnot coefficient of performance of cycle?

(a) 0.2 (b) 1.2
(c) 5 (d) 6

Solution: (c)

$$\text{COP}_R = \frac{T_2}{T_1 - T_2}$$

$$= \frac{250}{50} = 5$$



Example - 1.5 A Carnot heat pump is used to maintain a room at a temperature of T°C, the initial temperature of the room was –10°C. If the power requirement of the pump is 20 kW and the heat provided to the room is 150 kW. What will be the value of T?

(a) 0 (b) 30
(c) 303 (d) Cannot be determined

Solution: (b)

$$W_{\text{input}} + Q_2 = Q_1$$

$$Q_2 = Q_1 - W_{\text{input}} = 150 - 20$$

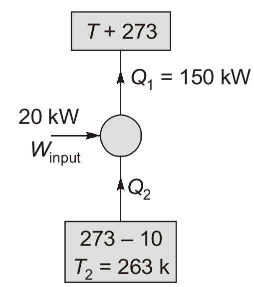
$$Q_2 = 130 \text{ kW}$$

$$\text{COP}_{\text{Carnot}} = \frac{T + 273}{T + 10}$$

Also, $$\text{COP}_{\text{HP}} = \frac{Q_2}{W_{\text{input}}} = \frac{150}{20} = 7.5$$

So, $$7.5 = \frac{T + 273}{T + 10}$$

$\Rightarrow$ $$T = 30.46°\text{C} \approx 30°\text{C}$$



Example - 1.6 If the efficiency of a Carnot engine is 40%. What is the COP of the Carnot refrigerator?

(a) 1 (b) 1.5
(c) 2.5 (d) 3

Solution: (b)

$\eta_E = 0.4 \Rightarrow$ $$\text{COP}_{\text{HP}} = \frac{1}{\eta_E} = \frac{1}{0.4} = 2.5$$

But $$\text{COP}_R = \text{COP}_{\text{HP}} - 1 = 2.5 - 1 = 1.5$$

Example - 1.7 A refrigerator working on a reversed Carnot cycle has a COP of 4. If it work as a heat pump and consumes 1 kW, the heating effect will be

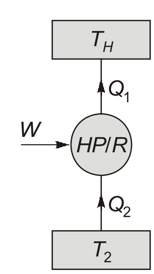
(a) 1 kW (b) 4 kW
(c) 5 kW (d) 6 kW

Solution: (c)

$$(\text{COP})_{\text{HP}} = 1 + \text{COP}_R$$

$$\frac{Q_1}{W} = 1 + 4$$

$$Q_1 = 5\text{ W} = 5 \times 1 = 5 \text{ kW}$$



1.5 Heat Pump vs Electric Resistance Heater

There are various parameter on the basis of which, it can be distinguished that which one is better heat pump or electric resistance heater.

S. No.	Parameters	Heat Pump	Electric Resistance Heater
1.	Floor space	More space	Less space
2.	Efficiency or (COP)	350% (COP 3.5)	100%
3.	Quick start-up	Late	Quick
4.	Life span	Around 15 years	5-10 years
5.	Energy cost	Less energy cost	High energy cost
6.	Maintenance	Low	Low
7.	Environmental impact	Less	High

- If 'W' is the energy consumption in electric resistance heater, its output is equal to W.
- If 'W' is the energy consumption of heat pump. Its output, $Q_k = (\text{COP})_{\text{pump}} W = \left(1 + \text{COP}_{\text{ref}}\right) W$
  COP_{ref} varies from 0 to ∞; COP_{pump} varies from 1 to ∞.
- When refrigeration/Heat pump cycle is reversed carnot cycle

