Dr. K GOVINDA RAJULU

M.Tech., Ph.D (IITR)
Principal &
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Jawaharlal Nehru Technological University Anantapur
Anantapuram – 515 002, Andhra Pradesh, India

PositionsHeld:

- Principal, JNTUA College of Engineering Anantapur
- Officer on Special Duty Anantapur
- Principal JNTUA College of Engineering Pulivendula
- Director of Evaluation Anantapur
- Director Foreign Affairs & Alumni Matters Anantapur
- Director, UGC Academic Staff College
- Officer on Special Duty Hyderabad
- Director of Evaluation Hyderabad
- Controller of Examinations Hyderabad
- Convenor, ECET (FDH)
- Convenor, ECET (FDH)
- Convenor, ECET (FDH)

Achievements:

- Received "Best Teacher Award" by the Govt. of Andhra Pradesh
- Conducted ECET(FDH), a statewide Entrance examination of combined AndhraPradesh as convener for the years 2005, 2006 and 2007
- Acted as AICTE Hearing committee and AICTE Inspection committee member for granting permission to start new engineering college.
- Acted as expert in National Board of Accreditation committees
- Implemented world bank project (TEQIP) worth Rs. 10.00 crores as Nodal officer
- As controller of Examinations, introduced and implemented EDEP (Electronics Distributions of Examination Papers) examination system in

the University examinations in all the constituent and Affiliated Engineering Colleges of JNT University Hyderabad

- As Director, UGC Academic Staff College conducted several faculty development programs for the staff of university and affiliated colleges.
- As Director of Evaluation introduced online internal examination system for all the constituent and affiliated colleges of the university.
- As Principal of the College organized several conferences and workshops for the students and several faculty development programs for teaching staff
- 101 Research papers in reputed journals and conferences
- Developed Infrastructure in JNTUA College of Engineering Pulivendula as Principal of the college.

Date of Birth:	5th April 1960
Educational Qualification:	M. Tech., Ph.D. (IITR)
Professional Position:	Professor of Mechanical Engg (since 2000)
Administrative Position:	Principal, JNTUA College of Engineering, Anantapur (Since July 2019)
Teaching experience:	35 + years teaching UG & PG students (since 1985)
Number of subjects taught:	19 Theory subjects (UG & PG together)
Research experience:	33+ years
No. of PG Theses:	75 +
No. of Ph. D's Awarded:	11 and (02 under evaluation process)
No. of Ph. D's in supervision	04
Research Publications:	

International Journals	77
National Journals	04
International Conferences	19
National Conferences	21

Performance Indices of Publications:	
	Total Citations 436
	h -Index 09
	i-10 Index 13
Text Books / Monographs:	01
Workshops / Seminars/ FDP Organized	22
Attended	11

I hereby declare that the information furnished is true to the best of my knowledge.

23.09.2019.

(Dr. K.GovindaRajulu)

Refrigeration

It means production of temperatures lower than surroundings.

or

It is artificial removal of heat from a substance or a space to produce a temperature lower than that which would exist.

Units of Refrigeration

The standard unit of refrigeration is 1 Ton (ITR). It is equivalent to the rate of heat transfer needed to produce 1 ton of ice at 0^0C from water at 0^0C in 24 hrs.

1 TR = 210 KJ/min = 3.5 KW

Refrigerating Effect

It is defined as the amount of cooling produced by a system.

or

It is the amount of heat removed (KJ) from the application by the refrigerant.

Coefficient of Performance (COP)

It is defined as the ratio of the heat extracted in the refrigerator (refrigerating effect) to the work done on the refrigerant to achieve that refrigerating effect.

C.O.P. = Q/W

It is the reciprocal of the efficiency of a heat engine therefore the C.O.P is always greater than 1.

