Unit No: 2
Introduction to Thermal Engineering

Objective: To explain the basic concept of engineering thermodynamics and its applications.

Outcome: student will be able to explain basic laws of thermodynamics and their applications.

~~Introduction:-~~

Thermal Engineering: Thermal engineering is the specialized sub-discipline of mechanical engineering that deals with the movement of heat energy and transfer. The energy can be transformed between two mediums or transferred in to other forms of energy.

Thermodynamics:

Thermodynamics is the branch of science which deals with relation between heat and work.

The concept of thermodynamics is used in industrial as well as domestic applications. In domestic applications it is used in refrigerators, air-conditioning systems, ovens, pressure cooker, etc. whereas in industrial applications it is used in I.C. engines, jet engines, power plants, etc.

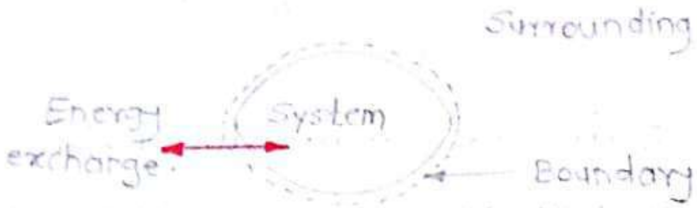
The behaviour of heat and work is governed by the laws of thermodynamics. Thermodynamics is basically concerned with four laws known as zeroth law, first law, second law, and thired law of thermodynamics.

Thermodynamics System, Surrounding and Boundary:

System: It is defined as a region in space or a quantity of matter upon which perticular attention is concentrated for the study of work and heat transfer and their conversions.

or

It is defined as a fixed mass in region of space under consideration to analyse a problem.



Surrounding : Everything external to the system is called as surrounding.

Boundary : Boundary is a real or imaginary boarder between the system and surrounding. Boundary separates the system and surrounding. Across the boundary, the energy (heat and work) and mass transfer takes place.

→ Based on mass and energy transfer between system and surrounding system can be classified as,

a) Closed system

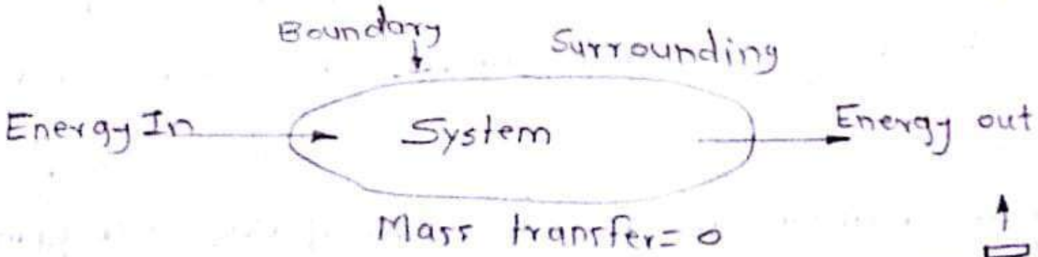
b) Open system

c) Isolated system.

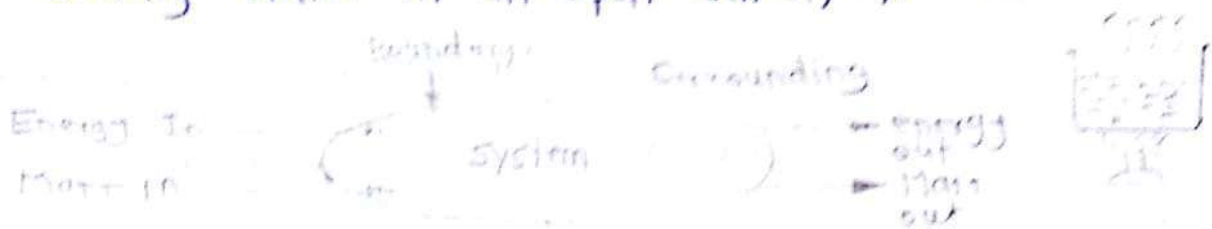
a) Closed System :

A system which allows energy transfer but does not allow mass transfer is called closed system.

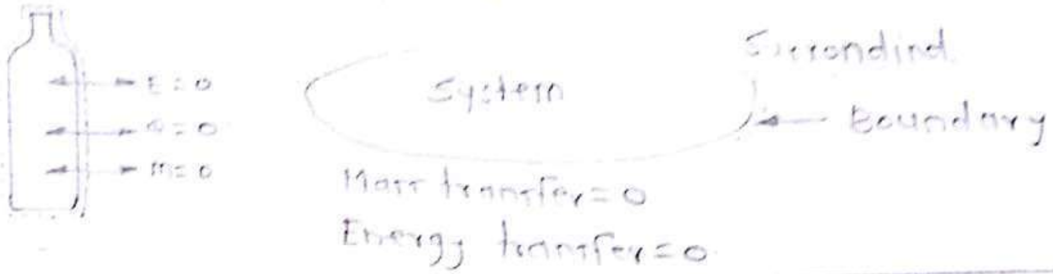
e.g. Pressure cooker, piston cylinder arrangement,



b) Open System: A system which allows mass as well as energy transfer is called as open system.
e.g. Boiling water in an open vessel, ~~or~~ turbine, etc.



c) ~~Closed~~ Isolated System: A system which neither allows mass transfer nor energy transfer is called as an isolated system.
e.g. Thermos flask. (Perfectly insulated container).



Heat: It is defined as the transfer of thermal energy between two system or between system and surrounding.

Work: Work is defined as the transfer of mechanical energy between two systems. or between system and surrounding.

Sign Convention:

Heat transfer to the system from surrounding is considered as positive and heat transfer from system to surrounding is considered as negative.

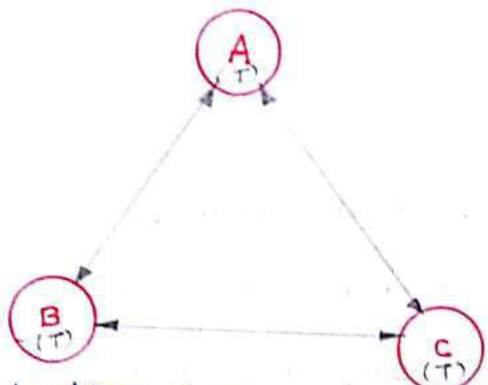
Work is done by the system on the surrounding is taken as positive and the work done by the surrounding on the system is taken as negative.

Laws of Thermodynamics :

Temperature is associated with the ability to disthtinguish hot from cold. when two bodies of different temp. are brought into contact, after some time, they attain a common temp. and are said to exist in thermal equilibrium.

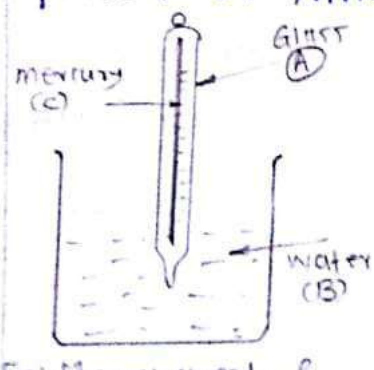
Statement : Zeroth Law of Thermodynamics :

" It states that, if two systems are in Thermal equilibrium with a third system, then they are in thermal equilibrium. with each other."



Consider three bodies A, B and C which are at diff. temp.

- If A & B are brought in contact with each other & they constitute thermal equilibrium. Later,
- If A & C are brought in contact with each other & they constitute thermal equilibrium.
- If A is in thermal equilibrium with both B & C after period of time, B & C will also be in equilibrium.



Ex: Measurement of water temp by Thermometer

If we want to measure temp of water by using thermometer, glass of thermometer will act like body (A), water (B) & mercury (c).

First Law of Thermodynamics:

J.P. Jule conducted several experiments and formulated the first law of thermodynamics.

Statements:

a) "Heat and work are mutually convertible but since energy can neither be created nor destroyed, the total energy associated with an energy conversion remains constant".

or

"When a system undergoes a thermodynamic cycle then the net heat supplied to the system from the surrounding is equal to the network done by the system on it's surrounding."

$$\oint dQ = \oint dW.$$

There is no machine which is capable of producing work without expenditure of energy.

Law of conservation of energy states that "The energy can neither be created nor be destroyed, it can be converted from one form to another and total energy in universe remains constant.

e.g. When stone is thrown from certain height with zero velocity initially, the potential energy of stone is converted into it's kinetic energy.

e.g. When brakes are applied to a moving vehicle, then due to friction the K.E. of vehicle is converted into heat energy betn road & tyres.

Basic Defination:

To understand the 2nd law of thermodynamics following basic definations should be clear:

1) Heat reservoir: A reservoir is defined as the source of infinite heat energy.

A finite amount of heat absorbed or rejected from the heat reservoir will not affect it's temp. i.e. temp of reservoir is constant.

Ex:— Atmosphere, Large bodies of water such as ocean, lakes or rivers

2) Heat Source: A reservoir that supplies energy in the form of heat to a system is called as heat source.

3) Heat Sink: A reservoir that absorbs energy in the form of heat from a system is called as heat sink.

Second Law of Thermodynamics:

Second law of thermodynamics comprises two statements

① Kelvin Planck statement ② Clausius statement.