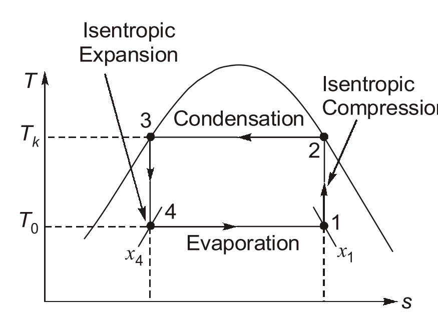
$$(\text{COP})_{\text{ref}} = \frac{Q_0}{Q_k - Q_0} = \frac{T_0}{T_K - T_0}; \quad (\text{COP})_{\text{pump}} = \frac{Q_k}{Q_k - Q_0} = \frac{T_k}{T_K - T_0}$$

- For high COP for refrigerator or heat pump
  T_0 should be as high as possible; T_K should be as low as possible
- Water is a better cooling medium than air (i.e. higher COP & lower power consumption for water in refrigerator) because, T_0 = Evaporator ; T_k = Heat rejection temperature
- Specific heat of water is about four times that of air. [For same heat output (Q_k) rise in water temperature is lower than air temperature (i.e. low T_k)].
- Water has high thermal conductivity than air. So for same temperature difference of (refrigerant and air) and (refrigerant & water), more heat can be transferred in water system. So for small refrigeration system (A.C., domestic refrigerator), air as cooling medium is used.
- For big refrigeration system (central A.C., ice plant, cold storage) water as cooling medium is used.

1.6 Vapour as Refrigerant in Reversed Carnot Cycle

The reversed carnot cycle can be made almost completely practical by operating in the liquid-vapour region of a pure substance as shown in figure below.

The isothermal process of heat rejection (2–3) and the heat absorption (4–1) of the carnot cycle are achieved by making use of phenomena of condensation and evaporation of a pure substance at constant pressure and temperature. This alternate condensation and evaporation of a working substance is accompained by alternate by alternate isentropic compression (1 –2) and expansion (3 – 4) processes. It may be noted that the vapour during compression is wet although it is dry-saturated at the end of the process. Such a compression is called wet compression. The thermodynamic analysis per unit mass of the refrigerant, for the four flow processes of the cycle, using steady state flow energy equation is as follows:



For Per Unit Mass of Vapour

Refrigerating effect = $q_0 = h_1 - h_4$

Heat reject $q_m = h_2 - h_3$

Compressor work w_c (consumed) = $h_2 - h_1$

Expander work w_e (gained) = $h_3 - h_4$

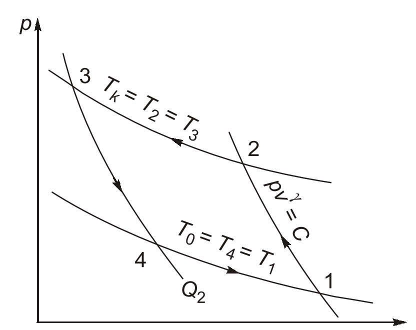
Net work = $w_c - w_e = (h_2 - h_1) - (h_3 - h_4)$

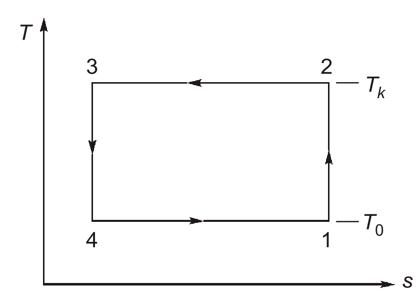
$$(COP)_{Ref} = \frac{q_0}{w} = \frac{h_1 - h_4}{(h_2 - h_1) - (h_3 - h_4)} = \frac{h_1 - h_4}{(h_2 - h_3) - (h_1 - h_4)}$$

1.6.1 Draw Back of Using Vapour as Refrigerant in Reversed Carnot Cycle

1. Liquid refrigerant may be trapped in heat of cylinder and damage the compressor valves.
2. Liquid droplets may wash away the lubricating oil from the walls of compressor cylinder.
3. Expander is costly and the work gained in expander is not significant.
   - The Carnot cycle is the most efficient between the given temperature limits (T_k and T_0)
   - Second law efficiency or exergetic efficiency for cooling or heating is $(\eta_{II}) = \dfrac{(COP)_{actual}}{(COP)_{Carnot}}$