Relative C.O.P. = Actual C.O.P/Theoritical C.O.P

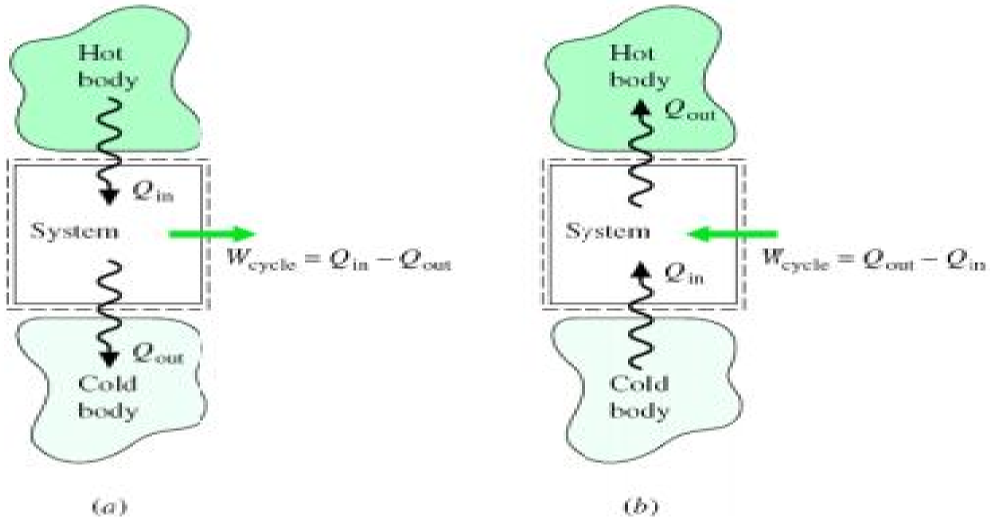


Fig. (*a*) Heat Engine (*b*) Refrigeration and heat pump cycles

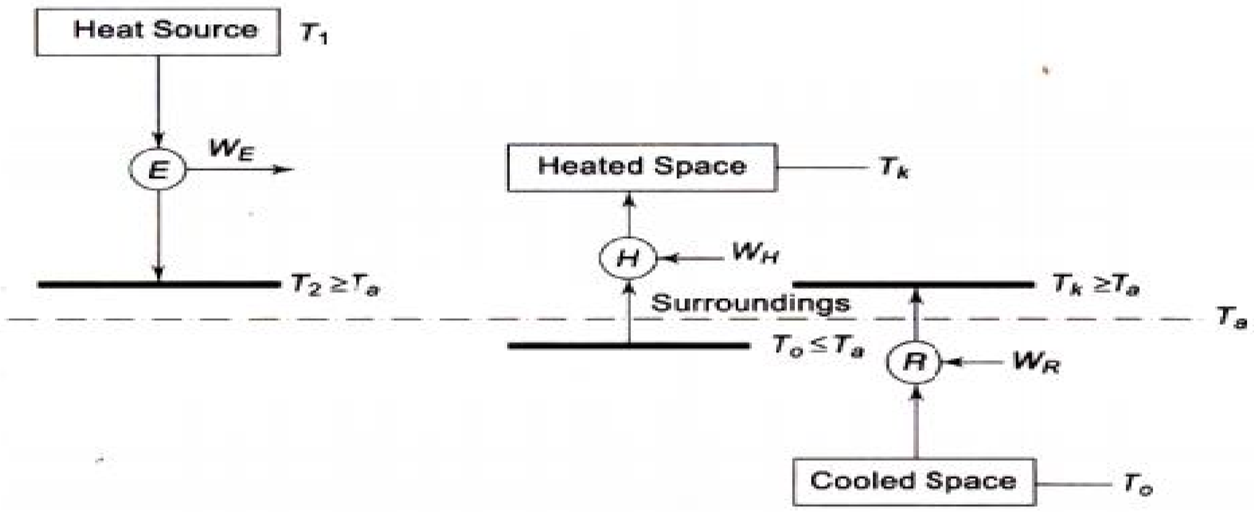


Fig. Comparison of heat engine, heat pump and refrigerating machine

Thermal efficiency for a heat engine (η_{HE}) is defined as:

$$\eta_{HE} = \frac{W_{cycle}}{Q_H} = 1 - \frac{Q_C}{Q_H}$$

Where W_{cycle} is the net work output, Q_C and Q_H and are the heat rejected to the low temperature reservoir and heat added (heat input) from the high temperature reservoir, respectively.