* Kelvin Plank statement:

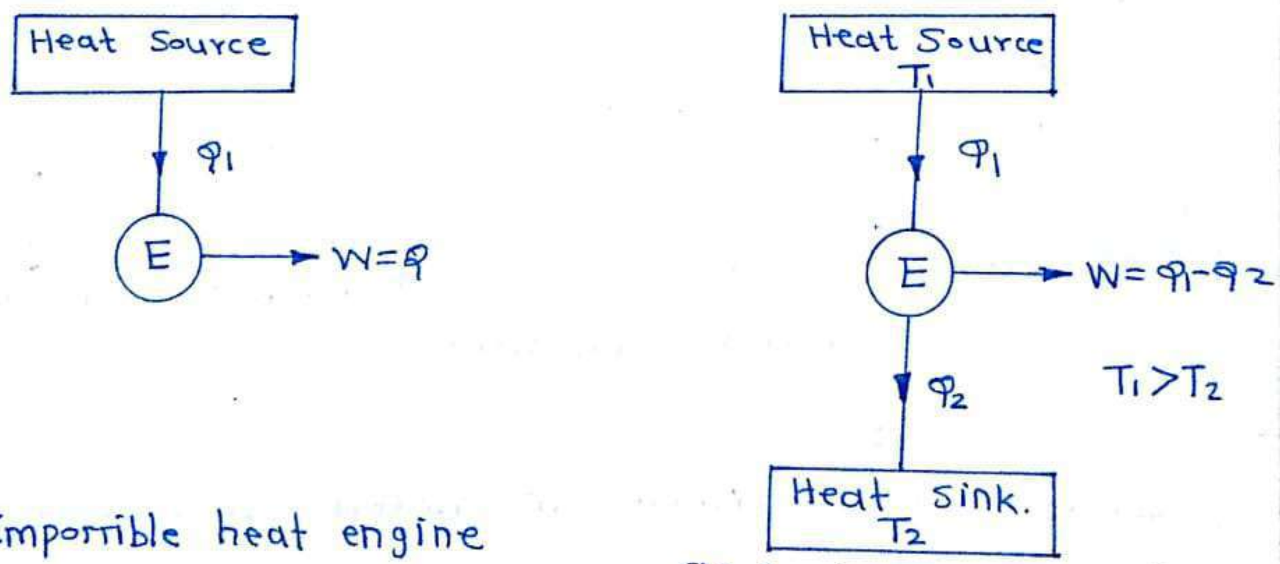
It states that, "it is impossible to construct an engine working in a cyclic process whose sole effect is the conversion of all the heat energy supplied to it into an equivalent amount of work."

<u>or</u>

"It is impossible to construct 100 % efficient heat engine.".

<u>or</u>

"No system, whose working fluid undergoes a cycle, can receive heat from a single source & produce work without rejecting heat to a lower temp sink."



a) Impossible heat engine as per Kelvin-Planck statement.

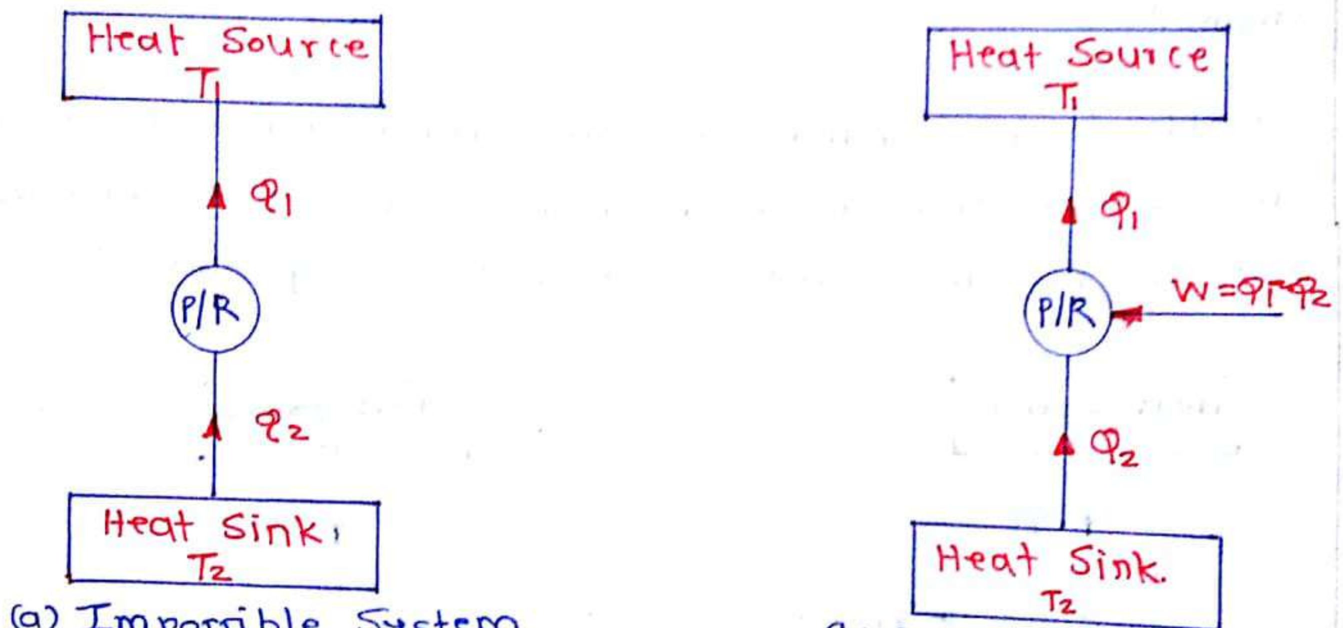
(b) Possible Heat engine as per kelvin plank statement.

Fig. Kelvin Planck statement.

* Clausius Statement:

It states that "It is impossible to construct a heat pump working in a cyclic process whose sole effect is the transfer of energy in the form of heat from a body at low temperature to a body at high temperature."

It means, energy in the form of work must be added or supplied to heat pump for tranferring the heat from cold body to hot body.



(a) Impossible System (b) Possible system.

Fig. Clausius Statement.

* Heat Engine:

It is a device which is working in a cycle converts energy, received in the form of heat into work.

Ex:- steam engine, steam turbine, petrol & diesel engine

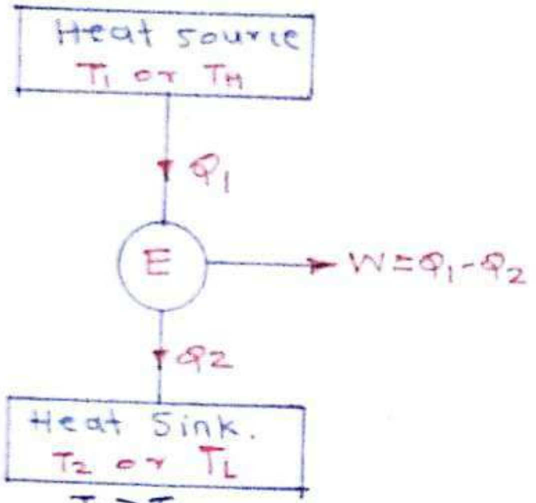


Fig: Heat Engine.

It receives heat Q_1 from heat source at T_1 or T_H, produces the mechanical work, W and the remaining energy is rejected to heat sink at T_2 or T_L ($T_H > T_L$).

According to First law of thermodynamics,

$$W = Q_1 - Q_2$$

Thermal efficiency(η) of Heat engine is equal to ratio of output work to input heat energy.

The thermal efficiency can be expressed as;

$$\eta = \frac{\text{Work output}}{\text{Energy Input}}$$

$$\eta = \frac{W}{Q_1}$$

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

$\therefore \eta = 1 - \frac{Q_2}{Q_1}$ or $\eta = 1 - \frac{T_2}{T_1}$ if T is in °K ~~sink~~

Now, as $\frac{Q_2}{Q_1} > 0$, $\eta < 1$.

Since Q_2 is lesser than Q_1 the efficiency of Heat engine is lesser than the unity (one).

* Heat Pump :

Heat pump is a device, which is working in a cycle, maintaining temp. of the system higher than temp. of surrounding.

Heat pump is a device operating on a cycle which removes heat from a body at low temp. and rejects it to a body at high temp. on the expense of external work supplied. such device is called a heat pump.

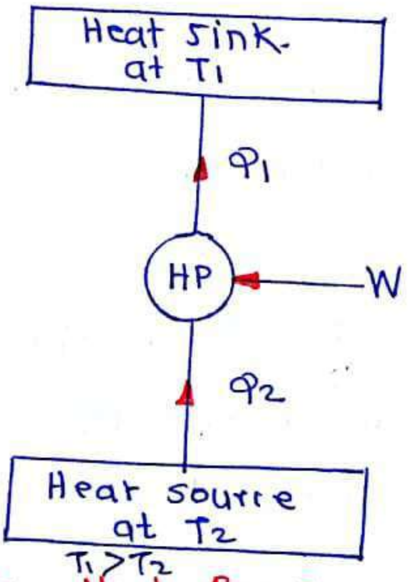


Fig: Heat Pump.

During cold weather, the energy from the atmosphere at lower temp is supplied to the heated at a higher temp. with the help of heat pump.

The performance of this system is calculated in terms of C.O.P (coefficient of performance) which is defined as,

$$(C.O.P)_p = \frac{\text{Heat Supplied}}{\text{Work input}}$$

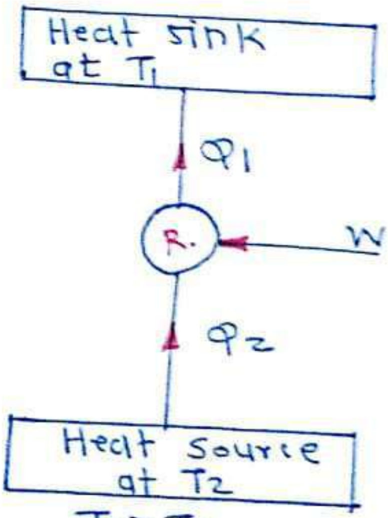
$$\therefore (C.O.P)_P = \frac{Q_1}{W}$$

$$(C.O.P)_P = \frac{Q_1}{Q_1 - Q_2} = \frac{T_1}{T_1 - T_2} \qquad (\because T_1 > T_2) \qquad \text{——— (1)}$$

Refrigerator : Refrigerator is a device which is working in a cycle, maintains a temp of system lower than the temp of surrounding.

or

Refrigerator is a device operating on a cycle which removes the heat from a body at low temp 'T_2' (heat source) and rejects it to a body at higher temp 'T_1' (heat sink) on the expence of external work supplied.



$T_1 > T_2$

fig: Refrigerator.

The performance of this system is calculated in terms of C.O.P. which is given as follows.

$$(C.O.P)_R = \frac{\text{Heat removed}}{\text{Work input}}$$

$$(C.O.P)_R = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2} \qquad \text{——— (2)}$$

from eqn (1) & (2)

$$(C.O.P)_P - (C.O.P)_R = 1$$

$$\therefore (C.O.P)_P = 1 + (C.O.P)_R \qquad \text{——— (3)}$$

From equation (3), it is clear that (C.O.P) of Heat pump, is always greater than unity by $(C.O.P)_R$. for operating between same temperature limits.

* Numericals on Heat Engine: Heat Pump, & Refrigerator:

1) A reversible engine with 40% efficiency discharges 1520 KJ of heat per minute at 27 °c to a pond. Find; the temperature of source which supplies the heat to engine & power developed by the engine.

