

LEARNING MATERIAL

SEMESTER : 4TH SEMESTER
BRANCH : MECHANICAL ENGINEERING
THEORY SUBJECT : THERMAL ENGINEERING -II (TH – 4)

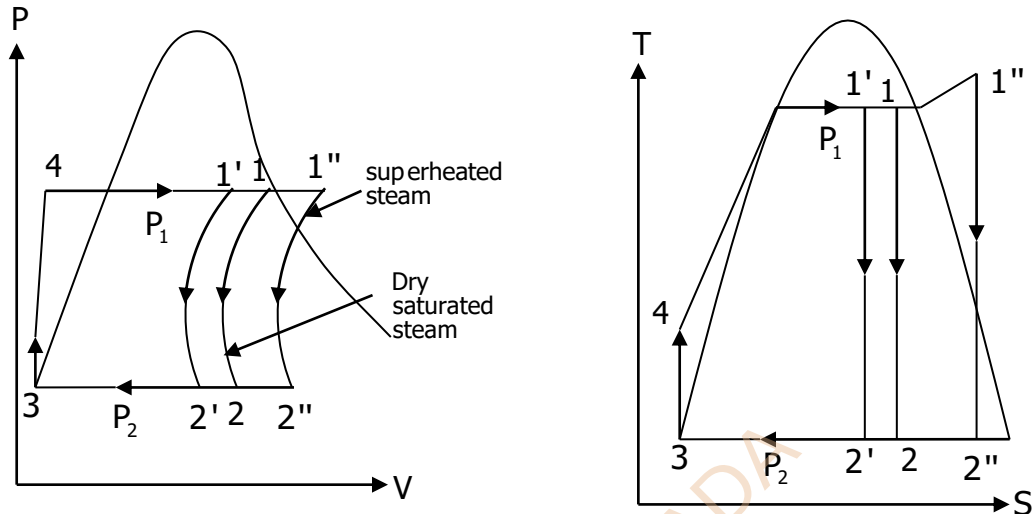
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CHAPTER – 1

Q. Explain Rankin Cycle P.V.R. temperature Entropy diagram Derive efficiency
2016 2(b)



Ans: Consider 1 kg of fluid in the cycle & applying steady flow energy equation to each component in the cycle.

1. For Boiler

$$h_{f4} + Q_1 = h_1$$

$$\Rightarrow Q_1 = h_1 - h_{f4}$$

2. For turbine

$$h_1 = W_T + h_2$$

$$\Rightarrow W_T = h_1 - h_2$$

3. For condenser, $h_2 = Q_2 + h_{f3}$

$$\Rightarrow Q_2 = h_2 - h_{f3}$$

4. For pump, $h_{f3} + w_p = h_{f4}$

$$\Rightarrow w_p = h_{f4} - h_{f3}$$

$$\therefore \text{Rankine} = \frac{W_{\text{net}}}{Q_1} = \frac{W_T - W_p}{Q_1} = \frac{(h_1 - h_2) - (h_{f4} - h_{f3})}{h_1 - h_{f4}}$$

For reversible adiabatic compression we get

$$Tds = dh - Vdp$$

$$dh = vdp \quad (\because ds=0)$$

$$\Rightarrow dh = hf_4 - hf_3 = v_3 (P_1 - P_2)$$

Where p is in bar and v is in m^3/kg

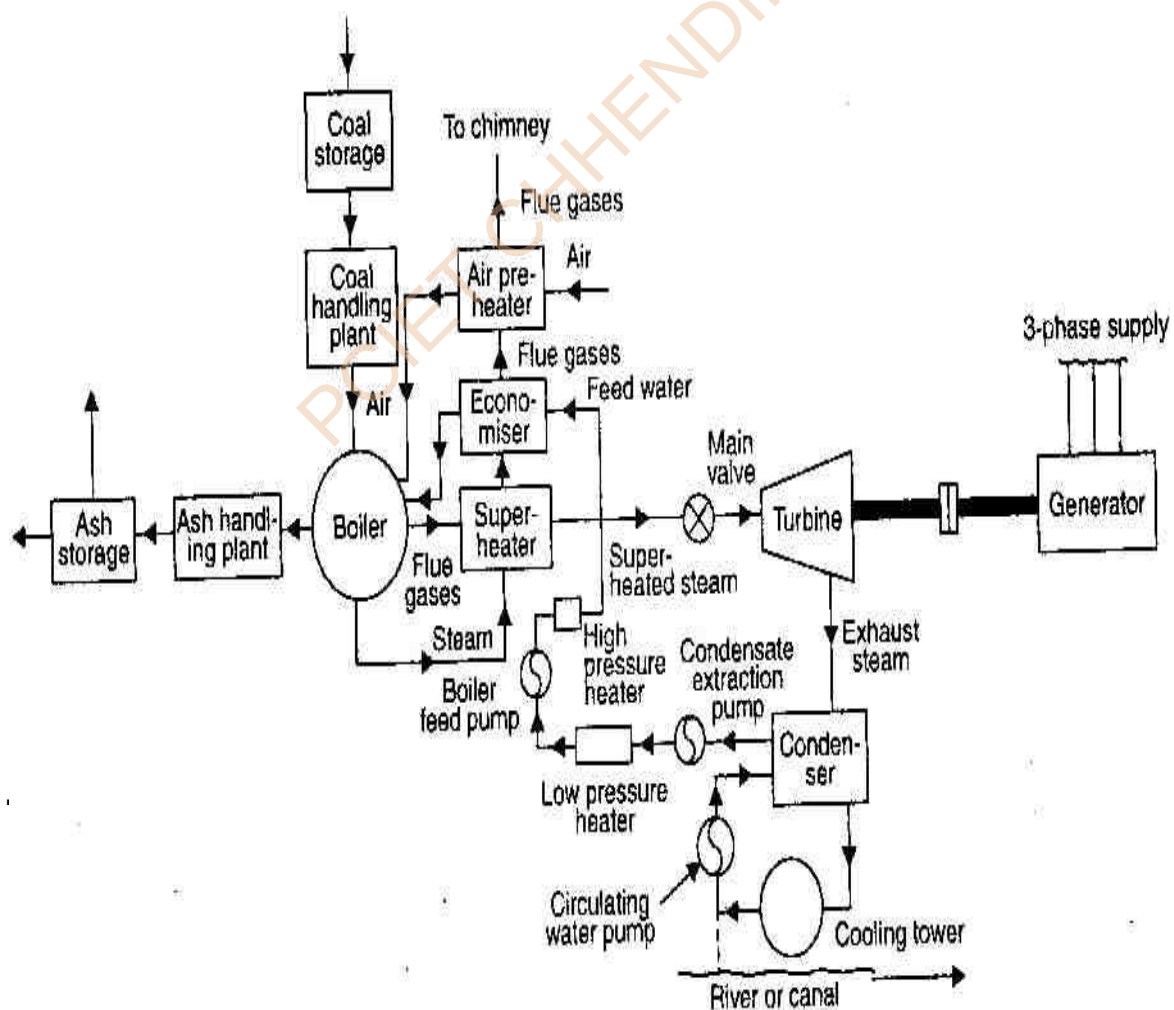
$$Hf_4 - hf_3 = v_3 (P_1 - P_2) \times 10^5 \text{ J/kg}$$

The feed pump ($hf_4 - hf_3$) being a small quantity in comparison with turbine work is neglected when boiler pressure are low.

$$\eta_{\text{Rankin}} = \frac{h_1 - h_2}{h_1 - hf_4}$$

Q. Lay out of steam power plant ? 2010 , 1(c), 2017/3.A

Ans:



The layout of steam power plant comprises of following four circuits.

1. Fuel & ash circuit.
2. Air and Gas circuit
3. Feed water and Steam circuit
4. Cooling water circuit.

1. Fuel and Ash circuit:-

In case of small power plant the quantity of coal being small. Manual unloading from rail car may be used but for large power station the unloading from railway siding is done with the help of wagon tippler and then the coal is conveyed to the coal handling plant. Then it is passes on to the furnaces through the fuel. Feeding devices. Ash resulting from the combustion of coal collects at the back of the boiler and is removed to ash storage yard through ash handling equipment.

2. Air & Gas Circuit:-

Air is taken in from atmosphere through the action of a forced or induced draught fan and passes on to the furnaces through the air-preheated. The flue gases after passing around boiler tubes and super heater tubes in the furnace pass through a dust catching device or precipitator, then through the economizer and finally through the air preheater before being exhausted to the atmosphere.

3. Feed water and steam flow circuit:-

The steam coming out of the turbine is condensed and the condensate is extracted from the condenser by the condensate extraction pump & is forced to the low pressure fuel, water heater where its temperature is raised by the heat from bled steam. The feed water is now pumped through deaerator to high pressure feed water heater , where its get heated by the heat from bled steam extracted at suitable point of the steam turbine. A small part of steam (about 1 %) of steam and water is passing through the different component of the system is lost. In boiler water is converted into high pressure steam, which is wet. Wet steam is passed through

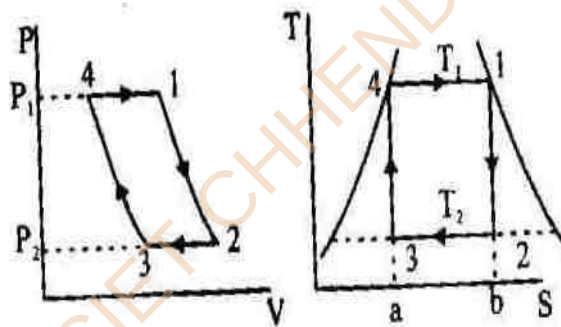
super heater where it is dried and further superheated and then supplied to the steam turbine through main valve.