1.7 Gas as Refrigerant in Reversed Carnot Cycle





Refrigerating effect,

$$q_0 = q_{4-1} = RT_0 \ln\frac{v_1}{v_4}$$

$$\left[\text{Net work} = \underset{\text{Consumed in compressor}}{(W_{2\text{-}3})} - \underset{\text{Gained from expander}}{(W_{4\text{-}1})}\right]$$

[(W_{1-2}) and W_{3-4} are same and opposite in sign.
So they cancel each other.]

$$\text{Net work} = RT_k \ln\frac{v_2}{v_3} - RT_0 \ln\frac{v_1}{v_4}$$

$$= R(T_k - T_0)\ln\frac{v_1}{v_4} \qquad \left[\because \frac{v_2}{v_3} = \frac{v_1}{v_4}\right]$$

$$(COP)_{Ref} = \frac{q_0}{w} = \frac{T_0}{T_k - T_0}$$

$$= \frac{1}{\left(\frac{T_k}{T_0}\right) - 1} = \frac{1}{r^{\gamma-1} - 1} \qquad \left[\because r = \frac{v_1}{v_2} = \frac{v_4}{v_3} = \left(\frac{T_k}{T_0}\right)^{\frac{1}{\gamma-1}}\right]$$

1.7.1 Draw Back of using Air as Refrigerant in Reversed Carnot Cycle

- Isothermal process of heat absorption and rejection being very slow is not possible.
- *P-v* diagram for gas is very narrow so very high stroke volume is needed to have desired refrigerating effect.

1.8 Limitations of Reversed Carnot Cycle

It is found that serious particle difficulties are encountered in the application of Carnot cycle. In the reversed Carnot cycle with vapour as refrigerant, the isothermal processes of condensation and evaporation are internally reversible processes, and there are easily achievable in particle although there may be some problem in having only partial evaporation. However, isentropic compression and expansion processes have some limitational. In brief, it is difficult to design an expander to handle a mixture of larger liquid and partly vapour. Also, because of the internal irreversiblities in the compressor and the expander, the actual COP is very low.

Student's Assignment

Q.1 In a certain ideal refrigeration cycle, the COP of heat pump is 5. The cycle under identical conditions running as heat engine will have efficiency as

(a) Zero (b) 0.20
(c) 1.00 (d) 6.00

Q.2 The COP of a refrigerator on a reversed Carnot cycle is 5. The ratio of higher absolute temperature to the lower temperature (i.e., T_2/T_1) is

(a) 1.25 (b) 1.3
(c) 1.4 (d) 1.2

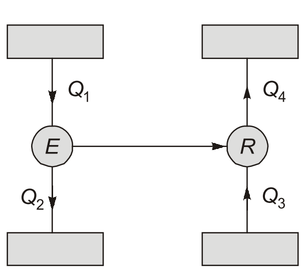
Q.3 A refrigerating machine working on reversed Carnot cycle takes out 2 kW of heat from the system at 200 K while working between temperature limits of 300 K and 200 K. COP and power consumed by the cycle will, respectively, be

(a) 1 and 1 kW (b) 1 and 2 kW
(c) 2 and 1 kW (d) 2 and 2 kW

Q.4 A refrigerating machine in heat pump mode has a COP of 4. If it is worked in refrigerator mode with power input of 3 kW, what is the heat extracted from the food kept in the refrigerator?

(a) 180 kJ/min (b) 360 kJ/min
(c) 540 kJ/min (d) 720 kJ/min

Q.5



In the figure shown above, E is the heat engine with efficiency of 0.4 and R is the refrigerator. If $Q_2 + Q_4 = 3Q_1$, the COP of the refrigerator is

(a) 3.0 (b) 4.5
(c) 5.0 (d) 5.5

Q.6 The refrigeration system of an ice plant working between temperature of –5°C and 25°C produces 20 kg of ice per minute from water at 20°C. The specific heat of water is 4.2 kJ/kg and latent heat of ice is 335 kJ/kg. The refrigeration capacity of the refrigeration plant is