→ Given:

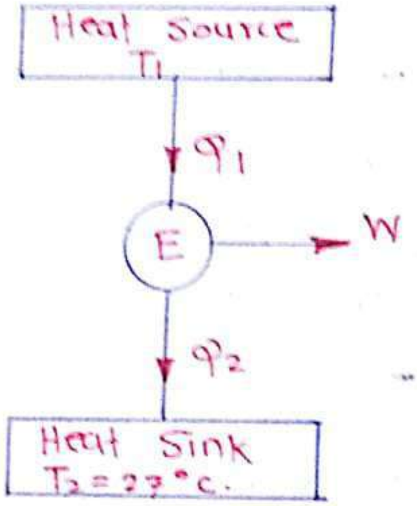
$T_2 = 27^\circ c = 27 + 273 = 300^\circ K.$

$q_2 = 1520$ kJ

$\eta = 40\%.$

$T_1 = ?$

Power = ?



→ $\eta = \dfrac{T_1 - T_2}{T_1}$

$\therefore 0.4 = \dfrac{T_1 - 300}{T_1}$ $\quad\therefore 0.4 T_1 = T_1 - 300$

$\therefore 0.6 T_1 = 300$

$\therefore \boxed{T_1 = 500 K}$

→ $\eta = \dfrac{W}{q_1}$

$\therefore \eta = \dfrac{W}{q_2 + W}$ $\quad$ (as $W = q_1 - q_2$)

$\therefore 0.4 = \dfrac{W}{1520 + W}$

$\therefore W = 0.4 W + 608$

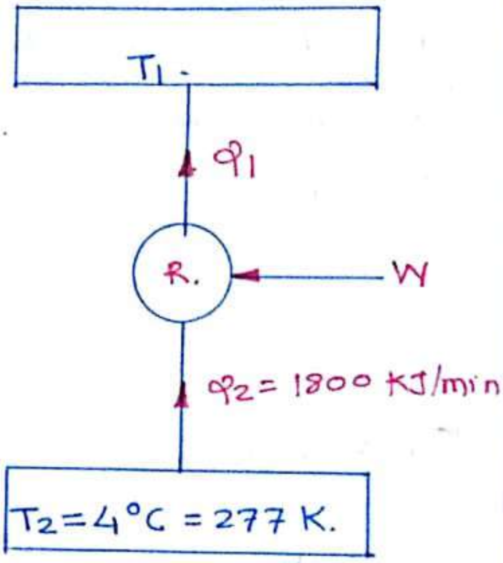
$\therefore 0.6 W = 608$

$\therefore W = 1013.3$ KJ/min

$\therefore \boxed{\text{Power} = \dfrac{1013.3}{60} = 16.9 \text{ KW.}}$

2) A refrigeration system is used to maintain a cold storage at 4°c. The heat leakage from surrounding into the cold storage is estimated to be 1800 KJ/min. IF C.O.P of the refrigeration system is 1.5. Find.
i) The amount of heat rejected to the surrounding. &
ii) The power required to drive the refrigeration System.

→ Given:



$T_2 = 4°C = 277\,°K.$

$q = 1800$ KJ/min

$COP = 1.5$

→ i) Amount of heat rejected to surroundings (Q_1) =

$$\therefore \quad C.O.P. = \frac{q_2}{W}$$

$$\therefore W = \frac{q_2}{COP} = \frac{1800}{1.5} = 1200 \text{ kJ/min.}$$

From 1^{st} law,

$$q_1 = q_2 + W$$

$$= 1800 + 1200$$

$$\boxed{q_1 = 3000 \text{ KJ/min}}$$

ii) Power required to drive the system (P)

$$P = \frac{W}{t} = \frac{1200}{60} \text{ K.J/sec.}$$

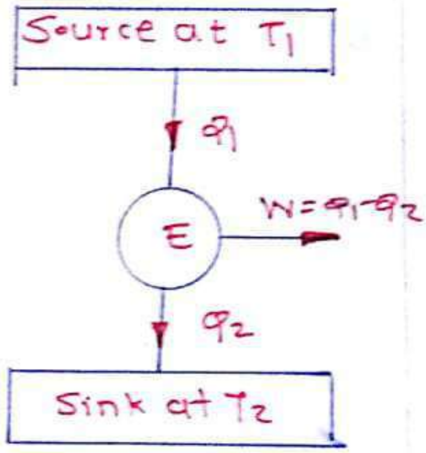
$$\therefore \boxed{P = 2 \text{ KW.}}$$

3) An Engine develops 80 KW of work output when heat is supplied at the rate of 240 KW. Find the efficiency of the engine and heat rejected to atmosphere. Draw the sketch of the system.

→ Given:

$W = 80\ KW = Q_1 - Q_2$

$Q_1 = 240\ KW.$, $\eta = ?$, $Q_2 = ?$



i) Efficiency of engine (η) :

$$\eta = \frac{\text{Work output}}{\text{Heat supplied}}$$

$$\eta = W/Q_1$$

$$\eta = \frac{80}{240} = 0.3333$$

$$\therefore \boxed{\eta = 33.33\ \%}$$

ii) Heat rejected to atmosphere or sink (Q_2) :

As $W = Q_1 - Q_2$

$$\therefore Q_2 = Q_1 - W$$

$$= 240 - 80$$

$$\therefore \boxed{Q_2 = 160\ KW.}$$

4) A heat engine operates between source & sink temperature of 235°C and 30°C respectively. If heat engine receives 35 KW from source. find (i) the net workdone by the engine. (ii) The heat rejected to the sink by the engine & (iii) The efficiency of engine.

→ Given:

$T_1 = 235\,°C = 235 + 273 = 508\ K$

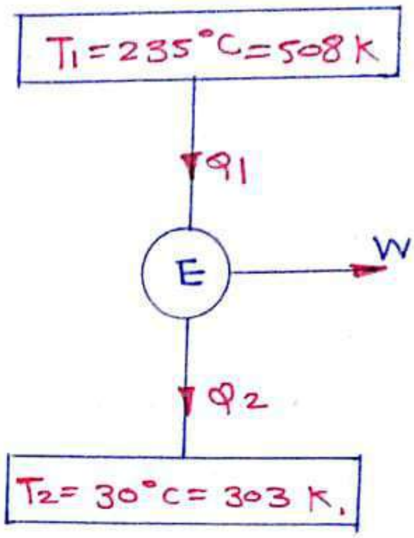
$T_2 = 30\,°C = 30 + 273 = 303\ K$

$Q_1 = 35\ KW$

$\eta = ?$

$W = ?$

$Q_2 = ?$



→ (i) Efficieny of engine: (η)

$$\eta = 1 - \frac{T_2}{T_1}$$

$$= 1 - \frac{303}{508}$$

$$= 0.40354$$

$$\therefore \boxed{\eta = 40.35\ \%}$$

ii) Net workdone (W):

$$\eta = \frac{\text{Work output}}{\text{Heat input}}$$

$$\eta = \frac{W}{Q_1}$$

$$\therefore W = \eta \times Q_1$$

$$= 0.40354 \times 35$$

$$\therefore \boxed{W = 14.124\ KW}$$

iii) Heat rejected to sink (Q_2):

$$\therefore Q_2 = Q_1 - W$$

$$= 35 - 14.124$$

$$\therefore \boxed{Q_2 = 20.876\ KW.}$$

5) A refrigerator with C.O.P of 1.5 absorbs heat from food compartment at the rate of 360 KJ/min. Draw the sketch of system & find.

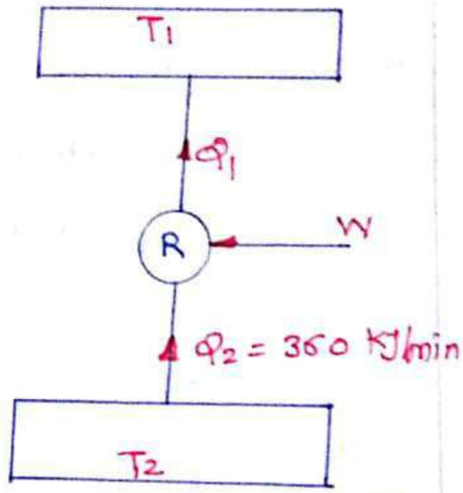
i) The power consumed by the refrigerator and

ii) The amount of heat rejected to surrounding.

→ Given: COP = 1.5

$q_2 = 360$ KJ/min

$q_2 = \frac{360}{60} = 6$ KJ/sec



→ i) Power consumed by refrigerator (W)

$\therefore COP = \frac{q_2}{W}$

$\therefore 1.5 = \frac{6}{W}$

$\therefore \boxed{W = 4 \text{ KJ/s}}$

ii) Heat rejected to surroundings (q_1)

From 1st law

$W = q_1 - q_2$

$\therefore q_1 = W + q_2$

$= 4 + 6$

$\therefore \boxed{Q_1 = 10 \text{ KW.}}$

x

6) A household refrigerator with C.O.P of 1.8 removes heat from the refrigerated space at the rate of 90 kJ/min. Determine, (i) Electrical power consumed by refrigerator and the rate of heat transfer to kitchen air.

→ Given:

COP = 1.8, $q_2 = 90$ KJ/min $= \frac{90}{60} = 1.5$ KJ/sec.

→ (i) Power consumed.

$\therefore COP = \frac{q_2}{W}$ $\therefore W = \frac{q_2}{COP} = \frac{1.5}{1.8}$

$\therefore \boxed{W = 0.833 \text{ KW}}$

(ii) Rate of heat transfer to kitchen (Q_1):

$\therefore Q_1 = Q_2 + W$

$= 1.5 + 0.833$

$\therefore \boxed{Q_1 = 2.333 \text{ KW.}}$

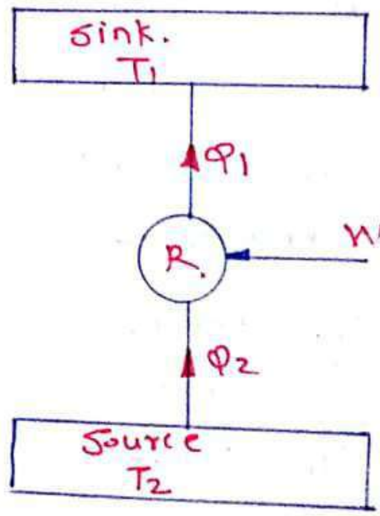
7) A carnot refrigerator consumes 2KW of power in summer when the surrounding temp is 40°c. and temp. of refrigerating is 10°c. It is estimated that 0.2 KW. per degree change in temp difference between atmospheric temp. and refrigerator temp. of energy leaks into refrigerator. Find the refrigerating effect needed as cop of refrigerator. In case the system works as heat pump find it's cop.