4. Cooling water circuit:-

The cooling water supply to the condenser helps in maintaining a low pressure in it. The water may be taken from a natural source such as river, lake or sea or the same water may be cooled and circulated over again. In the later case the cooling arrangement is made through spray pond or cooling tower.

Q. Describe Carnot vapor cycle with steam with the help of P.V. and T-S diagram and deduce a formula for its thermal efficiency.(2015)

Ans: Carnot cycle with vapor is shown on P-V and T-S diagrams. It consists of (i) two constant pressure (reversible isothermal) operations (ii) two reversible adiabatic operations.



(i) Process (4–1) [Iso-thermal heat addition]

Water at saturation temperature (T_4) is heated at boiler pressure P_1 to form dry saturated steam.

(ii) Process (1–2) [Adiabatic expansion]

During this process steam is expanded adiabatically from pressure p_1 to p_2 and temperature T_1 , T_2 . The point '2' represents the condition of steam after expansion.

(iii) Process (2–3) [Iso-thermal heat rejection]

During this operation heat is rejected at constant pressure p_2 and temperature T_1 . At the steam is exhausted it becomes wetter and cooled from 2 to 3.

(iv) Process (3–4) [Adiabatic compression]

In this operation the wet steam at '3' is compressed isentropically till the steam regains its original state of temperature T_1 and pressure p_1 . Thus cycle is completed. Thermal efficiency of the Carnot vapor cycle is given by

$$\begin{aligned}\eta_{Th} &= \frac{\text{Work done}}{\text{Heat supplied}} \\ &= \frac{\text{Heat supplied} - \text{Heat rejected}}{\text{Heat supplied}} \\ &= \frac{T_1(S_2 - S_3) - T_2(S_2 - S_1)}{T_1(S_2 - S_3)} \\ &= \frac{(T_1 - T_2)(S_2 - S_3)}{T_1(S_2 - S_3)} \\ &= \frac{T_1 - T_2}{T_1} = 1 - \frac{T_2}{T_1}\end{aligned}$$

- Q.** In a Carnot cycle heat is supplied at 350°C and heat rejected 25°C the fluid is water the entropy change for this process 1.438 kJ/kg k is cycle operates on a stationary mass of 1 kg of water. Find the heat supplied work-done, heat rejected and pressure during heat reception.(2009)

Given data :

$$T_1 = 350^\circ\text{C} = 350 + 273 = 623 \text{ K}$$

$$T_2 = 25^\circ\text{C} = 25 + 273 = 298 \text{ K}$$

$$S_2 - S_1 = 1.438 \text{ kJ/kg k}$$

$$M = 1 \text{ kg.}$$

Heat supplied :

$$(S_2 - S_1) T_1$$

$$\Rightarrow 1.438 \times 623$$

$$\Rightarrow 895.874 \text{ J/kg k}$$

Neat work done:-

$$= \text{Heat supplied} - \text{Heat rejected}$$

$$= (S_2 - S_1) T_1 - (S_2 - S_1) T_3$$

$$= 895.875 - 1.438 \times 298$$

$$= 467.351 \text{ J/kg k}$$

Heat rejection :

$$= (S_2 - S_1)T_3$$

$$= 1.438 \times 298$$

$$= 428.524$$

**Q. in which way rankine cycle is different from the carnot vapour cycle
?2017/1.a**

Ans:

Sr. No.	Carnot Cycle	Rankine Cycle
1.	It is a theoretical cycle. . It gives maximum efficiency between two temperature difference	This one is a practical cycle of steam engine and turbine.
2.	Heat is added and rejected at constant temperature.	Heat is added and rejected at constant pressure.
3.	It has highest efficiency between two temperature differences.	Rankine cycle has lower efficiency than Carnot cycle.
4.	Carnot cycle uses air as the working substance.	Rankine cycle uses water as working substance.
5.	Carnot cycle is ideal cycle for heat engine.	It is ideal cycle for vapor power engine.

Q. In a steam engine (2008)

- (i) inlet to turbine – 6Mpa – 880°C – Nil
- (ii) exist from turbine inlet to condenser – 10 kpa – 0.9 – 250 velocity
- (iii) exist from condenser inlet to the pump .9 kpa , saturated liquids
- (iv) exist from pump inlet to boiler 7 mpa
- (v) exist from boiler – 6.5 mpa – 400°C

Calculate :-

- (i) power output of the turbine

- (ii) Heat transfer per hour in boiler and condenser
- (iii) Mass of cooling water circulated per hour in the condenser. Chose the inlet temperature of water 20°C and 30°C at exist from the condenser
- (iv) diameter of the pipe connecting to the turbine with the condenser.

Ans: Power output of the turbine

$$W_T = h_1 - h_2$$

$$P = W_T \times m_s$$

Steam Table

$$A_T \text{ 60 bar 380}^\circ \text{ temp}$$

$$H_1 = 305^\circ.27$$

$$A_t = 0.1 \text{ bar}$$

$$H_2 = h_f + x h_{fg} = 2345.41$$

$$P = W_T \times m_s$$

$$W_T = 704.79 \text{ kJ/kg}$$

$$\Rightarrow P = 1000/3600 \times 704.79$$

$$= 1957.75 \text{ kw}$$

Formula:

$$\left[\text{minimum enthalpy} + \frac{\text{maximum enthalpy} - \text{minimum enthalpy}}{\text{maximum temp.} - \text{minimum temp.}} \right]$$

$$\left[h_1 = 3045.8 + \frac{(3180.1 - 3045.8)}{380 - 350} \right]$$

Q. An engine working on Carnot cycle receives heat at 800°C and rejects it at 30°C. Find efficiency of cycle. If the engine receives 5000 kJ of heat per minute from source. Calculate the power developed by engine.(2015)

$$t_1 = 800^\circ$$

$$t_3 = 30^\circ\text{C}$$

$$T_1 = t_1 + 273 = (800 + 273)\text{K} \\ = 1073 \text{ K}$$

$$T_3 = t_3 + 273 = (30 + 273)\text{K} = 303 \text{ K}$$

$$Q = 5000 \text{ kJ/min} = 5000/60 \text{ kJ/s} = 83.33 \text{ kJ/s}$$

Thermal efficiency of Carnot cycle,

$$\eta_{\text{carnot}} = \frac{T_1 - T_3}{T_1} = \frac{1073 - 303}{1073} = 0.717 = 71.7\%$$

$$\eta_{\text{carnot}} = \frac{\text{work done}}{\text{Heat supplied}}$$

$$\text{or work done / sec} = \eta_{\text{carnot}} \times \text{Heat supplied}$$

$$= 83.33 \times 0.717 = 59.75 \text{ kJ / s} = 59.75 \text{ kW}$$

$\therefore$ Power developed by engine

$$= \text{work done / sec} = 59.75 \text{ kW.}$$

2017/1.b

Problem-1 A powerplant is supplied with dry saturated steam at a pressure of 16 bar and exhausts at 0.3 bar. Using steam table find efficiency of Carnot cycle.

Solution - Given data

$p_1 = 16 \text{ bar}$
 $p_2 = 0.3 \text{ bar}$

From steam table at $p_1 = 16 \text{ bar}$
 Corresponding saturation temperature
 $t_1 = 201.4^\circ\text{C}$
 $T_1 = (t_1 + 273) \text{ K} = (201.4 + 273) \text{ K} = 474.4 \text{ K}$

At $p_2 = 0.3 \text{ bar}$, $t_2 = 69.1^\circ\text{C}$
 $T_2 = (t_2 + 273) \text{ K} = (69.1 + 273) \text{ K} = 342.1 \text{ K}$

Efficiency of Carnot cycle

$$\eta_{\text{Carnot}} = \frac{T_1 - T_2}{T_1} = \frac{474.4 - 342.1}{474.4} = 0.279 \text{ or } 27.9\%$$

(Ans)

Problem-2 A steam turbine receives superheated steam at a pressure of 15 bar having degree of superheat of 110°C . The exhaust pressure is 110°C and exhaust pressure is 0.07 bar and expansion is isentropic. Calculate (i) Heat supplied (ii) Heat rejected (iii) Net work done (iv) Thermal efficiency

2017/1.c

Solution - Given data -

$p_1 = 15 \text{ bar}$ and A - mass flow

$t_{\text{sup}} - t_s = 110^\circ \text{C}$

$p_3 = 0.07 \text{ bar}$

From steam table at $p_1 = p_2 = 15 \text{ bar}$

$$h_2 = h_{g2} = 2792.2 \text{ kJ/kg}$$

$$s_2 = s_{g2} = 6.445 \text{ kJ/kgK}$$

At pressure $p_3 = 0.07 \text{ bar}$

$$h_{f3} = 163.4 \text{ kJ/kg}$$

$$h_{fg3} = 2409.1 \text{ kJ/kg}$$

$$s_{f3} = 0.559 \text{ kJ/kgK}$$

$$s_{fg3} = 7.717 \text{ kJ/kgK}$$

During isentropic expansion (2-3)
entropy remains constant
 $s_2 = s_3$

$$s_2 = s_3 \Rightarrow 6.445 = s_{f3} + x_3 s_{fg3}$$

$$\Rightarrow 6.445 = 0.559 + x_3 \times 7.717$$

$$\Rightarrow x_3 = \frac{6.445 - 0.559}{7.717} = 0.76$$

$$h_2 = h_{\text{sup}} = h_g + C_p (t_{\text{sup}} - t_s)$$

$$= 2792.2 + 2.1 \times 110 = 3023.2 \text{ kJ/kg}$$

$$h_3 = h_{f3} + x_3 h_{fg3} = 163.4 + 0.76 \times 2409.1 = 1994.3 \text{ kJ/kg}$$

$$\text{Rankine Efficiency, } \eta_{\text{Rankine}} = \frac{h_2 - h_3}{h_2 - h_{f3}}$$

$$= \frac{3023.2 - 1994.3}{3023.2 - 163.4} = 0.36 \text{ or } 36\%$$

(Ans)

(2-1) 2(c) In an air standard cycle with diesel compression ratio 14 the condition of air at the start of compression stroke are 1 bar and 300K. After addition of heat at constant pressure the temperature rises to 2775K. Determine thermal efficiency of cycle and net work done per kg of air.