(a) 9040 kJ/min (b) 8750 kJ/min
(c) 8380 kJ/min (d) 8010 kJ/min

Q.7 One ton of refrigeration is equivalent to SI unit of

(a) 1 kW (b) 2.5 kW
(c) 3.5 kW (d) 5 kW

Q.8 Efficiency of a Carnot engine is 75%. If the cycle direction is reversed, COP of the reversed Carnot cycle is

(a) 1.33 (b) 0.75
(c) 0.33 (d) 1.75

Q.9 The refrigeration system works on:

(a) Zeroth law of thermodynamics
(b) First law of thermodynamics
(c) Seconds law of thermodynamics
(d) None of these

Q.10 A Carnot refrigerator operates between 300.3 K and 273 K. The fraction of cooling effect required as work input is:

(a) 20% (b) 10%
(c) 50% (d) Cannot be calculated

Q.11 A Carnot refrigeration cycle has a COP of 4. The ratio of higher temperature to lower temperature will be
(a) 2.5 (b) 2.0
(c) 1.5 (d) 1.25

Q.12 A heat pump working on a reversed Carnot cycle has a COP of 5. It works as a refrigerator taking 1 kW of work input. The refrigerating effect will be
(a) 4 kW (b) 1 kW
(c) 2 kW (d) 5 kW

Q.13 The COP of a Carnot refrigerator in winter as compared to in summer will be:
(a) Large (b) Small
(c) Unpredictable (d) Same

Q.14 A heat pump operating between high temperature T_1 and low temperature T_2 has its COP expressed as
(a) $\frac{T_1}{T_1 - T_2}$ (b) $\frac{T_2}{T_1 - T_2}$
(c) $\frac{T_1 - T_2}{T_1 + T_2}$ (d) $\frac{T_1 + T_2}{T_1 - T_2}$

Q.15 In a reversed Carnot refrigeration cycle, the condenser and evaporator are at 27°C and – 13°C, respectively. The COP of this cycle is:
(a) 6.5 (b) 7.5
(c) 10.5 (d) 15.5

Q.16 COP for refrigerator and heat pump are related as:
(a) $COP_h = COP_r - 1$
(b) $COP_h = COP_r$
(c) $COP_h = COP_r + 1$
(d) $COP_h = \frac{1}{COP_r}$

Q.17 In a cylinder under steady state conduction with uniform heat generation, the temperature gradient at half the radius location will be
(a) one half of that at surface
(b) one fourth of that at surface
(c) twice that at surface
(d) four times that at surface

Q.18 The power (kW) required per ton of refrigeration is *N*/COP, where COP is the coefficient of performance, then *N* is equal to
(a) 2.75 (b) 3.50
(c) 4.75 (d) 5.25

Q.19 A refrigerating machine in heat pump mode has a C.O.P. of 4. If it is worked in refrigerator mode with a power input of 3 kW, what is the heat extracted from the food kept in the refrigerator?
(a) 180 kJ/min. (b) 360 kJ/min.
(c) 540 kJ/min. (d) 720 kJ/min.

Q.20 A refrigeration system operates on the reversed Carnot cycle. The temperature for the system are :
Higher temperature = 40°C
Lower temperature = 20°C
The capacity of the refrigeration system is 10 TR. What is the heat rejected from the system per hour if all the losses are neglected ?
(a) 1.25 kJ/hr (b) 1.55 kJ/hr
(c) 2.3 kJ/hr (d) None of these

Q.21 In a one ton capacity water cooler, water enters at 30°C at the rate of 200 litres per hour. The outlet temperature of water will be (specific heat of water = 4.18 kJ/kgK)
(a) 3.5°C (b) 6.3°C
(c) 23.7°C (d) 15°C

Q.22 A refrigerating machine having coefficient of performance equal to 2 is used to remove heat at the rate of 1200 kJ/min. What is the power required for this machine?
(a) 80 kW (b) 60 kW
(c) 20 kW (d) 10 kW