Given:

Surrounding temp. $t_1 = 40°c$

Refrigeration temp, $t_2 = 10°c$

$W = 2 \text{ KW.}$



i) Refrigerating effect (Q_2):

$Q_2 = 0.2 \times (t_1 - t_2)$

$= 0.2 \; (40 - 10)$

$Q_2 = 6 \text{ KW}$

ii) cop of refrigerator:

$\therefore \text{cop} = \frac{Q_2}{W} = \frac{6}{2}$

$\text{cop} = 3$

iii) c.o.p of heat Pump

$Q_1 = W + Q_2$

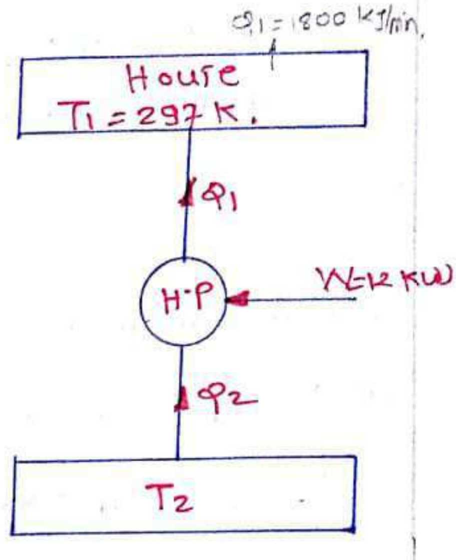
$= 2 + 6 = 8 \text{ KW.}$

$\therefore (\text{COP})_{HP} = \frac{Q_1}{W} = \frac{8}{2} = 4.$

8) A heat pump is used to maintain the house at 24°c The house is losing the heat at the rate of 1800 KJ/min to the surrounding. If the heat ~~at the rate of 1800 kJ/min~~ is driven by an electric motor of power rating 12 KW. find.

(i) The amount of heat absorbed from surrounding. and

(ii) The cop of the heat pump.



→ Given: $Q_1 = 1800$ KJ/min

$$Q_1 = \frac{1800}{60} = 30 \text{ KJ/sec.}$$

$$T_1 = 24+273 = 297\,°K.$$

$$W = 12 \text{ KW.}$$

$$Q_2 = ?$$

$$(COP)_{HP} = ?$$

→ (i) Heat absorbed from surrounding (Q_2)

$$W = Q_1 - Q_2$$

$$12 = 30 - Q_2$$

$$\therefore \boxed{Q_2 = 18 \text{ KW.}}$$

(ii) COP of heat pump:

$$(COP)_{HP} = \frac{Q_1}{W} = \frac{30}{12} = 2.5$$

$$\boxed{\therefore (COP)_{H.P} = 2.5}$$

9) A reversible heat engine develops 30 KW of workoutput with efficiency of 30%. Find the heat supplied to the engine and heat rejected from the engine. If the engine is reversed to act as refrigerator with same rate of energy transfer, Find the COP.

Given : $W = 30 \text{ KW}$,

$\eta = 30\% = 0.3$

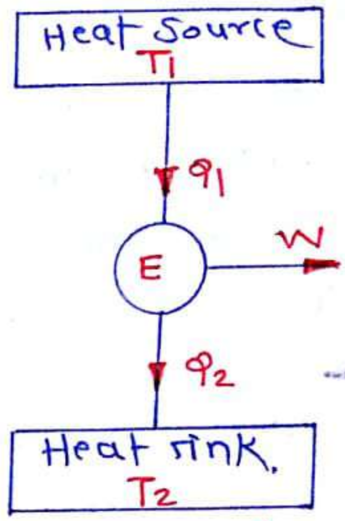


Fig. Heat Engine.

i) Heat supplied and heat rejected

$$\eta = \frac{\text{Work output}}{\text{Heat supplied}} = \frac{W}{q_1}$$

$$\therefore 0.3 = \frac{30}{q_1}$$

$\therefore$ Heat supplied, $q_1 = \frac{30}{0.3} = 100 \text{ KW}$.

Now, $W = q_1 - q_2$

$\therefore q_2 = q_1 - W$

$\therefore$ Heat rejected,

$q_2 = q_1 - W$

$q_2 = 100 - 30$

$\therefore \boxed{q_2 = 70 \text{ KW.}}$

ii) COP of refrigerator :

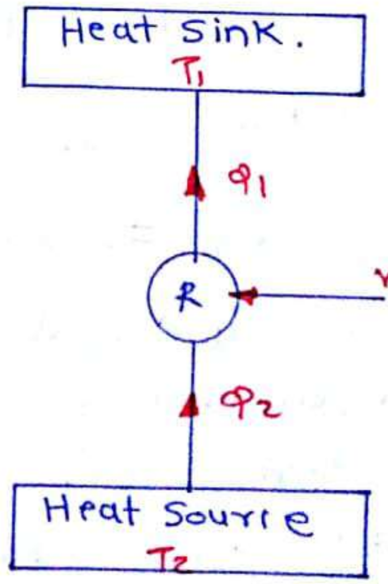
$$(COP)_R = \frac{\text{Desired effect}}{\text{Work input}}$$

$$= \frac{q_2}{W}$$

$$= \frac{70}{30}$$

$$= 2.33.$$

$\therefore \boxed{(COP)_R = 2.33}$



10) The COP of a refrigerator operating on reversed carnot cycle is 5.4, when it maintains -5°c in the evaporator. Determine the condenser temp. & refrigerating effect, if the power required to run the refrigerator is 3.2 KW.

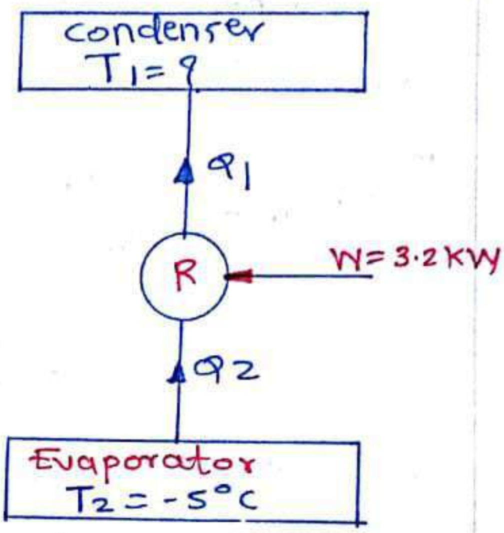
→

Given: COP = 5.4.

Evaporator temp = T_2 = -5 °c.

condenser temp = T_1 = ?

Refrigerating effect = ?



→

$$(COP)_R = \frac{q_2}{W} = 5.4$$

$$\therefore q_2 = 5.4 \times 3.2$$

$$\therefore q_2 = 17.3 \text{ KW.}$$

$$(C.O.P)_R = \frac{T_2}{T_1 - T_2} = \frac{-5+273}{T-(-5+273)}$$

$$\therefore 5.4 = \frac{268}{T_1+5}$$

$$\therefore 268 = 5.4 T_1 + 27.$$

$$\therefore T_1 = 44.62° = 317.63°K = \text{condenser temp.}$$

11) A reversible heat pump is used for heating a building in the winter season. The heat is absorbed from the earth by a fluid circulating in pipes & delivers to the building to maintain the temp. of 23° c. Determine the amount of heat supplied to the building if one KW-hr of electrical energy is needed to operate the heat pump. The soil temp may be taken as 0°c.

→ Given:

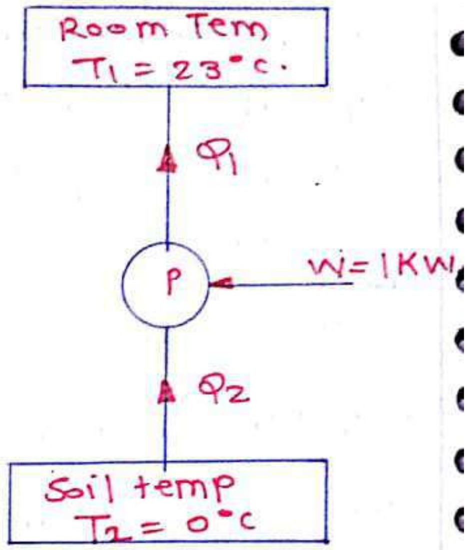
$T_1 = 23°C = 23+273 = 296°K.$

$T_2 = 0°C = 273 K$

$W = 1$ KW hr.

$= 1 (KJ/s) \times 3600$ sec

$W = 3600$ KJ



→ $(COP)_{HP} = \frac{Q_1}{Q_1 - Q_2} = \frac{T_1}{T_1 - T_2}$

$= \frac{296}{296-273}$

$\boxed{(COP)_{HP} = 12.86}$

$\therefore (COP)_{H.P} = \frac{Q_1}{W}$

$\therefore 12.86 = \frac{Q_1}{3600}$

$\therefore \boxed{Q_1 = 46296 \text{ KJ.}}$

—×—

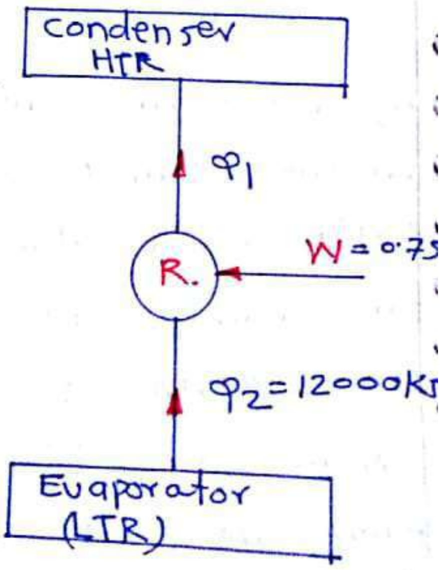
12) Find the coefficient of performance & heat transfer rate in the condenser of a refrigerator in KJ/h, which has a refrigeration capacity of 12000 KJ/hr when power input is 0.75 KW.