Solution - Given data:

Compression ratio (r) = $\frac{V_4}{V_1}$ $p_1 = p_2$

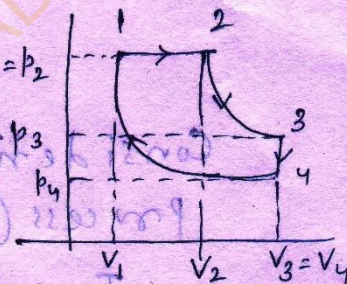
$p_1 = 1 \text{ bar} = 10^5 \text{ N/m}^2 = 1 \text{ bar}$

$T_1 = 300 \text{ K}$ $T_2 = 2775 \text{ K}$

Assume $C_p = 1.005 \text{ kJ/kgK}$

for air $C_v = 0.718 \text{ kJ/kgK}$

$\gamma = 1.4$



Considering isentropic compression

(1-2) process (1-2)

$p_1 V_1^\gamma = p_2 V_2^\gamma$

or $\frac{p_1}{p_2} = \left(\frac{V_2}{V_1} \right)^\gamma = (14)^\gamma$

$\frac{p_1}{p_2} = \frac{10^5}{p_2} = (14)^{1.4} = 40.23 \times 10^5 \text{ N/m}^2$

$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1} \right)^{\gamma-1} = (14)^{0.4} = 2.87$

or $T_2 = T_1 \times 2.87 = 300 \times 2.87 = 862 \text{ K}$

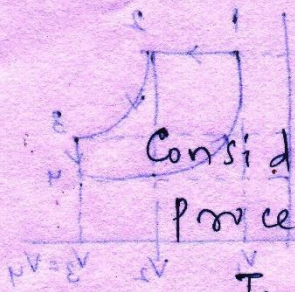
Considering constant pressure process (1-2).

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad \text{or} \quad \frac{T_2}{T_1} = \frac{V_2}{V_1} = \rho = \frac{2775}{862} = 3.2$$

Efficiency of diesel cycle

$$\eta_{\text{diesel}} = 1 - \frac{1}{(\gamma)^{\gamma-1}} \left[\frac{\rho^{\gamma} - 1}{\gamma(\rho - 1)} \right]$$

$$= 1 - \frac{1}{(1.4)^{1.4-1}} \left[\frac{(3.2)^{1.4} - 1}{1.4(3.2 - 1)} \right] = 0.54 \text{ or } 54\%$$



Considering isentropic expansion process (2-3)

$$\frac{T_2}{T_3} = \left(\frac{V_3}{V_2} \right)^{\gamma-1} = \left(\frac{\rho}{\rho} \right)^{\gamma-1} = \left(\frac{1.4}{3.2} \right)^{1.4-1} = 1.8$$

$$\Rightarrow T_3 = \frac{T_2}{1.8} = \frac{2775}{1.8} = 1542 \text{ K}$$

Heat supplied, $Q_{1-2} = m C_p (T_2 - T_1)$

$$= 1 \times 1.005 \times (2775 - 862) = 1962.57 \text{ kJ}$$

Heat rejected, $Q_{2-3} = m C_v (T_2 - T_3)$

$$= (1 \times 0.718 \times (1542 - 300)) = 891.75 \text{ kJ}$$

Work done = Heat supplied - Heat rejected

$$= 1962.57 - 891.75 = 1070.82 \text{ kJ}$$

$$\eta = \frac{W}{Q_{\text{supplied}}} = \frac{1070.82}{1962.57} = 0.54 \text{ (Ans)}$$

5(c) Calculate the heat loss per square meter of surface area for furnace wall 25 cm thick which has inside temperature of 1050°C and outside temperature of 50°C . Also calculate the thermal resistance and conductance of wall given that $k = (1.1 + 0.00116t) \text{ W/m}^\circ\text{C}$ where t is in degree Centigrade.

Solution - Given data:

Temperature of inner surface

$$t_1 = 1050^\circ\text{C}$$

Temperature of outer surface

$$t_2 = 50^\circ\text{C}$$

$$A = 1 \text{ m}^2$$

Thickness of wall, $L = 25 \text{ cm} = 0.25 \text{ m}$

Mean temperature, $t_m = \frac{t_1 + t_2}{2}$

$$= \frac{1050 + 50}{2} = \frac{1100}{2} = 550^\circ\text{C}$$

Thermal conductivity, $k = 1.1 + 0.00116 t_m$

$$= 1.1 + 0.00116 \times 550 = 1.73 \text{ W/m}^\circ\text{C}$$

Heat loss per square meter of

surface area, $Q = \frac{kA(t_1 - t_2)}{L}$

$$= \frac{1.73 \times 1 \times (1050 - 50)}{0.25} = 6920 \text{ J} = 6.92 \text{ kJ}$$

Thermal resistance $= \frac{L}{KA} = \frac{0.25}{1.73 \times 1} = 0.140 \text{ hm}$

Thermal conductance $= \frac{KA}{L} = \frac{1.73 \times 1}{0.25} = 6.9 \text{ mho}$ (Ans)

Temperature of inner surface $t_1 = 1020^\circ\text{C}$

Temperature of outer surface $t_2 = 20^\circ\text{C}$

Thickness of wall $L = 0.25 \text{ m}$

Mean temperature $t_m = \frac{t_1 + t_2}{2} = \frac{1020 + 20}{2} = 520^\circ\text{C}$

Thermal conductivity $K = 1.1 + 0.0016 t_m$

$K = 1.1 + 0.0016 \times 520 = 1.73 \text{ W/m}^\circ\text{C}$

Heat loss per square meter of surface area $Q = \frac{K A (t_1 - t_2)}{L}$

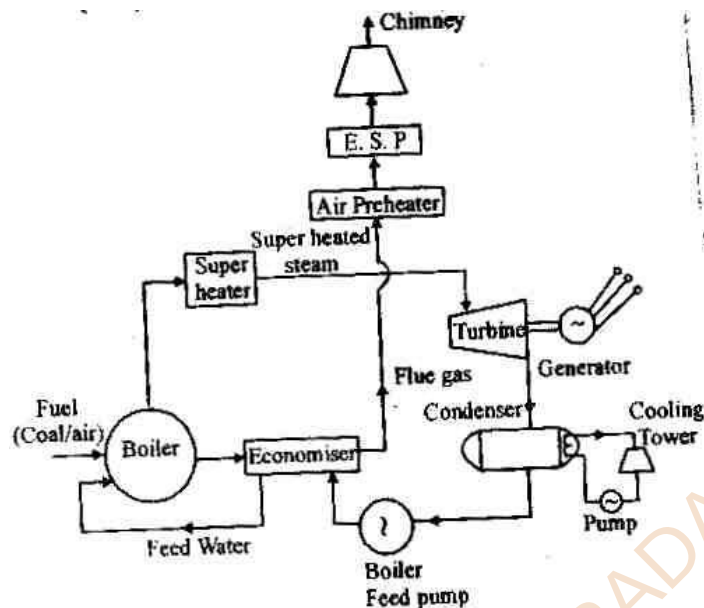
$Q = \frac{1.73 \times 1 \times (1020 - 20)}{0.25} = 6900 \text{ W/m}^2$

Q. What are the main components of steam power plant.(2015)

- (i) Boiler
 - (a) Super-heater
 - (b) Re-heater
 - (c) Economizer
 - (d) Air-heater
- (ii) Steam turbine
- (iii) Generator
- (iv) Condenser
- (v) Cooling towers
- (vi) Circulating water pump
- (vii) Boiler feed pump
- (viii) Wagon tippler
- (ix) Crusher house
- (x) Coal mill
- (xi) Induced draught fans
- (xii) Ash precipitators
- (xiii) Boiler chimney
- (xiv) Forced draught fans
- (xv) Water treatment plant

(xvi) Control room

(xvii) Switch yard



Functions of a Steam Power Plant :

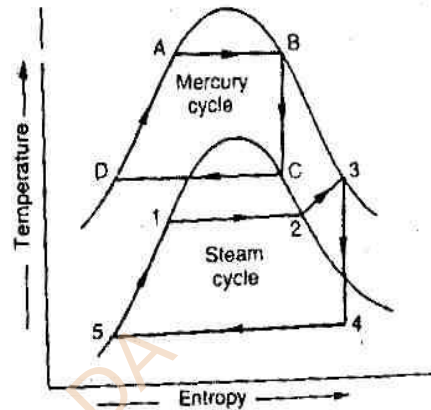
Function of a Steam Power Plant

- (i) Boiler – Water is converted into wet steam.
- (ii) Super-heater – It converts wet steam into super heated steam.
- (iii) Turbine – Steam at high pressure expands in the turbine and drives the generator.
- (iv) Condenser – It condenses steam used by the steam turbine. The condensed steam is used as a feed water.
- (v) cooling tower – It cools the condenser circulating water. Condenser cooling water absorbs heat from steam. This heat is discharged to atmosphere in cooling tower
- (vi) Condenser circulating water pump – It pumps water in the water tubes of boiler against boiler steam pressure.
- (vii) Feed water pump – It pumps water in the water tubes of boiler against boiler steam pressure.
- (viii) Economizer – In economizer heat in flue gases is partially used to heat incoming feed water.