It follows from Carnot's theorem that for a reversible cycle $\left(\frac{Q_C}{Q_H}\right)$ is a **function of temperatures** of the two reservoirs only. i.e. $\frac{Q_C}{Q_H} = \phi(T_C, T_H)$.

If we choose the absolute (*Kelvin*) temperature scale then:

$$\frac{Q_C}{Q_H} = \frac{T_C}{T_H}$$

$$\text{hence, } \eta_{Carnot,HE} = 1 - \frac{Q_C}{Q_H} = 1 - \frac{T_C}{T_H}$$

The efficiency of refrigerator and heat pump is called as **Coefficient of Performance (COP).** Similarly to heat engines, Carnot coefficient of performance for heat pump and refrigerators $(COP)_{HP}$ and $(COP)_R$ can be written as;

$$COP_{Carnot,HP} = \frac{Q_H}{W_{cycle}} = \frac{Q_H}{Q_H - Q_C} = \frac{T_H}{T_H - T_C}$$

$$COP_{Carnot,R} = \frac{Q_C}{W_{cycle}} = \frac{Q_C}{Q_H - Q_C} = \frac{T_C}{T_H - T_C}$$

Where

- W_{cycle} = work input to the reversible heat pump and refrigerator
- Q_H = heat transferred between the system and the hot reservoir
- Q_C = heat transferred between the system and cold reservoir
- T_H = temperature of the hot reservoir.

The Performance of the heat pump is expressed by the ratio of the amount of heat delivered to the hot body (Q_h) to the amount of work required to be done on the system (W_p). This ratio is called coefficient of performance or energy performance ratio (E.P.R) of a heat pump.

$$(C.O.P.)_p \ or \ E.P.R = \frac{Q_h}{W_p} = \frac{Q_h}{Q_h - Q_c} = 1 + \frac{Q_c}{Q_h - Q_c} = 1 + (C.O.P.)_R$$

From the above we see that the C.O.P. may be less than one or greater than one depending on the type of refrigeration system used. But the C.O.P. of the heat pump is always greater than one.

If the thermal efficiency of a heat engine is 30% and if it is reversed in the operation to work as a refrigerator or a heat pump with same operationg conditions then what will be COP of refrigerator and heat pump?

$$n_E = \frac{Q_h - Q_c}{Q_h} = 1 - \frac{Q_c}{Q_h}$$

$$0.3 = 1 - \frac{Q_c}{Q_h} \quad ; \quad \frac{Q_c}{Q_h} = 0.7$$

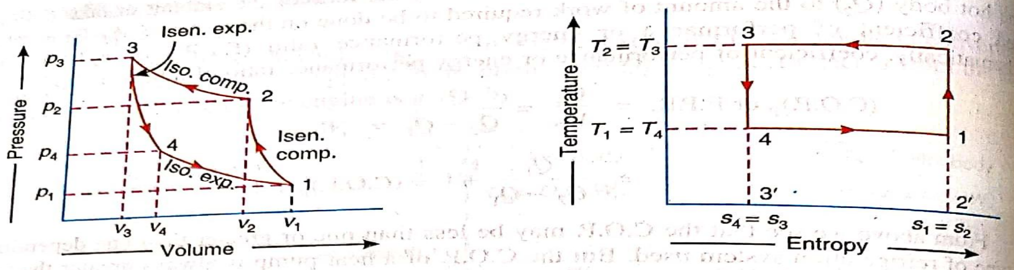
$$(C.O.P)_R = \frac{Q_c}{Q_h - Q_c}$$

Devide Nr & Dr by Q_H

$$(C.O.P)_R = \frac{Q_c/Q_h}{1 - Q_c/Q_h} = \frac{0.7}{1 - 0.7} = 2.33$$

$$(C.O.P)_P = \frac{Q_h}{Q_h - Q_c} = \frac{1}{1 - \frac{Q_c}{Q_h}} = \frac{1}{1 - 0.7} = 3.33$$

Reversed Carnot Cycle (Ideal Cycle)



(*a*) *p-v* diagram. (*b*) *T-s* diagram.