→ Given: Refrigeration capacity $Q_2 = 12000$ KJ/hr

power input $= W = 0.75$ KW.

$= 0.75 \times 3600$ KJ/hr

$\therefore W = 2700$ KJ/hr



$(COP)_R = \frac{Q_2}{W} = \frac{12000}{2700} = 4.44$

$\therefore \boxed{(COP)_R = 4.44}$

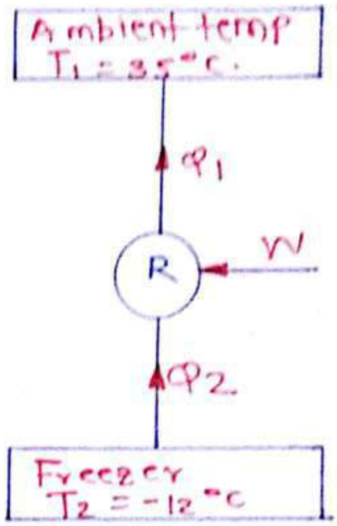
Heat transfer in condenser

$W = Q_1 - Q_2 \quad \therefore Q_1 = W + Q_2$

$\therefore \boxed{Q_1 = 14700 \text{ KJ/hr}}$

13) A domestic food refrigerator maintains a temp of −12°c. The ambient air temp is 35°c. If heat Leaks into the freezer at the continuous rate of 2 KJ/sec, Determine the least power necessary to pump this heat out continuously.

Given:



$T_2 = -12 + 273 = 261°K$

$T_1 = 35 + 273 = 308°K$.

Rate of heat leakage in to the Freezer $= 2$ KJ/sec

∴ We have to remove that much of heat from freezer to maintain at −12°c.

For minimum power requirement or for reversible heat pump or Refrigeration system.

$$\frac{Q_2}{T_2} = \frac{Q_1}{T_1}$$

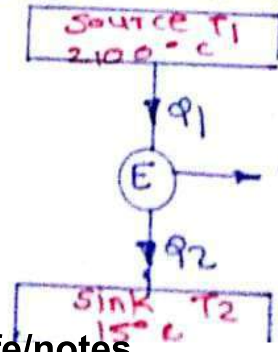
$$\therefore \frac{2}{261} = \frac{Q_1}{308} \qquad \therefore \boxed{Q_1 = 2.36 \text{ KJ/sec}}$$

But : $W = Q_1 - Q_2$

$\therefore W = 2.36 - 2$

$\therefore \boxed{W = 0.36}$

14) What is the highest possible theoretical efficiency of a heat engine operating with a hot reservoir of furnance gases at 2100°c. when the cooling water available at 15°c :

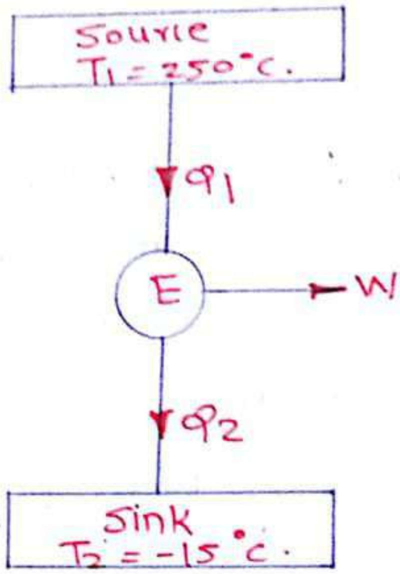


Efficiency of engine : $\eta = \frac{T_1 - T_2}{T_1}$

$= \frac{2373 - 288}{2373}$

$\therefore \eta = 0.878$ $\boxed{\therefore \eta = 87.8\%}$

15) A heat engine operates on a cycle temp of heat source & heat sink is 250°C & -15°C respectively. If the system receives 90 KJ from source, find i) Efficiency of the engine, ii) Network transfer iii) Heat rejected to sink.



Given: $T_1 = 250 + 273 = 523$ K

$T_2 = -15 + 273 = 258$ K.

$q_1 = 90$ KJ.

i) $\eta_{carnot} = \frac{T_1 - T_2}{T_1}$

$= \frac{523 - 258}{523}$

$\therefore \boxed{\eta = 50.6\%}$.

ii) Net work transfer $= W =$

as, $\eta = \frac{W}{q_1}$

$\therefore W = \eta \times q_1 = 0.506 \times 90$

$\therefore \boxed{W = 45.54 \text{ KJ.}}$

iii) Heat rejected to the sink, q_2

$\therefore q_2 = q_1 - W.$

$\therefore q_2 = 90 - 45.54$

$\therefore \boxed{q_2 = 44.46 \text{ KJ}}$.

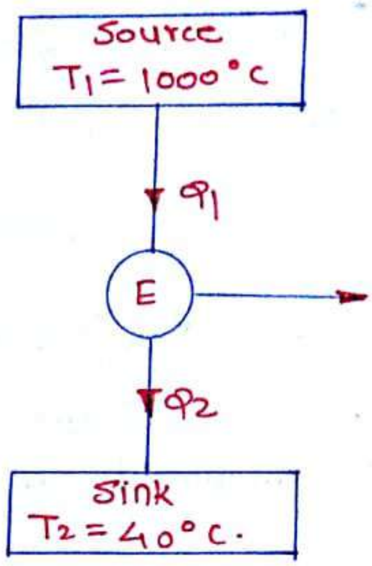
16) A cyclic heat engine operates between a source temp of 1000°C & a sink temp of 40°C. Find the list rate of heat rejection per kW net output of the heat engine.

16 →

Given: $T_1 = 1000 + 273 = 1273\,°K$

$T_2 = 40 + 273 = 313\,°K$.

$Q_2 = ?$



→

$$\eta = \frac{T_1 - T_2}{T_1} = \frac{1273-313}{1273}$$

$\therefore \boxed{\eta = 0.754}$

but, $\eta = \frac{W}{Q_1} = \frac{1}{Q_1} = \underline{\underline{0.754}}$

$\therefore Q_1 = 1.326$ KW.

$\therefore Q_1 = Q_2 + W$

$\therefore Q_2 = Q_1 - W$

$\therefore Q_2 = 1.326 - 1$

$\therefore \boxed{Q_2 = 0.326 \text{ KW}}$ is the least rate of heat rejection.

—— × ——

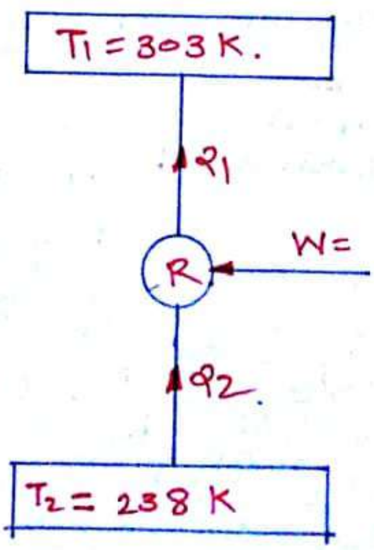
17) A fish freezing plant requires 40 tons of refrigeration. The freezing temp is $-35\,°c$, while the ambient temp is $30°c$. If the performance of the plant is 30% of the theoretical reversed carnot cycle working within the same temp. limits, calculate the power required. [1 TR = 210 KJ/min].

→ Given:

cooling required = 40 Tons

= 40 × 210

= 8400 KJ/min.



Ambient temp, $T_1 = 30 + 273$

$T_1 = 303$ K.

Freezing temp, $T_2 = -35 + 273$

$T_2 = 238$ K.

$\rightarrow (C.O.P)_R = 30\%\ (C.O.P)_{carnot}$

$$= 0.3 \times \frac{T_1}{T_1 - T_2}$$

$$= 0.3 \times \frac{303}{303 - 238}$$

$$(C.O.P)_R = 1.098$$

Now workdone needed to produce cooling of 40 tons is calculated as follows

$$(C.O.P)_R = \frac{\text{cooling required}}{\text{Work supplied.}}$$

$$1.098 = \frac{8400}{W}$$

$$\therefore W = \frac{8400}{1.098} \text{ KJ/min}$$

$$\therefore W = 7650.25 \text{ KJ/min}$$

$$\therefore \boxed{W = 127.50 \text{ KW}}. \quad \text{(Power required).}$$

18) Source '1' can supply energy at the rate of 12000 KJ/min at 320°c. A second source '2' can supply energy at the rate of 120000 KJ/min at 70°c. which source (1 or 2) would you choose to supply energy to an ideal reversible heat engine that is produce large amount of power if the temp of surrounding is 35°c.

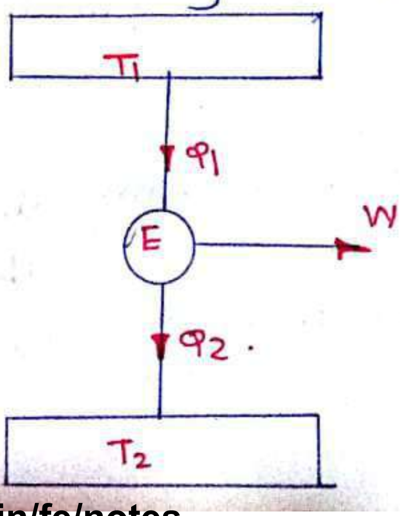
$\rightarrow$ Given:

Source '1': $Q_1 = 12000$ KJ/min

$T_1 = 320 + 273 = 593$ K

$T_2 = 35 + 273 = 308$ K

$$\therefore \eta_1 = \frac{T_1 - T_2}{T_1} = \frac{593 - 308}{593} = 48.06\%$$



$\therefore \eta_1 = \dfrac{W_1}{Q_1}$

$\therefore \eta_1 \times Q_1 = W_1$

$\therefore W_1 = 12000 \times 0.4806$

$\therefore \boxed{W_1 = 5767.2 \text{ KJ/min}}$

→

Source '2' : $Q_2 = 120000$ KJ/min

$T_1 = 70 + 273 = 343$ K.

$T_2 = 35 + 273 = 308$ K.