- (ix) Air pre-heater – In air pre-heater heat in flue gases is partially used to heat incoming air.

Q. Binary Vapor Cycle(2016)

The binary vapor cycle on a T-s diagram is shown in fig. the line AB represents the operation of liquid mercury plotted to the same temperature scale as that of steam. But the scale is the corresponding pressures for the mercury lower. The mercury vapor at B has a much higher temperature than the steam at the same pressure. The mercury vapors are now extended isentropically in a mercury turbine as presented by the line BC in fig. the condensation of mercury is shown by the line CD. During condensation, the latent heat is utilization for evaporating a corresponding amount of steam. The line DA represents the heating of mercury. Thus the mercury has completed a circle ABCD.



The steam cycle is represented by 1-2-3-4-5 as shown in fig. The line 1-2 represents the evaporation of steam by the condensing mercury. The line 2-3 represents the superheating of the steam by the flue gases. The steam is now expanded isentropically through a steam turbine as shown by the line 3-4. The condensation of the exhaust steam is represented by the line 4-5. The heating of feed water is represented by the line 5-1. This completes the steam cycle.

Notes: 1 It is found that 8.196 kg of mercury is required per kg of steam to obtain the correct amount of heat from the condensing mercury for evaporating the steam. It may be seen from the areas of T-s diagram that the mercury for the high temperature range of the cycle gives a higher efficiency than that obtained from steam with the same addition of heat.

2. The relation between the two cycles is that the heat lost by mercury in CD is equal to the heat gained of steam in 1-2. Mathematically, heat lost by mercury at CD is equal to heat gained by steam at 1-2.

CHAPTER:2

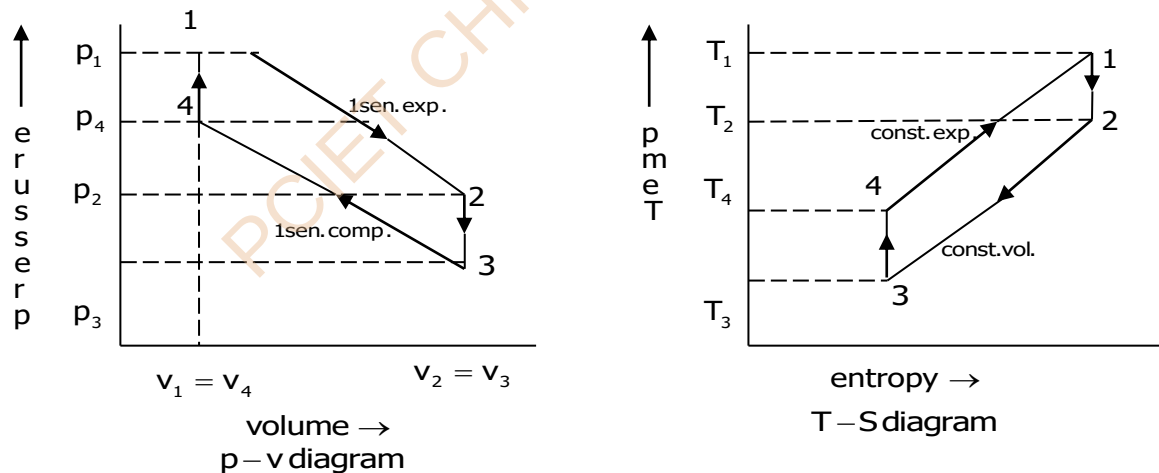
Q. Describe the efficiency of Otto cycle with the help of P-V and T-S diagram for its thermal efficiency AND mean effective pressure.2016/2017/2.B

Ans: The first successful engine working on this cycle was built by A. these days many gas petrol and many of the oil engines run on this cycle. It is also known as constant volume cycle as the heat is received and rejected at a constant volume.

This cycle is taken as a standard of comparison for internal combustion engines. For the purpose of comparison with other cycles, the air is assumed to be the working substance.

The engine conceived by Otto has air enclosed in a cylinder, whose walls are perfectly non-conductor of heat, but the bottom is a perfect conductor of heat. There is also a hot body and cold body and an insulating cap, which are alternately brought in contact with the bottom of the cylinder.

The ideal Otto cycle consists of two constant volume and two reversible adiabatic or isentropic processes as shown on P-V and T-S diagrams in fig. (a) and



Let the engine cylinder contain m kg of air at point 1, let p_1 , T_1 and v_1 be the pressure, temp., and volume of the air. Following are the four stages of the ideal cycle.

1. First state (Reversible adiabatic or isentropic expansion)

The air is expanded reversibly and adiabatically from initial temp T_1 to a temp. T_2 as shown by the curve 1-2 in fig. (a) and (b). In this process no heat is absorbed or rejected by the air.

2. Second stage (constant volume cooling)

The air is cooled at constant volume from temp. T_2 to a temp. T_3 as shown by the curve 2-3 in fig. (a) and (b). We know that heat rejected by the air during this process.

$$Q_{2-3} = MC_v (T_2 - T_3)$$

3. Third state (Reversible adiabatic or isentropic compression)

The air is compressed reversibly and adiabatically from temp. T_3 to a temp. T_4 as shown in by the curve 3-4 in fig (a) and (b). In this process no heat is absorbed or rejected by the air.

4. Fourth stage (constant volume heating)

The air is now heated at constant volume from temp. T_4 to a temp. T_1 as shown by the curve 4-1 in fig. (a) and (b). We know that heat absorbed by the air during this process.

We see that the air has been brought back to its original conditions of pressure, volume and temp., thus completing the cycle.

We know that work done = Heat absorbed – heat rejected

$$Mv (T_1 - T_4) - m c_v (T_2 - T_3)$$

∴ Ideal efficiency of air standard efficiency

$$\begin{aligned} \eta &= \frac{\text{work done}}{\text{Heat absorbed}} \\ &= \frac{m c_v (T_1 - T_4) - m c_v (T_2 - T_3)}{m c_v (T_1 - T_4)} \\ &= 1 - \frac{T_2 - T_3}{T_1 - T_4} = 1 - \frac{T_3 \left(\frac{T_2}{T_3} - 1 \right)}{T_4 \left(\frac{T_1}{T_4} - 1 \right)} \text{----- (i)} \end{aligned}$$

We know that for reversible adiabatic or isentropic process 1-2

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2} \right)^{\gamma-1} = \left(\frac{1}{r} \right)^{\gamma-1} \text{----- (ii)}$$

$$R = \text{expansion ratio} = v_2/v_1$$

Where similarly for reversible adiabatic or isentropic compression process 3-4

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3} \right)^{\gamma-1} = \left(\frac{1}{r} \right)^{\gamma-1} \text{----- (iii)}$$

R= compression ratio = $v_3/v_4 = v_2/v_1$

Where from equations (ii) and (iii), we find that

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} = \left(\frac{1}{r} \right)^{\gamma-1} = \frac{1}{(r)^{\gamma-1}} \text{ or } \frac{T_1}{T_4} = \frac{T_2}{T_3}$$

Substituting the value of T_1/T_4 in equation (i)

$$\eta = 1 - \frac{T_3}{T_4} = 1 - \frac{T_2}{T_1} = 1 - \frac{1}{(r)^{\gamma-1}} \text{-----} \left(\frac{T_3}{T_4} = \frac{T_2}{T_1} \right) \text{----- (iv)}$$

Compression ratio,

$$r = \frac{\text{Total Cylinder Volume}}{\text{Clearance Volume}}$$

$$r = \frac{V_1}{V_2} = \frac{V_4}{V_3} = \frac{V_c + V_s}{V_c}$$

Pressure ratio,

$$k = \frac{p_3}{p_2} = \frac{p_4}{p_1} \quad \left[\text{See p-V diagram above for understanding} \right]$$