Fig. 2.2. Reversed Carnot cycle.

The four processes of the cycle are as follows :

1. ***Isentropic compression process.*** The air is compressed isentropically as shown by the curve 1-2 on *p-v* and *T-s* diagrams. During this process, the pressure of air increases from p_1 to p_2, specific volume decreases from v_1 to v_2 and temperature increases from T_1 to T_2. We know that during isentropic compression, no heat is absorbed or rejected by the air.

2. ***Isothermal compression process.*** The air is now compressed isothermally (*i.e.* at constant temperature, $T_2 = T_3$) as shown by the curve 2-3 on *p-v* and *T-s* diagrams. During this process, the pressure of air increases from p_2 to p_3 and specific volume decreases from v_2 to v_3. We know that the heat rejected by the air during isothermal compression per kg of air,

$$q_{2-3} = \text{Area } 2\text{–}3\text{–}3'\text{–}2'$$
$$= T_3 (s_2 - s_3) = T_2 (s_2 - s_3)$$

3. ***Isentropic expansion process.*** The air is now expanded isentropically as shown by the curve 3-4 on *p-v* and *T-s* diagrams. The pressure of air decreases from p_3 to p_4, specific volume increases from v_3 to v_4 and the temperature decreases from T_3 to T_4. We know that during isentropic expansion, no heat is absorbed or rejected by the air.

4. ***Isothermal expansion process.*** The air is now expanded isothermally (*i.e.* at constant temperature, $T_4 = T_1$) as shown by the curve 4-1 on *p-v* and *T-s* diagrams. The pressure of air decreases from p_4 to p_1, and specific volume increases from v_4 to v_1. We know that the heat absorbed by the air (or heat extracted from the cold body) during isothermal expansion per kg of air,

$$q_{4-1} = \text{Area } 4\text{–}1\text{–}2'\text{–}3'$$
$$= T_4 (s_1 - s_4) = T_4 (s_2 - s_3) = T_1 (s_2 - s_3)$$

We know that work done during the cycle per kg of air

$$= {}^*\text{Heat rejected} - \text{Heat absorbed} = q_{2-3} - q_{4-1}$$
$$= T_2 (s_2 - s_3) - T_1 (s_2 - s_3) = (T_2 - T_1)(s_2 - s_3)$$

∴ Coefficient of performance of the refrigeration system working on reversed Carnot cycle,

$$(\text{C.O.P.})_R = \frac{\text{Heat absorbed}}{\text{Work done}} = \frac{q_{4-1}}{q_{2-3} - q_{4-1}}$$

$$= \frac{T_1(s_2 - s_3)}{(T_2 - T_1)(s_2 - s_3)} = \frac{T_1}{T_2 - T_1}$$

Though the reversed Carnot cycle is the most efficient between the fixed temperature limits, yet no refrigerator has been made using this cycle. This is due to the reason that the isentropic processes of the cycle require high speed while the isothermal processes require an extremely low speed. This variation in speed of air is not practicable.

Note : We have already discussed that C.O.P. of a heat pump,

$$(\text{C.O.P.})_P = (\text{C.O.P.})_R + 1 = \frac{T_1}{T_2 - T_1} + 1 = \frac{T_2}{T_2 - T_1}$$

and C.O.P. or efficiency of a heat engine,

$$(\text{C.O.P.})_E = \frac{1}{(\text{C.O.P.})_P} = \frac{T_2 - T_1}{T_2}$$

Limitations of Carnot Cycle

1. Isoentropic (Reversible adiabatic) compression and expansion are not possible due to friction.
2. Isothermal heat addition and heat rejection are not possible as they require temp. differential, if the process does not involve phase change.
3. Isothermal process needs slow speeds where as isentropic process needs high speeds of the compressor. This contradictory requirement of different process can not be achieved.