$\therefore \eta_2 = \dfrac{T_1 - T_2}{T_1} = \dfrac{343-308}{343} = 10.2\%$

$\therefore \eta_2 = \dfrac{W_2}{Q_2} = 0.102$

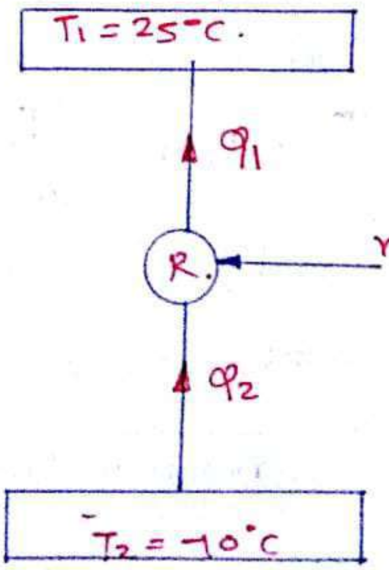
$\therefore W_2 = \eta_2 \times Q_2$

$W_2 = 0.102 \times 120000$

$\therefore \boxed{W_2 = 12240 \text{ KJ/min.}}$

By W_1 & W_2, as $W_2 > W_1$ – W_2 is selected.

19) An inventor claims to have developed a refrigeration unit which maintains $-10°c$ in the refrigerator which is kept in room where the surrounding temp. is $25°c$. & which has cop of 8.9. How do you evaluate his claim?



→

Maximum cop of refrigerator

$(COP)_R = (COP)_{\text{reversed carnot cycle}}$

$(COP)_R = \dfrac{-10+273}{25-(-10)} = \dfrac{263}{35} = 7.5.$

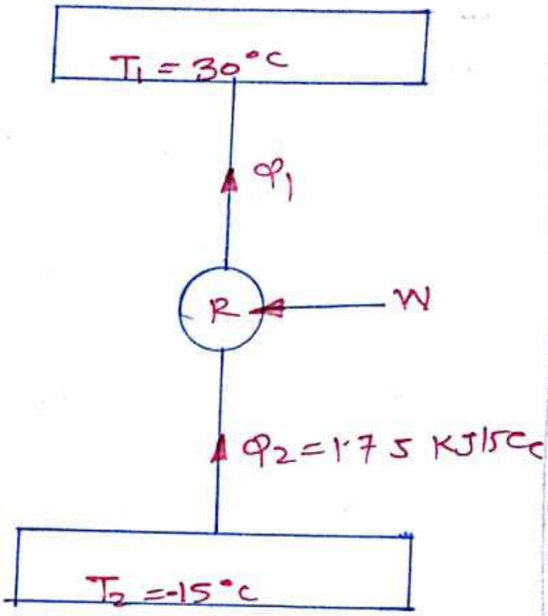
As c.o.p claimed by the inventor is 8.5 which is higher than the max^m possible for the given temp. range. so his claim is invalid.

20) A domestic food freezer maintains a temp of $-15°c$ The ambient air temp $30°c$. If the heat leaks into the freezer 1·75 KJ/sec. continuously. what is the least power necessary to pump this heat out continuously?

→ Given: $T_2 = -15°c$

$T_1 = 30°c$.

$Q_2 = 1·75$ KJ/sec.



→ $(C.O.P)_R = \frac{Q_2}{W}$ also. —— ①

$(C.O.P)_R = \frac{T_2}{T_1 - T_2}$ —— ②

∴ From eqⁿ ① & ②

$$\frac{T_2}{T_1 - T_2} = \frac{Q_2}{W}$$

$$\therefore \frac{-15+273}{30-(-15)} = \frac{1·75}{W}$$

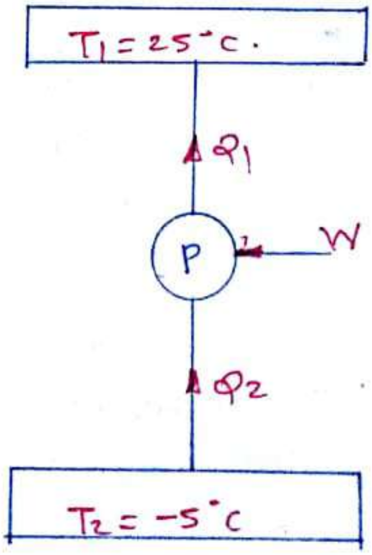
$\therefore \boxed{W = 0·305 \text{ KW}}$

—— × ——

21) A heat pump is used to maintain an auditorium hall at $25°c$ when the atmospheric temp is $-5°c$. The heat load of the hall is 2400 KJ/min. Calculate the power required to run the actual heat pump. if. cop is 25%. of the carnot heat pump.

→ Given: $T_1 = 25°c$, $T_2 = -5°c$, $Q_1 = 2400$ KJ/min

$W = ?$, $COP = 25\%$



→ $(COP)_{HP} = \frac{T_1}{T_1 - T_2} = \frac{25+273}{25-(-5)} = 9·93$

Actual C.O.P = $0·25 \times 9·93 = 2·482$.

$\therefore$ Actual (COP) $= \frac{Q_1}{W} = \frac{2400}{60} \times \frac{1}{W} = 2·482$

$\therefore \boxed{W = 16·1 \text{ KW}.}$

* Heat Transfer :

Heat : Heat is the mechanism by which energy is tranferred across a boundary between system, without transfer of mass because of the temp. difference in two systems.

The heat or energy transfer takes place from higher temp. to lower temp.

Defination of Heat transfer :→

Heat transfer is a discipline of thermal engineering that concerns the generation, use, conversion, and exchange of thermal energy between physical systems.

Heat transfer is classified into various mechanisms, such as thermal conduction, thermal convection, thermal radiation and transfer of energy by phase changes.

Modes of Heat transfer :→

When temp. difference or gradient exists, heat is always transferred in the direction of lower temp. This heat can be transferred by three modes:

1. Conduction
2. Convection
3. Radiation

1. Conduction :

Conduction is the transfer of energy from the more energetic particles of a substance to the adjucent less energetic ones as a result of interaction between the particles.

Conduction can takes place in solids, liquids or gases. In gases & liquids, conduction is due to the collision of the molecules during their random motion.

In solid, it is due to the combination of vibration of molecules in a lattice & the energy transfer by free electrons.

Ex- When a solid rod of metal is heated from one end, then it's other end will also be get hot.

Convection:

Convection is the mode of heat transfer between a solid surface and the adjacent liquid or gas that is in motion and it involves the combined effects of conduction & fluid motion.

or

Convection is the transfer of heat within a fluid by mixing of one portion of the fluid with another

Ex: When the wind is blowing, the flowing air carries heat away from our body and we feel cool.

Consider a hot tea kept on table, the air which is in direct contact with the top surface of hot tea and cup gets heated this air near the hot surface expands & become less dense and rises, that's how tea losses heat by convection.

Hence, convection is associated with transfer of heat due to flowing fluid.

Radiation:

Radiation is the energy emitted by matter in the form of electromagnetic waves, as a result of the changes in the electronic configurations of the atoms or molecules.

or

Radiation is heat transfer through space by electromagnetic waves.

Unlike conduction and convection, radiation can occur in empty space also i.e. does not require any medium to tranfer. Radiation does not rely on contact between the heat source and the heated object. Radiation heat transfer does not involve any mass transfer.

Ex. • Heat transfer from sun to earth is through radiation and • cooking food in microwave oven is through radiation also, • During winter season, we feel warm while standing infront of electric heater or fire.

* Laws of Heat Transfer:

1) Fourier's Low of conduction:

It states that rate of heat flow by conduction per unit area normal to the direction of heat flow in any direction directly proportional to the temperature gradient present in that direction.

The rate of heat conduction (Q_{cond}) through a layer of constant tickness (Δx) is proportional to the temp. diff. (ΔT) across the layer ~~&~~ the area (A) normal to the direction of transfer and inversely proportional to the tickness of the layer.

Therefore,

$$\frac{q}{A} \propto A\frac{dT}{dx}$$

or $$q \propto A\frac{dT}{dx}$$

$$\therefore \quad q = -KA\frac{dT}{dx}$$

Where,

q = Rate of heat flow (J/sec or Watt)

A = Area normal to the direction of heat flow in (m^2)

$\frac{dT}{dx}$ = Temp gradient in the diration of heat flow in (°c/m or K/m)

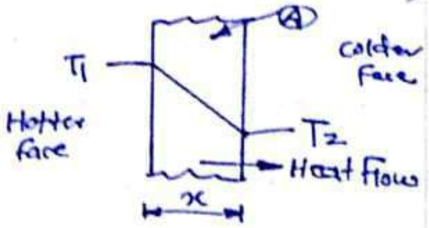
K = constant of proportionality and it is called as thermal conductivity of the material in $\left(\frac{W}{m\text{-}K}\right.$ or $\frac{W}{m\text{-}°c}$

The negative sign in the above equation indicates that, the heat always flows in the direction of lower temp. Hence temp gradient in the direction of heat flow is negative.

To understand this in better way.

Consider a slab of thickness (x), area of cross-section (A). It has one end at higher temp (T_1), and other end at lower temp (T_2).

Fourier's law can be stated as heat transfer 'q' is directly proportional to temp. difference $T_1 - T_2$ and inversely proportional to thickness 'x'.



$$q \propto \frac{A(T_1 - T_2)}{x}$$

$$\therefore \quad q = \frac{KA}{x}(T_1 - T_2).$$

Where K = Thermal conductivity. i.e. constant of proportionality.

2) Newton's Law of Cooling :

It states that the rate of heat transfer is directly proportional to surface area and the temperature difference between the surface and flowing fluid in the direction of heat flow.

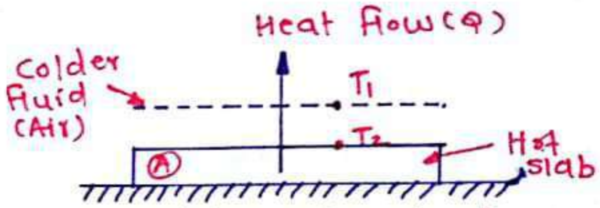


Fig. Hot slab losing heat to air.

$Q \propto A(T-T_f)$

$\therefore Q = hA(T-T_f)$

where,

Q = Rate of heat flow in J/sec or Watt

A = Surface area in m^2,

T = Temp. of the surface in °C or K.

T_f = Temp. of surrounding fluid in °C or K.

h = Constant of proportionality and it is called as convective heat transfer coefficient in $\frac{W}{m^2 \, °C}$ or $\frac{W}{m^2 K}$

"Heat transfer per unit area is called as heat flux".

Heat flux $q = \frac{Q}{A}$ (W/m^2).