In process 1-2 (isentropic compression),

$$\frac{p_2}{p_1} = \left(\frac{V_1}{V_2} \right)^{\gamma} = r^{\gamma}$$

In process 3-4 (isentropic expansion),

$$\frac{p_3}{p_4} = \left(\frac{V_4}{V_3} \right)^{\gamma} = r^{\gamma}$$

Also from the [p-V diagram](#) above,

$V_1 = V_4$ and $V_2 = V_3$

Let $V_c = V_2 = V_3 = 1$

Work done during Otto cycle,

$W = \text{Work done during isentropic expansion (process 3-4)} - \text{Work done during isentropic compression (process 1-2)}$

$$W = \frac{p_3 V_3 - p_4 V_4}{\gamma - 1} - \frac{p_2 V_2 - p_1 V_1}{\gamma - 1}$$

$$W = \frac{1}{\gamma - 1} \left[\left(p_3 V_3 - p_4 V_4 \right) - \left(p_2 V_2 - p_1 V_1 \right) \right]$$

$$W = \frac{1}{\gamma - 1} \left[V_3 \left\{ p_3 - p_4 \left(\frac{V_4}{V_3} \right) \right\} - V_2 \left\{ p_2 - p_1 \left(\frac{V_1}{V_2} \right) \right\} \right]$$

$$W = \frac{1}{\gamma - 1} \left[V_3 \left(p_3 - p_4 r \right) - V_2 \left(p_2 - p_1 r \right) \right] \text{ [Since, } \frac{V_4}{V_3} = \frac{V_1}{V_2} = r]$$

$$W = \frac{1}{\gamma - 1} \left[\left(p_3 - p_4 r \right) - \left(p_2 - p_1 r \right) \right] \text{ [Since, } V_3 = V_2 = 1]$$

$$W = \frac{1}{\gamma - 1} \left[p_4 r \left(\frac{p_3}{p_4} r - 1 \right) - p_1 r \left(\frac{p_2}{p_1} r - 1 \right) \right]$$

$$W = \frac{1}{\gamma - 1} \left[p_4 r \left(\frac{r^\gamma}{r} - 1 \right) - p_1 r \left(\frac{r^\gamma}{r} - 1 \right) \right] \text{ [Since, } \frac{p_3}{p_4} = \frac{p_2}{p_1} = r^\gamma]$$

$$W = \frac{r}{\gamma - 1} \left[p_4 \left(r^{\gamma-1} - 1 \right) - p_1 \left(r^{\gamma-1} - 1 \right) \right]$$

$$W = p_1 r / \gamma - 1 \left[\left(\frac{p_4}{p_1} \right) \left(r^{\gamma-1} - 1 \right) - \left(r^{\gamma-1} - 1 \right) \right]$$

$$W = \frac{p_1 r}{\gamma - 1} \left[k \left(r^{\gamma-1} - 1 \right) - \left(r^{\gamma-1} - 1 \right) \right] \text{ [Since, } \frac{p_4}{p_1} = \frac{p_3}{p_2} = k]$$

$$W = \frac{p_1 r}{\gamma - 1} \left(r^{\gamma-1} - 1 \right) (k - 1)$$

This is the expression for work done (W) in terms of r, k, γ and p₁.

Now, let us derive an expression for stroke volume V_s in terms of r .

We know that in Otto cycle,

$V_s = V_1 - V_2$ (See [p-V diagram](#) above)

$$V_s = V_2 \left(\left(\frac{V_1}{V_2} \right) - 1 \right)$$

$$V_s = r - 1 \quad \left[\text{Since, } V_3 = V_2 = 1 \text{ and } \frac{V_1}{V_2} = r \right]$$

Now, Mean effective pressure,

$$P_m = \frac{W}{V_s}$$

$$P_m = \frac{P_1 r}{\gamma - 1} \left(r^{\gamma-1} - 1 \right) \frac{(k - 1)}{(r - 1)}$$

The above expression can be written as

$$P_m = P_1 r \frac{\left(r^{\gamma-1} - 1 \right)}{(r - 1)} \frac{(k - 1)}{(\gamma - 1)}$$

which is the required expression for mean effective pressure of otto cycle

Q. An engine, working on the Otto cycle has a cylinder diameter of 150 mm and a stroke of 225 mm, the clearance volume is 1.25×10^{-3} . Find the air standard efficiency of this engine. Take $\gamma = 1.4$ (2013)

Ans: Given data:

$$D = 150 \text{ mm} = 0.15 \text{ m}$$

$$L = 225 \text{ mm} = 0.225 \text{ m}$$

$$V_c = 1.25 \times 10^{-3} \text{ m}^3$$

$$\gamma = 1.4$$

We know that swept volume

$$v_s = \frac{\pi}{4} \times d^2 \times L$$

$$= \frac{\pi}{4} (0.15)^2 (0.225) = 3.976 \times 10^{-3} \text{ m}^3$$

$$\begin{aligned} \text{ompression ratio } r &= \frac{V_c + V_s}{V_c} \\ &= \frac{1.25 \times 10^{-3} + 3.976 \times 10^{-3}}{1.25 \times 10^{-3}} \\ &= 4.18 \end{aligned}$$

We know that air standard efficiency

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}} \Rightarrow 1 - \frac{1}{(4.18)^{1.4-1}} = 1 - \frac{1}{1.772}$$

- Q. A certain quantity of air at a pressure of 1 bar and temp 70°C is compressed reversibly and adiabatically until the pressure is 7 bar in an Otto cycle engine. A 60 kJ of heat per kg of air now added at constant volume. Determine**
- (i) Compression ratio of the engine**
 - (ii) Temperature at the end of compression**
 - (iii) Temperature at the end of heat addition (2009)**

Ans: Given data

$$P_3 = 1 \text{ bar} = 1 \times 10^5 \text{ pas cal}$$

$$T_3 = 70^\circ\text{C} = 70 + 273 = 343 \text{ K}$$

$$P_4 = 7 \text{ bar} = 7 \times 10^5 \text{ pas cal}$$

$$Q_{4-1} = 460 \text{ kJ}$$

$$M = 1 \text{ kg}$$

$$CP = 1 \text{ KJ/ kg K}$$

$$CV = 0.707 \text{ kJ/kg k}$$

$$\gamma = 1.4$$

- (i) Compression Ratio of the engine

$$R = \text{Compression ratio of the engine} = v_3/v_4$$

$$\text{We know that } p_3 v_3^\gamma = p_4 v_4^\gamma$$

$$\frac{v_3}{v_4} = \left(\frac{p_4}{p_3} \right)^{\frac{1}{\gamma}}$$

$$\text{or } r = \left(\frac{7}{1} \right)^{\frac{1}{1.41}} = (7)^{0.709} = 3.97$$

- (ii) Temperature at the end of compression.

Let, T_4 = Temperature at the end of compression

We know that
$$\frac{T_3}{T_4} = \left(\frac{v_4}{v_3} \right)^{\gamma-1}$$

$$= \left(\frac{1}{r} \right)^{\gamma-1} = \left(\frac{1}{3.97} \right)^{1.41-1}$$

$$= (0.252)^{0.41} = 0.568$$

$$T_4 = \frac{T_3}{0.568} = \frac{343}{0.568} = 604\text{K} = 331^\circ\text{C}$$

(iii) Temperature at the end of heat addition

Let T_1 = Temperature at the end of heat addition

We know that heat added at constant volume (Q_{4-1})

$$\Rightarrow 460 = M_{cv} (T_1 - T_4)$$

$$\Rightarrow 1 \times 0.707 (T_1 - 604) \text{ kJ}$$

$$\therefore T_1 - 604 = 460/0.707 = 651$$

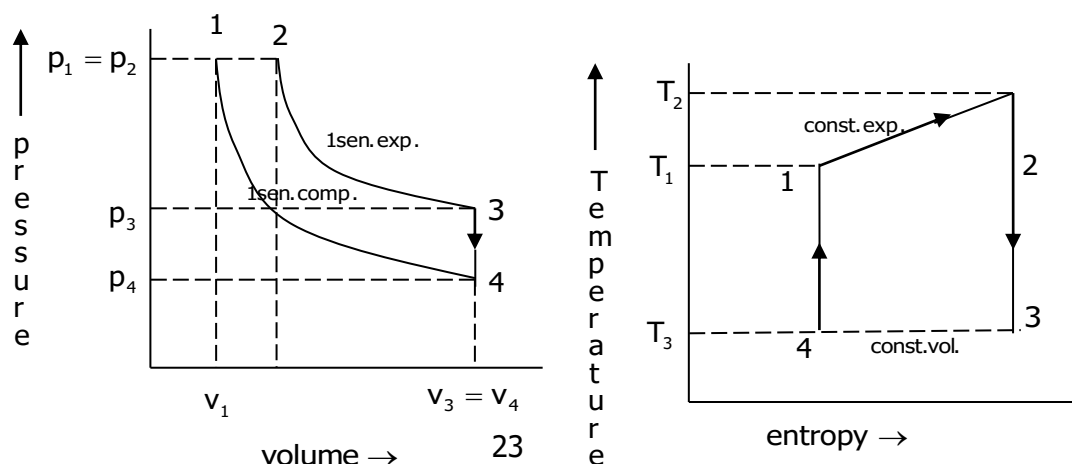
$$\text{Or } T_1 = 1255 \text{ K} = 982^\circ\text{C}.$$

Q. Derive the efficiency of Diesel cycle.2009

Ans: The cycle was devised by Dr. Rudolph diesel in 1893 with an ideal to attain a higher thermal efficiency, with a high compression ratio. This is an important cycle on which all the diesel engine work. It is also known as constant pressure cycle as heat is received at a constant pressure.

The engine imagined by diesel has air enclosed in the 4 cylinder, whose walls are perfectly non-conductor of heat, but bottom is a perfect conductor of heat. Again, there is a hot body cold body and air insulating cap, which are alternately brought in contact with the cylinder.

The ideal diesel cycle consists of two reversible adiabatic or isentropic a constant pressure and a constant volume process. These processes are represented on P-V and T-S diagram as shown in fig.



Let the engine cylinder contain m kg of air at point 1. At this point let, P_1 , T_1 and V_1 be the pressure, temperature and volume of the air. Following are four stages of an ideal diesel cycle.

1. First stage (constant pressure heating)

The air is heated at constant pressure from initial temperature T_1 to a temperature T_2 represented by the curve 1-2 in fig.

∴ Heat supplied to the air,

$$Q_{1-2} = mc_p (T_2 - T_1)$$

Note : Since the supply of heat is cut off at point 2., therefore it is known as cut-off point.

2 Second state (Reversible adiabatic or isentropic expansion)

The air is expanded reversibly and adiabatically from temperature T_2 to a temperature T_3 as shown by the curve 2-3 in fig. In this process, no heat is absorbed or rejected by the air.