Q.23 A cold storage has capacity for food preservation at a temperature of – 3°C when the outside temperature is 27°C. The minimum power required to operate with a cooling load of 90 kW is
(a) 20 kW (b) 15 kW
(c) 10 kW (d) 5 kW

Q.24 Two reversible refrigerators are arranged in series and their COPs are 5 and 6 respectively. The COP of composite refrigeration system would be:
(a) 1.5 (b) 2.5
(c) 3.5 (d) 4.5

Q.25 An ideal refrigerator working on a reversed Rankine cycle has a capacity of 3 tons. The COP of the unit is found to be 6. The capacitor of the motor required to run the unit is

(Take 1T = 210 kJ/min)

(a) 1.85 kW (b) 1.75 kW
(c) 1.65 kW (d) 1.5 kW

Q.26 A refrigerator works on reversed Carnot cycle producing a temperature of –40°C. Work done per TR is 700 kJ per ten minutes. What is the value of its COP?

(a) 3 (b) 4.5
(c) 5.8 (d) 7

Q.27 A reversed Carnot cycle working as a heat pump has COP of 7. What is the ratio of minterm to maximum absolute temperature?

(a) $\frac{7}{8}$ (b) $\frac{1}{6}$
(c) $\frac{6}{7}$ (d) $\frac{1}{7}$

ANSWER KEY // STUDENT'S ASSIGNMENT

1. (b)	**2.** (d)	**3.** (c)	**4.** (c)	**5.** (c)
6. (c)	**7.** (c)	**8.** (c)	**9.** (c)	**10.** (b)
11. (d)	**12.** (d)	**13.** (a)	**14.** (a)	**15.** (a)
16. (c)	**17.** (b)	**18.** (b)	**19.** (c)	**20.** (d)
21. (d)	**22.** (d)	**23.** (c)	**24.** (b)	**25.** (b)
26. (a)	**27.** (c)			

HINTS & SOLUTIONS // STUDENT'S ASSIGNMENT

1. (b)

Given;

COP of the heat pump = 5

As we know; $\eta_{engine} = \frac{1}{(COP)_{HP}}$

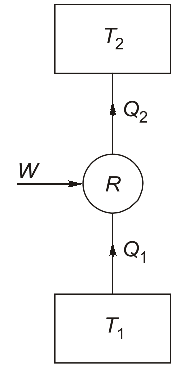
$\Rightarrow \eta_{engine} = \frac{1}{5} = 0.20$

2. (d)

Given;

COP of refrigerator = 5

We know,



$$COP = \frac{T_1}{T_2 - T_1}$$

$$5 = \frac{T_1}{T_2 - T_1}$$

$$\Rightarrow \frac{T_2 - T_1}{T_1} = \frac{1}{5}$$

$$\Rightarrow \frac{T_2}{T_1} - 1 = \frac{1}{5}$$

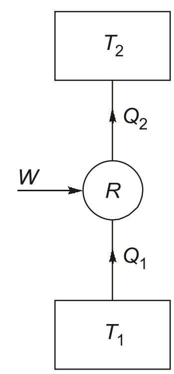
$$\Rightarrow \frac{T_2}{T_1} = \frac{1}{5} + 1 = 1.2$$

3. (c)

Given; $Q_1 = 2$ kW

Lower temperature, $T_1 = 200$ K

Higher temperature, $T_2 = 300$ K



We know, $COP = \frac{T_1}{T_2 - T_1}$

$$= \frac{200}{300 - 200} = 2$$

Also, COP can be written as:

$$COP = \frac{Q_1}{W} = 2$$

$$\Rightarrow W = \frac{Q_1}{2} = \frac{2}{2} = 1 \text{ KW}$$

4. (c)