1. In S.I. unit, one ton of refrigeration is equal to

(A) 210 kJ/ min (B) 21 kJ/ min

(C) 420 kJ/ min (D) 840 kJ/ min

Answer: A

2. One ton of refrigeration is equal to the refrigeration effect corresponding to melting of 1000 kg of ice

(A) In 1 hour (B) In 1 minute

(C) In 24 hours (D) In 12 hours

Answer: C

3. A refrigeration system

(A) Removes heat from a low temperature body and delivers it to a high temperature body

(B) Removes heat from a high temperature body and delivers it to a low temperature body

(C) Rejects energy to a low temperature body

(D) None of the above

Answer – A

4. The C.O.P. of a heat pump working on a reversed Carnot cycle is

(A) $T_1/(T_2 - T_1)$ (B) $(T_2 - T_1)/T_1$
(C) $(T_1 - T_2)/T_1$ (D) $T_2/(T_2 - T_1)$
Answer – D

5. The relative coefficient of performance is equal to
(A) (Theoretical C.O.P.)/ (Actual C.O.P.)
(B) (Actual C.O.P.) /(Theoretical C.O.P.)
(C) (Actual C.O.P.) × (Theoretical C.O.P.)
(D) None of these
Answer - B

6. The C.O.P. of a Carnot refrigerator in winter will be __________ as compared to C.O.P. in summer.
(A) Same (B) Lower
(C) Higher (D) None of these
Answer - C

7. The coefficient of performance of a domestic refrigerator is ________ as compared to a domestic air-conditioner.

(A) Same
(B) Less
(C) More
(D) None of these
Answer - B

8. The C.O.P. of a refrigerator working on a reversed Carnot cycle is (where T_1 = Lowest absolute temperature, and T_2 = Highest absolute temperature)

(A) $T_1 / (T_2 - T_1)$ (B) $(T_2 - T_1)/T_1$
(C) $(T_1 - T_2)/T_1$ (D) $T_2/ (T_2 - T_1)$

Answer - A

9. If a heat pump cycle operates between the condenser temperature of +27°C and evaporator temperature of -23°C, then the Carnot COP will be

(A) 0.2 (B) 1.2
(C) 5 (D) 6
Answer – D

$$(C.O.P.)_p = \frac{T_2}{T_2 - T_1} = \frac{300}{300 - 250} = 6$$

10. A heat pump working on a reversed Carnot cycle has a C.O.P. of 5. It works as a refrigerator taking 1 kW of work input. The refrigerating effect will be

(A) 1 kW (B) 2 kW
(C) 3 kW (D) 4 kW
Answer - D

$$(C.O.P.)_p = \frac{Q_2}{W} = 5 ; \quad Q2 = 5W = 5X1 = 5kW$$

$$Q_1 = Q_2 - W = 5 - 1 = 4kW$$

11. A refrigeration cycle operates between condenser temperature of + 27°C and evaporator temperature of -23°C. The Carnot coefficient of performance of cycle will be

(A) 0.2 (B) 1.2
(C) 5 (D) 6
Answer – C

$$(C.O.P.)_R = \frac{T_1}{T_2 - T_1} = \frac{250}{300 - 250} = 5$$

30. The domestic refrigerator uses following type of compressor

(A) Centrifugal

(B) Axial

(C) Miniature sealed unit

(D) Piston type reciprocating

Answer - D

Find the C.O.P. of the refrigerating system if the work input is 80 KJ/Kg and refrigerating effect produced is 160 KJ/Kg or refrigerant flowing.

Q = 160 KJ/Kg ;   W = 80 KJ/Kg

C.O.P = Q /W = 160/80 = 2.

Derive the relationship between the COP of a heat pump and the COP of a refrigerator.

- OR Prove that the COP of heat pump is greater than one.
- COP for heat pump = $\frac{Heat\ Supplied}{Work\ Input}$

$$\therefore COP\ for\ heat\ pump = \frac{Q_2}{(Q_2 - Q_1)}$$

$$\therefore COP\ for\ heat\ pump = \frac{Q_2 - Q_1 + Q_1}{(Q_2 - Q_1)}$$

$$\therefore COP\ for\ heat\ pump = 1 + \frac{Q_1}{(Q_2 - Q_1)}$$

$$\therefore COP\ for\ heat\ pump = 1 + COP\ for\ refrigerator - (proved)$$

Thus COP of Heat pump is always greater than one.