3. Third Stage (Constant volume cooling)

The air is now cooled at constant volume from temperature T_3 to a temperature T_4 as shown by the curve 3-4 in fig.

∴ Heat rejected by the air,

$$Q_{3-4} = mc_v (T_3 - T_4)$$

4. Fourth stage (Reversible adiabatic or isentropic compression)

The air is compressed reversibly and adiabatically from temperature T_4 to a temperature T_1 represented by the curve 4-1 in fig. In this process, no heat is absorbed or rejected by the air.

We see that the air has been brought back to its original conditions of pressure, volume and temperature, thus completing the cycle, we know that

Work done = Heat absorbed – Heat rejected

$$mc_p (T_2 - T_1) - mc_v (T_3 - T_4)$$

∴ Air standard efficiency

$$\begin{aligned} \eta &= \frac{\text{workdone}}{\text{Heat absorbed}} = \frac{mc_p (T_2 - T_1) - mc_v (T_3 - T_4)}{mc_p (T_2 - T_1)} \\ &= 1 - \frac{C_v}{C_p} \left(\frac{T_3 - T_4}{T_2 - T_1} \right) = 1 - \frac{1}{\gamma} \left(\frac{T_3 - T_4}{T_2 - T_1} \right) \end{aligned}$$

Now let compression ratio

$$r = \frac{V_4}{V_1}$$

$$\text{cut-off ratio, } p = \frac{V_2}{V_1}$$

$$\begin{aligned} \text{Expansion ratio, } r_1 &= \frac{V_3}{V_2} = \frac{V_4}{V_2} \\ &= \frac{V_4}{V_1} \times \frac{V_1}{V_2} = r \times \frac{1}{p} = \frac{r}{p} \end{aligned}$$

We know for constant pressure heating process 1 – 2

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

$$T_2 = T_1 \times \frac{V_2}{V_1} = T_1 \times p$$

Similarly, for reversible adiabatic or isentropic expansion process 2–3.

$$\frac{T_3}{T_2} = \left(\frac{V_2}{V_3} \right)^{\gamma-1} = \left(\frac{1}{r_1} \right)^{\gamma-1} = \left(\frac{p}{r} \right)^{\gamma-1}$$

$$\therefore T_3 = T_2 \left(\frac{p}{r} \right)^{\gamma-1} = T_1 \times p \left(\frac{p}{r} \right)^{\gamma-1}$$

And for reversible adiabatic or isentropic compression process 4–1

$$\frac{T_1}{T_4} = \left(\frac{V_4}{V_1} \right)^{\gamma-1} = (r)^{\gamma-1} \text{ or } T_1 = T_4(r)^{\gamma-1}$$

Substituting the value of T_1 in equations (ii) and (iii)

$$T_2 = T_4(r)^{\gamma-1} \times p$$

$$T_3 = T_4(r)^{\gamma-1} \times p \left(\frac{p}{r} \right)^{\gamma-1} = T_4 p^\gamma$$

Now substituting the value of T_1 , T_2 and T_3 in equation (i)

$$\begin{aligned} \eta &= 1 - \frac{1}{\gamma} \left[\frac{(T_4 p^\gamma) - T_4}{T_4(r)^{\gamma-1} p - T_4(r)^{\gamma-1}} \right] \\ &= 1 - \frac{1}{(r)^{\gamma-1}} \left[\frac{p^{\gamma-1}}{\gamma(p-1)} \right] \end{aligned}$$

CHAPTER:3

- Q. An ideal diesel engine has a diameter of 150mm and stroke of 250 mm. the clearance volume is 10 percent of stroke volume. Determine the compression ratio and air standard efficiency of the engine if cut off takes place at 6 percent of stroke.**

D = 150 mm = 0.15 m, L = 200 mm = 0.2 m, $V_c = 0.1 \times V_s$ 2016

Ans:compression ratio (r)

$$\begin{aligned}\text{Stroke volume, } V_s &= \frac{\pi}{4} \times d^2 \times L = \frac{\pi}{4} \times (0.15)^2 \times 0.2 \\ &= 3.53 \times 10^{-3} \text{ m}^3\end{aligned}$$

$$\begin{aligned}\text{clearance volume, } V_c &= 0.1 \times V_s = 0.1 \times 3.53 \times 10^{-3} \\ &= 0.353 \times 10^{-3} \text{ m}^3\end{aligned}$$

$$\begin{aligned}\text{compression ratio, } r &= \frac{\text{Total volume}}{\text{clearance volume}} \\ &= \frac{V_s + V_c}{V_c} = \frac{0.353 \times 10^{-3} + 3.53 \times 10^{-3}}{0.353 \times 10^{-3}} = 11\end{aligned}$$

Air standard efficiency

Since cut off takes place at 6 % of stroke volume at the cut off

$$\begin{aligned}V_2 &= V_1 + 0.06 \times V_s = V_c + 0.06 \times V_s \\ &= 0.353 \times 10^{-3} + 0.06 \times 3.53 \times 10^{-3} = 0.565 \times 10^{-3} \text{ m}^3\end{aligned}$$

$$\text{cut off ratio, } P = \frac{V_2}{V_1} = \frac{V_2}{V_c} = \frac{0.565 \times 10^{-3}}{0.353 \times 10^{-3}} = 1.6$$

$$\begin{aligned}\text{Air standard Efficiency, } \eta &= 1 - \frac{1}{(r)^{\gamma-1}} \left[\frac{p^\gamma - 1}{\gamma(p-1)} \right] \\ &= 1 - \frac{1}{(11)^{1.4-1}} \left[\frac{(1.6)^{1.4} - 1}{1.4(1.6-1)} \right] = 1 - \frac{1}{2.61} \times 1.11 \\ &= 0.5753 \text{ or } 57.53\%\end{aligned}$$

Q. A diesel engine has a compression ratio of 18 and cut off takes place at 5 % of stroke calculate air standard efficiency by taking $\gamma = 1.4$. 2015

Ans: Given

$$r = V_4/V_1 = 18$$

Since cut off takes place at 5 % of stroke

$$\text{Volume at cut off, } V_2 = V_1 + 0.05 (V_4 - V_1)$$

$$\text{Let us assume, } V_1 = V_C = 1 \text{ m}^3$$

$$V_4 = 18 \text{ m}^3$$

$$\text{Stroke volume} = V_4 - V_1 = 18 - 1 = 17 \text{ m}^3$$

$$\text{Volume at cut off } V_2 = V_1 + 0.05 (V_4 - V_1)$$

$$= 1 + 0.05 \times (18-1) = 1.85 \text{ m}^3$$

$$\text{Cut off ratio, } P = \frac{V_2}{V_1} = \frac{1.85}{1} = 1.85$$

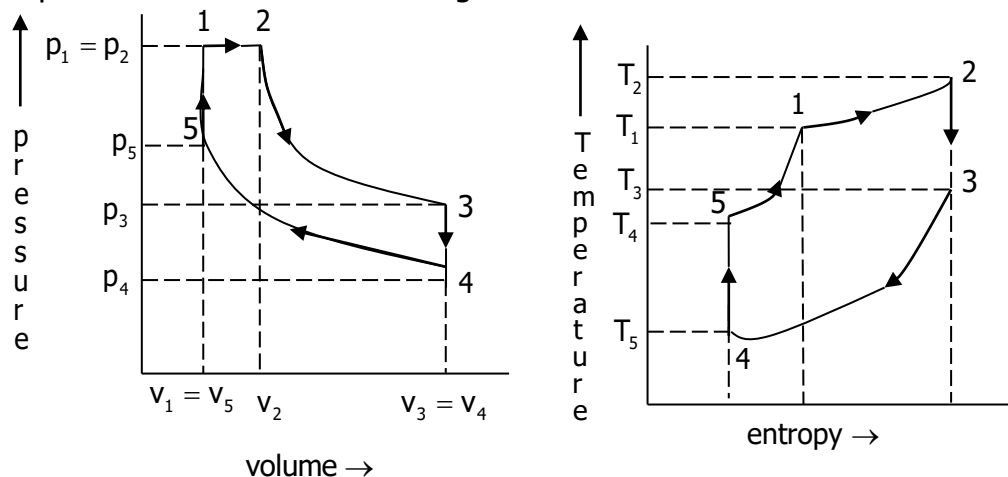
$$\text{Air standard efficiency, } \eta = \frac{1}{r^{\gamma-1}} \left[\frac{p^\gamma - 1}{\gamma(p - 1)} \right]$$

$$= 1 - \frac{1}{(18)^{1.4-1}} \left[\frac{(1.85)^{1.4} - 1}{1.4(1.85 - 1)} \right]$$

Q. Derive the efficiency of Dual Cycle ? 2008

Ans: The cycle is a combination of Otto and Diesel cycle. It is sometimes called semi diesel cycle, because semi diesel engines work on this cycle. In this cycle heat is absorbed partly at a constant volume and partly at a constant pressure.

The ideal dual combustion cycle consist of two reversible adiabatic or isentropic, two constant volume and a constant pressure process. This process are represented on P-V and T-S diagram.



DUAL COMBUSTION CYCLE:-

Let the engine cylinder contain m kg of air at point 1. At this point, let P_1 , T_1 and V_1 be the pressure temperature and volume of air. Following are the five stages of an ideal dual combustion cycle.

FIRST STAGE:-

The air is heated at constant pressure from initial temperature T_1 to a temperature T_2 represented by the curve 1 -2.

Heat absorbed by the air $Q_{1-2} = m_{cp} (T_2 - T_1)$

SECOND STAGE:-

The air is expanded reversibly and adiabatically from temperature T_2 to temperature T_3 as shown by the curve 2-3. In this process no heat is absorbed or rejected by the air.