Given; COP = 4

Power input, $W = 3$ kW

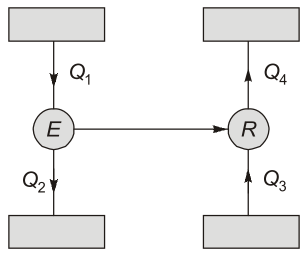
We know, $COP = \frac{\text{Heat extracted}}{\text{Work input}}$

$$4 = \frac{\text{Heat extracted}}{3}$$

$\Rightarrow$ Heat extracted = 4 × 3 = 12 kW

= 12 × 60 kJ/min = 720 kJ/min

5. (c)



$$\eta = 1 - \frac{Q_2}{Q_1} = 0.4$$

$$\Rightarrow \quad \frac{Q_2}{Q_1} = 0.6 \qquad \text{...(i)}$$

$$COP_R = \frac{Q_3}{Q_4 - Q_3} \qquad \text{...(ii)}$$

Given, $Q_2 + Q_4 = 3Q_1$

From equation (i),

$$Q_2 = 0.6Q_1$$

$$\therefore \quad 0.6Q_1 + Q_4 = 3Q_1$$

$$\Rightarrow \quad Q_4 = 2.4Q_1 \qquad \text{...(iii)}$$

From conservation of energy, the work output from engine will be work consumed by refrigerator,

$$Q_1 - Q_2 = W = Q_4 - Q_3$$

$$Q_1 - 0.6Q_1 = Q_4 - Q_3$$

$$0.4Q_1 = 2.4Q_1 - Q_3$$

$$\Rightarrow \quad Q_3 = (2.4 - 0.4)Q_1 = 2Q_1$$

$$\Rightarrow \quad Q_3 = 2Q_1 \qquad \text{...(iv)}$$

From equation (ii), (iii) and (iv),

$$COP = \frac{2Q_1}{2.4Q_1 - 2Q_1} = \frac{2}{0.4}$$

$$COP = 5$$

6. (c)

$\because$ Specific heat of ice is not given so it is assumed that ice is formed at 0°C. Hence refrigeration capacity

$$= (mC_W \Delta T + mL)$$

$$= 20 \times 4.2 \times 20 + 20 \times 335$$

$$= 8380 \text{ kJ/min}$$

7. (c)

Amount of heat required to extract from 1 ton of water at 0°C in order to convert it into equivalent ice at 0°C in a day or 24 hrs.

1 ton = 3.5 kW = 210 kJ/min. = 50 Kcal/min

8. (c)

Given: $\eta_{HE} = 0.75$

We know $\eta_{HE} = \dfrac{1}{(COP)_{HE}} = \dfrac{1}{(COP)_R + 1}$

$$\frac{1}{(COP)_R + 1} = \eta_{HE} = 0.75 = \frac{3}{4}$$

$$(COP)_R + 1 = \frac{4}{3}$$

$$(COP)_R = \frac{4}{3} - 1 = 0.33$$

9. (c)

According to second law of thermodynamics. It is not possible for heat to flow from a colder body to a warmer body without any work having been done to accomplish this flow.

In a refrigerator or an AC, electrical energy is used to do the work of heat transfer via their various components.

10. (b)

We know

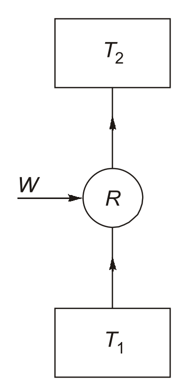
$$(COP)_R = \frac{T_L}{T_H - T_L} = \frac{273}{303.3 - 273} = 10$$

$$(COP)_R = \frac{Q}{W_{I/P}}$$

$$\therefore \quad \frac{W_{I/P}}{Q} = \frac{1}{10} = 0.1 = 10\%$$

11. (d)

We know, $(COP)_R = \dfrac{T_1}{T_2 - T_1}$



$$\Rightarrow \quad \frac{T_1}{T_2 - T_1} = 4$$

$$\Rightarrow \quad \frac{T_2 - T_1}{T_1} = \frac{1}{4}$$

$$\Rightarrow \quad \frac{T_2}{T_1} - 1 = \frac{1}{4}$$

$$\Rightarrow \quad \frac{T_2}{T_1} = \frac{1}{4} + 1 = 1.25$$