3) Steafan Boltzman Law :

It states that the emissive power of a black body is directly proportional to the fourth power of it's absolute temperature.

The steafan Boltzman law is used to find the emissive power of black body.

$\therefore E_b \propto T^4$

$\therefore E_b = \sigma \cdot T^4$.

where,

E_b = Emissive power of a black body per unit area in W/m^2.

T= Absolute temp in K,

σ = Constant of proportionality and it is called as steafan Boltzmann's constant in $W/m^2\text{-}K^4$

($\sigma = 5.67 \times 10^{-8}$ $W/m^2 \cdot K^4$).

* Difference between Thermodynamics & Heat Transfer

Thermodynamics	Heat Transfer
1. It deals with the amount of heat and work during process.	1. It deals with the rate of energy transfer.
2. It tell us why process will occur.	2. It tell how process will occur.
3. It will not give information about how long it will take to reach to final state of equilibrium	3. It gives a idea of how long a heat transfer will occur.
4. It deals with time & equilibrium phenomenon	4. It deals with time & non-equilibrium phenomenon.
5. Thermodynamics use following laws - Zeroth law of Thermodynamics - First law of Thermodynamics - 2nd law of Thermodynamics	5. Heat transfer use following laws - Fourier's law - Newtons law of cooling - stefan Boltzman law
6. It tell us, How much heat is transferred (δQ)	6. It tell us, how (with which mode) δQ is transferred.
7. It tell us, How much work is done (δW)	7. It tell us, at what rate δQ is transferred.
8. It tell us, final state of the system	8. It tell us, temperature distribution inside the system.

*1) Numericals on Fourier's law of conduction:

22) The glass windows of a room has total area of $10 m^2$ and glass is 4 mm tick. Calculate the quantity of heat leaving from room through glass, when inside surface of window is at 25°c. and outside surface is at 10° c. The value of thermal conductivity for a glass is 0.84 W/mk.

→ Given: $A = 10 m^2$

$x = 4 \text{ mm} = 4 \times 10^{-3} m$

$T_1 = 25°c$

$T_2 = 10°c$

$K = 0.84 \text{ W/mk}$.

→

$$Q = \frac{KA}{x}(\Delta T)$$

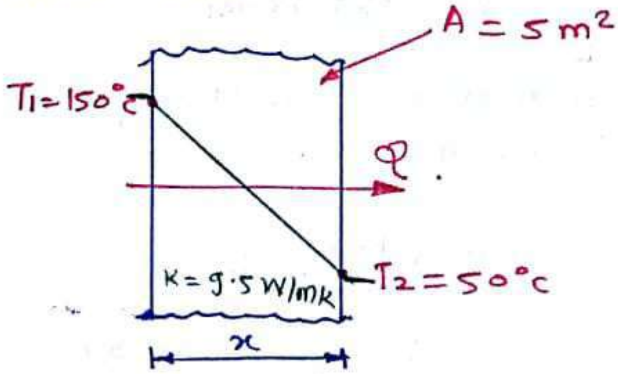
$$= \frac{KA}{x}(T_1 - T_2)$$

$$= \frac{0.84 \times 10}{4 \times 10^{-3}}(25-10)$$

$$\therefore \boxed{Q = 31.500 \times 10^3 W.}$$

23) A plane wall 15 cm thick, cross-sectional area $5 m^2$, thermal conductivity 9.5 W/mk. inner and outer surface temperature 150°c and 50°c respectively. Determine i) Heat flow rate and ii) Heat flux.

→ Given: $x = 15 cm = 0.15 m$



$A = 5 m^2$

$K = 9.5 \text{ W/mk}$

$T_1 = 150°C$

$T_2 = 50°c$.

Sol^n • Heat transfer rate (φ)

$$\varphi = \frac{KA}{x}(\Delta T)$$

$$= \frac{KA}{x}(T_1 - T_2)$$

$$= \frac{9.5 \times 5}{0.15}(150 - 50)$$

$$= 31666.667 \text{ W}$$

$$\varphi = 31.666 \text{ KW.}$$

• Heat flux (q)

$$q = \frac{\varphi}{A}$$

$$= \frac{31666.667}{5}$$

$$= 6333.33 \text{ W/m}^2$$

$$\boxed{q = 6.33 \text{ KW/m}^2}$$

---

24) A copper plate of thickness 50 mm is maintained at 150°c on one side and 25°c on other side. If the thermal conductivity of copper is 350 W/mK. calculate heat transfer rate per unit area.

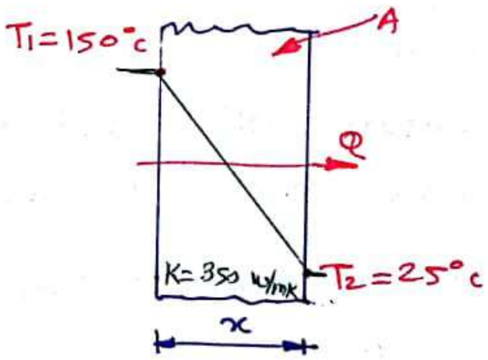
→ Given:

$x = 50 \text{ mm} = 0.05 \text{ m}$

$T_1 = 150°C$

$T_2 = 25°C$

$K = 350 \text{ W/mK.}$



Sol^n

Heat flux = Heat flow per unit area

$$\therefore q = \frac{\varphi}{A}$$

$$\therefore q = \frac{K}{x}(T_1 - T_2)$$

$$= \frac{350}{0.05}(150 - 25)$$

$$\therefore q = 875000 \frac{W}{m^2}$$

$$\therefore \boxed{q = 875 \text{ KW/m}^2}$$

---

*2) Numericals on Newton's Law of cooling :

25) Calculate rate of heat transfer by convection between roof of area $20 \times 20 m^2$ and ambient air, if roof temp. is 10°c and air temp is 40°c. Assume average heat transfer coefficient for convection as 10 W/m^2K. comment about heat flow.

→ Given:

$A = 20 \times 20 \ m^2 = 400 \ m^2$

$T = 10°c$

$T_F = 40°c$

$h = 10 \ W/m^2K.$

$Q = ?$

Soln → The rate of heat transfer from roof

From Newtons law of cooling,

$Q = hA(\Delta T)$

$= hA(T - T_F)$

$\therefore Q = 10 \times 400 \times (10 - 40)$

$\therefore \boxed{Q = -120 \times 10^{-3} \ W.}$

Negative sign indicates that, the direction of heat flow is opposite to the direction of x, It means heat flow from roof to the surrounding.

26) A wire 1.5 mm in diameter and 150 mm long is submerged in fluid. An electric current is passed through wire and is increased until the fluid reaches 100°c. Under the condition if convective heat transfer coefficient is 4500 $W/m^2°c$ Find How much electrical power must be supplied to wire to maintain wire surface at 120°c. ?

→ Given:

Wire diameter $d = 1.5 \ mm = 1.5 \times 10^{-3} \ m.$

$L = 150 \ mm = 0.15 \ m.$

Temp. of wire $T = 120°c.$

Temp. of fluid $T_F = 100^\circ C$

$h = 4500\ W/m^2{}^\circ C.$

Electrical power $\varphi = ?$

Soln →

$$\varphi = hA(T - T_F)$$

$$= h \times \pi d L \times (T - T_F)$$

$$= 4500 \times \pi \times 1.5 \times 10^{-3} \times 0.15 \times (120 - 100)$$

$$\therefore \boxed{\varphi = 63.617\ W}$$

—— × ——

27) A wall of oven at temp. 150°C is in contact with atmosphere at 25°c. If the surface area in contact with air is 2m x 2m. calculate heat flow rate. (coefficient of convection is 40 W/m²k).

Given →

Wall surface temp $T_1 = 150^\circ C$.

Atm. air temp $T_2 = 25^\circ C$.

$A = 2 \times 2 = 4 m^2$

$h = 40\ W/m^2 k.$

heat flow rate $\varphi = ?$

Soln →

By Newtons law of cooling.

$$\varphi = hA(T_1 - T_2)$$

$$= 40 \times 4 \times (150 - 25)$$

$$\therefore \varphi = 20000\ \text{Watt}$$

$$\therefore \boxed{\varphi = 20\ KW.}$$

—— × ——

*3) Numericals on steafan - Boltzman Law :

28) A 60 W incandescent lamp has coil surface temperature of 2500 K. Estimat and room temp. of 300 K. Estimate the surface area of the coil.

→ Given:

$T_1 = 2500\,K$ Assume $\sigma = 5.67 \times 10^{-8}\ W/m^2\text{-}K^4$

$T_2 = 300\,K$

$q = 60\,W$.

Soln

A = Surface area = ?

→ Calculate the surface area of the coil.

From stefan Boltzman Law,

$E = \sigma T^4$

or $\frac{q}{A} = \sigma T^4 = \sigma(T_1^4 - T_2^4)$

$\therefore \frac{60}{A} = 5.67 \times 10^{-8}[(2500)^4 - (300)^4]$

$\therefore \boxed{A = 2.7095 \times 10^{-5}\ m^2}$

—— × ——

29) Consider a black body at temperature of 1800 K. Calculate the emissive power.

→ Given:

Black body at $T = 1800\,K$.

Assume $\sigma = 5.67 \times 10^{-8}\ W/m^2K^4$

Soln

→

$E = \sigma T^4$

$= 5.67 \times 10^{-8} \times 1800^4$

$\therefore E = 595213.92\ W/m^2$

$\therefore \boxed{E = 59.52\ KW/m^2.}$

—— × ——

30) Consider a person standing in a room maintained at 22°C at all the times. The inner surface of the walls, floors, & the ceiling of the house are observed to be at an average temp. of 10°C winter & 25°C in summer. Determine the rate of radiation heat transfer between this person & the surrounding surfaces if the exposed area & the avg. outer surfaces temp. of the person are 1.4 m² & 30°C respectively (E = 0.95 for person).

→ The net rates of radiation heat transfer from the body to the surrounding walls, ceiling & floor in winter & summer are.

$$\dot{Q}_{rad, winter} = E \sigma A_s (T_s^4 - T^4_{surr(winter)})$$

$$= 0.95 \times 5.67 \times 10^{-8} \times 1.4 [(30+273)^4 - (10+273)^4]$$

$\therefore \boxed{\dot{Q}_{rad, winter} = 152 \text{ W.}}$

&

$$\dot{Q}_{rad, summer} = E \sigma A_s (T_s^4 - T^4_{surr(summer)})$$

$$= 0.95 \times 5.67 \times 10^{-8} \times 1.4 [(30+273)^4 - (25+273)^4]$$

$\therefore \boxed{\dot{Q}_{rad (sumer)} = 40.9 \text{ W.}}$

—×—

★ I. C. Engines ★

Introduction:

Any machine which derives heat energy from the combustion of fuel and convert part of this energy into mechanical work is called as heat engine.