THIRD STAGE:-

The air is now cooled at constant volume from temperature T_3 to temperature T_4 as shown by the curve 3-4.

Heat rejected by the air, $Q_{3-4} = m_{cv} (T_3 - T_4)$

Fourth stage:

The air is compressed reversibly and adiabatically from temperature T_4 to a temperature T_5 as shown by the curve 4-5. In this process, no heat is absorbed or rejected by the air.

FIFTH STAGE:-

The air is finally heated at constant volume from temperature T_5 to a temperature T_1 as shown by the curve 5-1.

Heat absorbed by the air $Q_{5-1} = m_{cv} (T_1 - T_5)$

We see that the air has been brought back to its original conditions of pressure, volume and temperature thus completing the cycle. We know that

$$\begin{aligned} \text{Work done} &= \text{Heat absorbed} - \text{Heat rejected} \\ &= [m_{cp} (T_2 - T_1) + m_{cv} (T_1 - T_5)] - m_{cv} (T_3 - T_4) \end{aligned}$$

$$\begin{aligned}
 \text{Air standard efficiency, } \eta &= \frac{\text{work done}}{\text{Heat absorbed}} \\
 &= \frac{mc_p(T_2 - T_1) + mc_v(T_1 - T_5) - mc_v(T_3 - T_4)}{mc_p(T_2 - T_1) + mc_v(T_1 - T_5)} \\
 &= 1 - \frac{c_v(T_3 - T_4)}{C_p(T_2 - T_1) + c_v(T_1 - T_5)} \\
 &= 1 - \frac{T_3 - T_4}{\gamma(T_2 - T_1) + (T_1 - T_5)}
 \end{aligned}$$

Now, let compression ratio,

$$r = \frac{V_4}{V_5} = \frac{V_3}{V_1}$$

$$\text{cut of ratio } \& \frac{V_2}{V_1} = \frac{V_2}{V_5}$$

$$\text{pressure ratio, } \alpha = \frac{p_1}{p_5}$$

We know that in constant pressure heating process 1-2,

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \text{ (charles law)}$$

$$T_2 = T_1 \times \frac{V_2}{V_1} = T_1 \dots \dots \dots \text{(ii)}$$

Similarly, in reversible adiabatic or isentropic expansion process 2-3

$$\begin{aligned}
 \frac{T_3}{T_2} &= \left(\frac{V_2}{V_3} \right)^{\gamma-1} = \left[\frac{V_2}{V_1} \times \frac{V_1}{V_3} \right]^{\gamma-1} = \left(\frac{p}{r} \right)^{\gamma-1} \\
 T_3 &= T_2 \left[\frac{s}{r} \right]^{\gamma-1} = T_1 s \left(\frac{s}{r} \right)^{\gamma-1} \dots \dots \dots \text{(iii)}
 \end{aligned}$$

In reversible adiabatic process 4 – 5,

$$\begin{aligned}
 \frac{T_5}{T_4} &= \left(\frac{V_4}{V_5} \right)^{\gamma-1} = (r)^{\gamma-1} \\
 T_5 &= T_4 (r)^{\gamma-1} \dots \dots \dots \text{(iv)}
 \end{aligned}$$

Now in constant volume heating process 5 – 1

$$\begin{aligned}
 \frac{p_5}{T_5} &= \frac{p_1}{T_1} \text{ (Gay lussac law)} \\
 T_1 &= T_5 \times \frac{p_1}{p_5} = T_5 \alpha (r)^{\gamma-1} \alpha \dots \dots \dots \text{(v)}
 \end{aligned}$$

Substituting the value of T_1 in equation (ii) and (iii)

$$\begin{aligned}
 T_2 &= T_4 (r)^{\gamma-1} \alpha s \\
 T_3 &= T_4 (r)^{\gamma-1} \alpha s \left(\frac{s}{r} \right)^{\gamma-1} = T_4 \alpha s
 \end{aligned}$$

Now substituting the values of T_1, T_2, T_3 and T_5 in equation (i)

$$\eta = 1 - \frac{T_4 \alpha s^{\gamma} - T_4}{\gamma \left[(T_4 (r)^{\gamma-1} \alpha s) - T_4 (r)^{\gamma-1} \alpha \right] + \left[T_4 (r)^{\gamma-1} \alpha - T_4 (r)^{\gamma-1} \right]}$$

$$\begin{aligned}
&= 1 - \frac{T_4 (\alpha S^{v-1})}{T_4 (r)^{v-1} [v(\alpha S - \alpha) + (\alpha - 1)]} \\
&= 1 - \frac{(\alpha S^v - 1)}{(r)^{v-1} [v\alpha(p - 1) + (\alpha - 1)]} \\
&= 1 - \frac{1}{(r)^{v-1}} \left[\frac{\alpha S^v - 1}{(\alpha - 1) + v\alpha(p - 1)} \right] \text{----- (vi)}
\end{aligned}$$

1. for Otto cycle, $s = 1$. Substituting this value in equation (vi)

$$\eta_{\text{otto}} = 1 - \frac{1}{(r)^{v-1}}$$

2. For Diesel cycle $\alpha = 1$, substituting this value in equation (vi)

$$\eta_{\text{diesel}} = 1 - \frac{1}{(r)^{v-1}} \left[\frac{s^v - 1}{v(s - 1)} \right]$$

3. The efficiency of dual combustion cycle is greater than diesel cycle and less than Otto cycle for the same compression ratio.

Q. Describe solid fuel and liquid fuel, with example ? 2008

Ans: Fuel

Fuel is defined as the medium by which we complete the combustion process or ignition process.

There are three types of fuel :-

- (i) Solid fuel (carbon fuel)
- (ii) Liquid fuel (Hydro carbon fuel)
- (iii) Gasofied fuel

(i) Solid Fuel:-

The natural solid fuel are peat, wood, coke, ignite, Bituminous coal.

→ Wood:-

- * Wood contain carbon and hydrogen.
- * Wood is converted into the coal when burnt in the absence of air.
- * The calorific value of wood is vary due to moisture contain on it.

- * The calorific value of wood is 19700 KJ/kg.

→ **Peat:-**

- * It is spongy humid substance found on boggy land.
- * It may be represented at the 1st stage in the formation of coal.
- * The large amount of water contains up to 30 % and therefore has to be dried and the calorific value is 23000 KJ/kg.

→ **Ignite:-**

- * It represents the next stage of peat for the formation of coal and is an intermediate.
- * It contains 40 % moisture and 60 % carbon.
- * Its calorific value is 25000 KJ/kg.

→ **Bituminous:-**

- * It represents the next stage of lignite in the formation of coal and contains very little moisture (4-6 %) and carbon percentage (75 – 90 %)
- * Its calorific value is 33500 KJ/kg.

→ **Coke:-**

- * It is produced when coal is strongly heated about 40 to 50 hr in the absence of air in a closed vessel. The process is known as carburization of coal.
- * It contains (85 – 90 %) carbon.
- * There are two types of coke
 - (i) Soft coke (500 – 700)
 - (ii) Hard coke (900 – 1100)

(ii) Liquid Fuel:-

It is derived from natural petroleum (crude oil). The crude oil is obtained from a bore hole in the earth. The natural petroleum may be separated into petroleum or gasoline, paraffin oil or kerosene oil etc. The liquid fuel consists of hydrocarbons.

→ **Gasoline or petrol:-**

- * It is lighter and most volatile liquid.
- * It mainly used for light petrol engine.
- * It is distilled at temp 65 – 220°C

→ **Paraffin oil or kerosene:-**

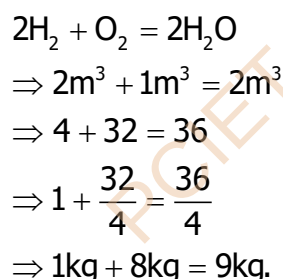
- * It is heavier and less volatile than petrol and used as heating and lightening the fuel.
- * It is distilled at the temp. (220°C – 345°C)

→ **Heavy Fuel:-**

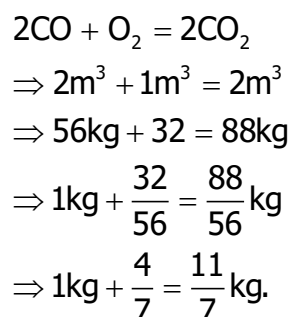
- * The liquid fuel distilled after petrol and kerosene is known as heavy oil.
- * These oil are used as diesel engine and oil heated boiler.
- * It is distilled at the temp 345°C to 470°C.

Q. Write down different combustion equation for gasified ?2016

Ans:



It means carbon monoxide required $\frac{4}{7}$ kg of oxygen for its complete combustion and produce $\frac{11}{7}$ kg of carbon dioxide.



It means 1 kg of hydrogen is required 8 kg. of oxygen for its complete combustion is produce 9 kg of steam or water.

$$\begin{aligned} & \text{CH}_4 + \text{CO}_2 \\ \Rightarrow & 1\text{m}^3 + 2\text{m}^3 = 1\text{m}^3 + 2\text{m}^3 \\ \Rightarrow & 16 + 64 - 44 + 36 \\ \Rightarrow & 1 + 4\text{kg} = \frac{11}{4}\text{kg} + \frac{9}{4}\text{kg}. \end{aligned}$$

It means 1 kg of methane is required 4 kg. of oxygen for its complete combustion is produce 11/4 kg carbon dioxide & 9/4 steam water.