Q. 2 A reverse Carnot cycle air refrigeration equipment has a compressor working with a compression ratio of 12. The temperature limits of the cycle are 300 K and 270 K. Determine the refrigerating effect and the COP of the unit.

(Pune University Dec 95)

Solution:

$T_2 = 300K;\ T_1 = 270K$

$$COP = \frac{T_1}{(T_2 - T_1)} = \frac{270}{(300-270)} = 9$$

$$COP = \frac{Q}{W} = 9$$

$$\therefore Q = 9 \quad x \quad W$$

$$\text{Refrigerating effect } \ Q = 9 \ x \ \frac{1}{(r)^{\gamma-1/\gamma}} = 9 \ x \ \frac{1}{(12)^{1.4-1/1.4}} = 4.42KW = 1.26TR - (Ans)$$

Q. 6 Determine the mass of ice produced from water per day for the following conditions:

Water temperature = 22°C
Tonnage of unit = 150 tons
Operating temperatures = -5°C and 28°C
Latent heat of ice = 330 KJ/Kg
Also, determine the power required to drive the unit.

Solution: T_1 = -5 + 273 = 268 K ; T_2 = 28+273 = 301 K

$$COP = \frac{T_1}{(T_2 - T_1)} = \frac{268}{301 - 268} = 8.12 - (Ans)$$

Refrigerating effect = Q = 150 TR = 525 kW

COP = 8.12 = Q/W = 525/W
∴ Power required to drive the unit = W = 64.65 KW – (Ans)

Total heat removed from water at 22°C to form ice at 0°C = H
∴ H = Latent heat + m x Cp x ΔT = 330 + 1 x 4.18 x (22-0) = 421.96 KJ/Kg
∴ Mass of ice produced = M = Q/H = 525/421.96 = 1.24 Kg/s
∴ Mass of ice produced daily = 24 x 60 x 60 x 1.24 Kg/s = 1,07,498 Kg – (Ans)

- **The coefficient of performance (COP) of a refrigerator working as a heat pump is given by: [GATE-1995; IES-1992, 1994, 2000]**
- (a)(COP)heat pump = (COP)refrigerator+ 2
- (b)(COP)heat pump = (COP)refrigerator+ 1
- (c)(COP)heat pump = (COP)refrigerator – 1
- (d)(COP)heat pump = (COP)refrigerator

Ans. (b) The COP of refrigerator is one less than COP of heat pump, if same refrigerator starts working as heat pump i.e. (COP)heat pump = (COP)refrigerator + 1

- **An industrial heat pump operates between the temperatures of 27°C and –13°C. The rates of heat addition and heat rejection are 750 W and 1000 W, respectively. The COP for the heat pump is: [GATE-2003]**

  (a) 7.5 (b) 6.5 (c) 4.0 (d) 3.0

- **Ans. (c)** $(COP) = Q1 / (Q1 - Q2) = 1000/(1000 – 750) = 4$

- **An irreversible heat engine extracts heat from a high temperature source at a rate of 100 kW and rejects heat to a sink at a rate of 50 kW. The entire work output of the heat engine is used to drive a reversible heat pump operating between a set of independent isothermal heat reservoirs at 17C and 75C. The rate (in kW) at which the heat pump delivers heat to its high temperature sink is: [GATE -2009]**

(a) 50 (b) 250 (c) 300 (d) 360

Ans. (c)

- **A Carnot cycle refrigerator operates between 250K and 300 K. Its coefficient of performance is:**

[GATE-1999]

(a) 6.0 (b) 5.0 (c) 1.2 (d) 0.8

Ans. (b)

$(COP) = T2/(T1 - T2) = 250/(300 - 250) = 5$

- **Round the clock cooling of an apartment having a load of 300 MJ/day requires an air-conditioning plant of capacity about [GATE-1993]**

  a) 1 ton b)5 tons c)10 tons d)100 tons

Ans. (a)