It may be externally or internally combustion type.

- In case of external combustion engines, the combustion of fuel takes place outside the cylinder.

Ex: steam engines, steam and gas turbines, air engines, etc.

- In case of internal combustion engines combustion of fuel in the presence of air takes place inside the cylinder and produced gases act on piston to develop the power.

Ex. Petrol engines, diesel engines, etc.

- I.C. engines are classified as:

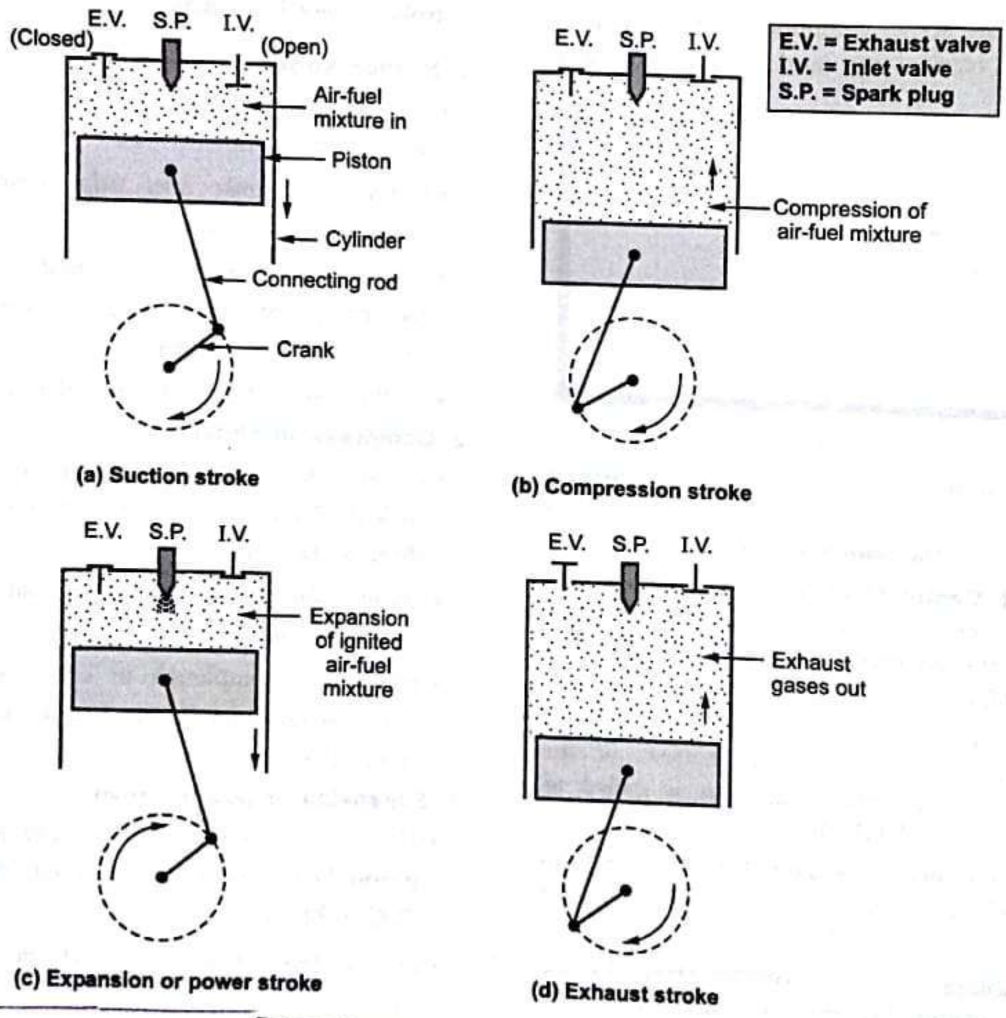
1. According to the cycle of operation
   a) Four stroke engines:
   b) Two stroke engines:
2. According to fuel used:
   a) Petrol engines
   b) Diesel engines
   c) Gas engines
3. According to method of ignition
   a) Spark ignition (S.I) engines
   b) Compression ignition (C.I.) engines.

* Four stroke (S.I) Petrol Engines:

Principle: The principle used in four stroke petrol engine is commonly known as otto cycle. It states that there would be one power stroke for every four strokes.

<u>or</u>

The four stroke S.I. engine works on the principle getting of one power stroke on two revolution of the crankshaft and considered as completion of one cycle.



(a) Suction stroke

(b) Compression stroke

(c) Expansion or power stroke

(d) Exhaust stroke

Suction stroke:

This stroke starts when the piston is at TDC and about to move downwards. During this stroke inlet valve remains open and exhaust valve remains closed. and air fuel mixture is drawn into cylinder and at the end of this stroke inlet valve closes.

Compression stroke:

During this stroke, the compression of fresh sucked charge takes place by the return stroke (BDC to TDC) of piston. During this stroke, both inlet and exhaust valve remains closed. Just before completion of compression stroke a charge is ignited by a spark plug and combustion takes place.

Power or Expansion stroke:

The products of combustion exerts pressure on the piston hence forcing it to move downward i.e. TDC to BDC During this stroke, both inlet and exhaust valve remains closed.

Exhaust stroke:

During this stroke piston moves from BDC to TDC & burnt gases inside the cylinder are exhausted.
At the end of power stroke the exhaust valve opens but inlet valve remains closed.

- In this way, again the inlet valve opens and the new cycle starts.

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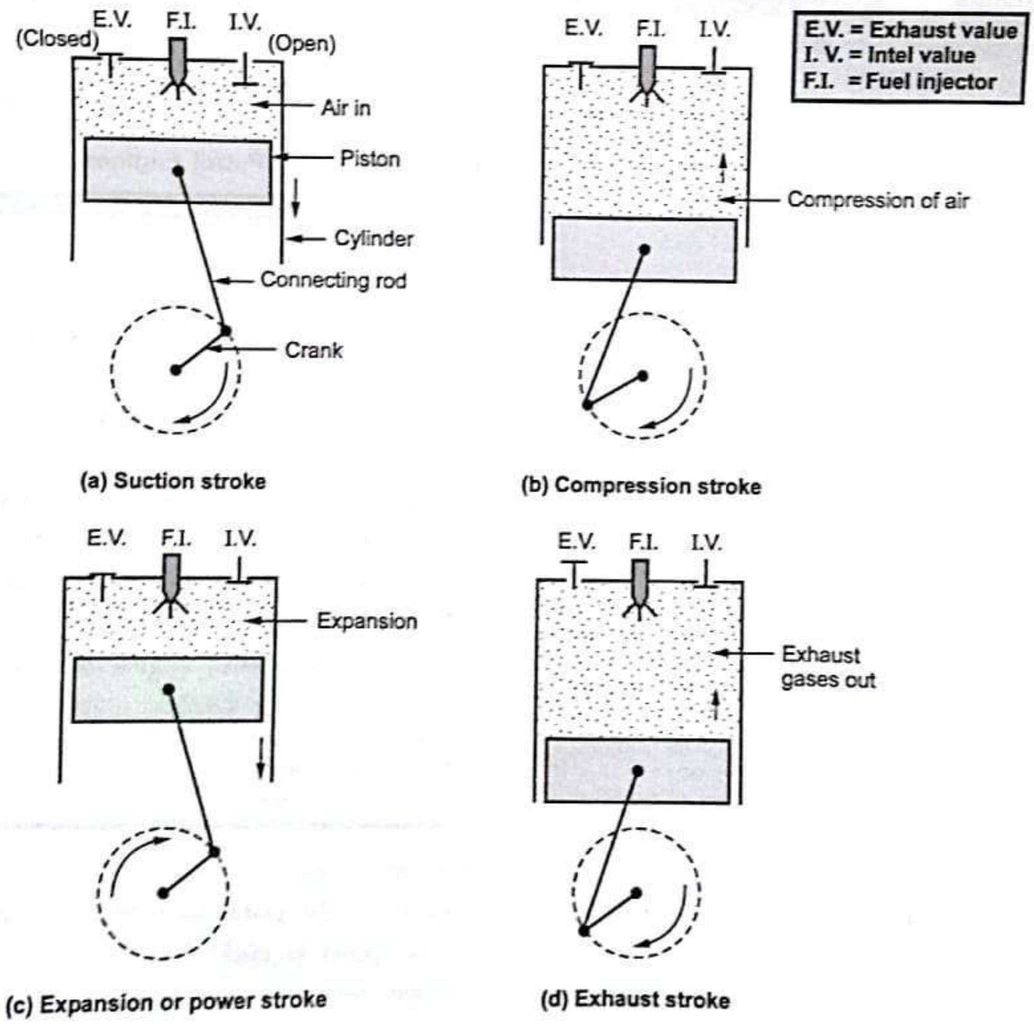
* Four stroke Diesel Engine (C.I. Engine):

Principle: The working principle used in Diesel engine is commonly known as Diesel cycle. i.e. Fuel is added to combustion chamber, then it is compressed which results in ignition.

or

The four stroke C.I. engine works on the principle getting of one power stroke on two revolution of the crankshaft completes one cycle.



• **Suction stroke :** →

During this stroke air is drawn into the cylinder and piston moves from TDC to BDC. The exhaust value remains closed during this stroke.

• **Compression stroke :** →

During this stroke the piston moves from BDC to TDC and both the values remains closed. and the air is compressed hence there is rise in the pressure and temp of the air. Before the end of this stroke, a fine spray of fuel is injected into the compressed air which is at high temp. and hence combustion takes place.

• **Expansion or Power stroke :** →

During this stroke both the values remain closed and the piston moves from TDC to BDC. The heat energy released by the combustion of fuel results in rise in pressure of the gases which drives the piston downwards. Hence power is developed.

• **Exhaust stroke :** →

In this stroke exhaust value is opened and inlet value remains closed and the piston moves from BDC to TDC. The upward movement of the piston forces the burnt gases out of the cylinder through the exhaust value.