210 kJ/min = 1 T refrigeration

Refrigeration capacity =300X1000/(24X60X210) = 1 ton

IES-1. A heat pump works on a reversed Carnot cycle. The temperature in the condenser coils is 27°C and that in the evaporator coils is –23°C. For a work input of 1 kW, how much is the heat pumped? [IES-2007]

(a) 1 kW (b) 5 kW (c) 6 kW (d) None of the above

IES-1. Ans. (c) For heat pump $(COP)_{HP} = \frac{Q_1}{W} = \frac{T_1}{T_1 - T_2} = \frac{300}{300 - 250}$ or $Q_1 = 6 \times W = 6$ kW

IES-2. A heat pump is used to heat a house in the winter and then reversed to cool the house in the summer. The inside temperature of the house is to be maintained at 20°C. The heat transfer through the house walls is 7·9 kJ/s and the outside temperature in winter is 5°C. What is the minimum power (approximate) required driving the heat pump? [IES-2006]

(a) 40·5 W (b) 405 W (c) 42·5 W (d) 425 W

IES-2. Ans. (b) $(COP)_{HP} = \frac{Q_1}{W} = \frac{T_1}{T_1 - T_2} = \frac{293}{15}$ or $W = \frac{7.9 \times 15}{293}$ kW = 405 W

IES-3. A refrigerator based on reversed Carnot cycle works between two such temperatures that the ratio between the low and high temperature is 0.8. If a heat pump is operated between same temperature range, then what would be its COP? [IES-2005]

(a) 2 (b) 3 (c) 4 (d) 5

IES-3. Ans. (d) $\frac{T_2}{T_1} = 0.8$ or $(COP)_{H.P} = \frac{T_1}{T_1 - T_2} = 5$

- **A refrigerator working on a reversed Carnot cycle has a C.O.P. of 4. If it works 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

[IES-2003]

Ans. (c) $(COP)_{Heat\ pump} = (COP)_{refrigerator} + 1 = 4 + 1 = 5$

or

$(COP)_{Heat\ pump} = Q_1/W$ = Heat effect / Work Input

Heating effect , $Q_1 = W \times (COP)_{Heat\ Pump} = 5kW$

The coefficient of performance (COP) of a refrigerator working as a heat pump is given by: [IES-1992, 1994, 2000; GATE-1995]

(a) $(COP)_{heat\ pump} = (COP)_{refrigerator} + 2$

(b) $(COP)_{heat\ pump} = (COP)_{refrigerator} + 1$

(c) $(COP)_{heat\ pump} = (COP)_{refrigerator} - 1$

(d) $(COP)_{heat\ pump} = (COP)_{refrigerator}$

Ans. (b) The COP of refrigerator is one less than COP of heat pump, if same refrigerator starts working as heat pump i.e. $(COP)_{heat\ pump} = (COP)_{refrigerator} + 1$

-9. A heat pump operating on Carnot cycle pumps heat from a reservoir at 300 K to a reservoir at 600 K. The coefficient of performance is: [IES-1999]

(a) 1.5 (b) 0.5 (c) 2 (d) 1

-9. **Ans. (c)** COP of heat pump $= \dfrac{T_1}{T_1 - T_2} = \dfrac{600}{600 - 300} = 2$

-10. The thermal efficiency of a Carnot heat engine is 30%. If the engine is reversed in operation to work as a heat pump with operating conditions unchanged, then what will be the COP for heat pump? [IES-2009]

(a) 0.30 (b) 2.33 (c) 3.33 (d) Cannot be calculated

-10. **Ans. (c)** Thermal Efficiency $= 0.3$

$$\Rightarrow 1 - \frac{T_2}{T_1} = 0.3 \qquad \Rightarrow \frac{T_2}{T_1} = 0.7$$

$$\text{COP of heat pump} = \frac{T_1}{T_1 - T_2} = \frac{1}{1 - 0.7} = \frac{1}{0.3} = 3.33$$

(or)

C.O.P $= T_1/(T_1-T_2) = T_1/(T_1-0.7T_1)$

$= T_1/T_1(1-0.7) = 3.33$