Q. Calculate minimum mass of air required for complete combustion ?2008

Ans: Mass of carbon = C

Mass of hydrogen = S₂

Mass of sulphur = S

8/3 C + 8H₂ + S

It some oxygen is already present in the fuel the total oxygen for the complete combustion of 1 kg fuel.

$$\left(\frac{8}{3}\text{C} + 8\text{H}_2 + \text{S} \right) - \text{O}_2$$

The 100 minimum air required for 1 kg. fuel.

$$\Rightarrow \frac{100}{23} \left[\left(\frac{8}{3}\text{C} + 8\text{H}_2 + \text{S} \right) - \text{O}_2 \right]$$

Similarly the volume of air required for complete combustion.

$$\text{So, } \frac{100}{21} \times (0.5\text{C}_0 + 0.5\text{H}_2 + 2\text{CH}_4 + 3\text{C}_2\text{H}_2) - \text{O}_2$$

Q. Define calorific value and describe with in types ?2008

Ans: The amount of heat given out by the complete combustion of 1 kg fuel it express on KJ/kg.

It is two types :-

(a) Higher calorific value

(b) Lower calorific value

(a) HIGHER CALORIFIC VALUE:-

It heat is recover from fluid gas and steam is conduct base to is room temperature. Then amount of heat produce per/Kg is known as higher calorific value

Formula $\rightarrow H C_v 33800 + 144000 H_2 + 9270$

(b) LOWER CALORIFIC VALUE:-

The heat absorbed or carried away by the product of combustion is not recovered and steam produced during combustion is not condensate. Then amount of heat often per/kg is known as lower calorific value.

Higher calorific value – Heat of steam from during combustion.

Q. A complete gas use age a fuel has the following volumetric compos ion $H_2 = 28 \%$, $CO = 12 \%$, $CH_4 = 2 \%$, $CO_2 = 16 \%$ and $N_2 = 42 \%$. Find the volumetric of air required from complete combustion of the gas, air content 21 % by volume of oxygen. 2007

Ans: Given Data:

$$H_2 = 28 \% = 0.28 \text{ m}^3$$

$$CO = 12 \% = 0.12 \text{ m}^3$$

$$CH_4 = 2 \% = 0.02 \text{ m}^3$$

$$CO_2 = 16 \% = 0.16 \text{ m}^3$$

$$N_2 = 42 \% = 0.42 \text{ m}^3$$

$$\text{Air} = 21 \% = 0.21$$

$$\begin{aligned} \text{Volumetric air} &= 100/21 (0.5CO + 0.5 H_2 + 2CH_4 + 3C_2H_4) - O_2 \\ &= 100/21 (0.5 \times 12 + 0.5 \times 28 + 2 \times 2 + 3 \times 2 - O_2) \\ &= 0.932 \text{ m}^3 \end{aligned}$$

Q. The volumetric unless of gas f $CO_2 = 14$, $CO = 1 \%$, $O_2 = 5 \%$, $N_2 = 80 \%$, calculated the flow gas composition by mass.2008

Ans: Given Data

$$CO_2 = 14 = 0.14 \text{ m}^3, \quad Co = 1 \% = 0.01 \text{ m}^3$$

$$O_2 = 0.05 \text{ m}^3, \quad N_2 = 80 \% = 0.80 \text{ m}^3$$

Constitant	Volume in 1m ³ of flow gas	Molecular mass	Proportional c= a × b	Mass in kg of flow gas d=c/Σc	% mass
CO ₂	0.14	44	6.16	$\frac{6.16}{30.44} = 0.202$	20.2%
CO	0.01	28	0.28	$\frac{0.28}{30.44} = 0.009$	0.9 %
O ₂	0.05	32	1.60	$\frac{1.60}{30.44} = 0.053$	5.3 %
N ₂	0.80	28	22.40 Σc=30.44	$\frac{22.40}{30.44} = 0.73$	73.61 %

The flow gas composition of mass is CO₂ = 20.2 %, CO = 0.9 %
O₂ = 5.3 %, N₂ = 73.61 %

Q. Define Enthalpy of formation and how does it differ from Enthalpy of combustion.2015,2017/4.b

Ans: A combustion reaction is a particular kind of chemical reaction in which products are formed from reactants with the release or absorption of energy as heat is transferred to or from the surroundings. In some substances like hydrocarbon fuels which are many in number and complex in structure the heat of reaction or combustion may be calculated on the basis of known values of the enthalpy for formation, ΔH_f of the constituent of the reactants and products at the temperature to (reference temperature). The enthalpy of formation.

The increase in enthalpy when a compound is formed from its constituent elements in their natural for hard state. The standard state is 25°C

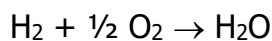
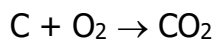
and 1 atm. Pressure, but it must be form in mind that can exist in natural form e.g., H₂O cannot be a vapor at 1 atm and 25°C.

Expression of a particular reaction, for calculation purposes, may be given as:

$$\Delta H_0 = \sum_P n_i \Delta H_{fi} - \sum_R n_i \Delta H_{fi}$$

Typical value of ΔH_f for carbon as a gas at 25°C (298K) is 714852 kJ/mole.

Enthalpy of combustion: The enthalpy of combustion of a substance is the energy released when on substance is completely burned in excess oxygen at 298 K and 1 bar pressure. Enthalpy of combustion is negative as these are exothermic. Standard enthalpy of combustion is : ΔH_c^0 , 298.



It may be expressed with the quantities:

- energy/ mole of fuel (KJ/mol)
- energy/mass of fuel.
- energy/volume of the fuel.

Q. Write Short Notes on the following :

Stoichiometric Air-Fuel (A/F) Ratio.2012

Ans: Stoichiometric (or chemically correct) mixture of air and fuel is one that contains just sufficient oxygen for complete combustion of the fuel.

A weak mixture is one which has an excess of air.

A rich mixture is one which has a deficiency of air.

The percentage of excess air is given as :

Percentage excess air

$$= \frac{\text{Actual A / F ratio} - \text{Stoichiometric A / F ratio}}{\text{Stoichiometric A / F ratio}}$$

(where A and F denote air and fuel respectively).

The ratio are expressed as :

For gaseous fuels By volume

For solid and liquid fuels By mass

For boiler plant the mixture is usually greater than 20 % weak, for gas turbines it can be as much as 300 % weak. Petrol engines have to meet various conditions of load and speed, and operate over a wide range of mixture strength. The following definition is used.

$$\text{Mixture strength} = \frac{\text{Stoichiometric A / F ratio}}{\text{Actual A / F ratio}}$$

The working value range between 80 % (weak) and 120 % (rich).

Q. Write short Notes on the following :

Qualities of I.C. Engine fuels: 2016

Ans: Fuel used in I.C. Engine should possess certain basic qualities which are important for smooth running of the engines. The important qualities of fuels for both S.I. and C.I. engines are discussed below:

S.I. Engine Fuel :-

- (i) Volatility : It is the main characteristic of S.I. engine fuels which determines its suitability for use in it. It should be highly volatile in the operating range of temperature to produce good mixing and combustion.
- (ii) Anti-knock quality: It should have sufficient resistance i.e., high octane number to avoid detonation.
- (iii) Gum deposits : It should not produce any sorts of gum deposits which will cause operating difficulties like sticking valves and piston rings, clogging of carburetor jets etc.
- (iv) Vapor lock characteristics: It should not produce high amount of vapor so that upset the carburetor metering or stopping of fuel flow to the engine can be avoided.
- (v) Starting and warm up : It should have low starting temperature for easy starting of the engine at room temperature.
- (vi) Operating range performance : It should have consistent operating performance for better engine efficiency.
- (vii) Sulphur content: It should be free from any sorts of sulphur or its compounds to avoid corrosion in engine elements, knocking etc.

C.I. Engine Fuel:

- (i) Knock characteristic: It should have high cetane value to avoid knocking.

- (ii) Volatility: It should be sufficiently volatile in the operating range of temperature to produce good mixing and combustion.
- (iii) Starting characteristics: It should possess enough volatility, high cetane value and low self-ignition temperature to ease engine starting quickly.
- (iv) Viscosity: It should be low viscous at the lowest operating temperature to flow easily through the fuel supply system.
- (v) Corrosion and wear: It should have low sulphur, ash etc. Content to avoid corrosion and wear of engine components before or after combustion.
- (vi) Smoking and vapor: It should not promote either smoke or vapor in the engine exhaust.
- (vii) Ease of handling: It should be a liquid that will readily flow under all conditions that are encountered in actual use.
- (viii) It should have low pour point.
- (ix) It should have a high flash and fire point.

Q. Define Octane Number: 2015

Ans: The Octane Number (ON) of a fuel is defined as the percentage by volume, of iso-octane in a mixture of iso-octane and normal heptanes, which exactly matches the knocking intensity of the fuel in a standard engine under a set of standard operating conditions.

Iso-octane (C_8H_{18}) chemically being a very good antiknock fuel is arbitrarily assigned a rating of 100 octane number. Normal heptanes (C_7H_{16}) on the other hand has very poor antiknock qualities and is given a rating of 0 octane number.

Q. Write the difference between 2 stroke & 4 stroke Engine.
2015,2017/3.C

4-Stroke Cycle Engine	2-Stroke Cycle Engine
i. There is one working stroke for every two revolutions of the crank shaft	i. There is one working stroke for each revolution of the crank shaft.
ii. Power developed is one half that of 2-stroke cycle engine for the reason stated in item no.1 above.	ii. Power developed is twice that of 4-stroke cycle engine for the reason stated in item no.1 above
iii. It is mostly a multi-cylinder engine.	iii. It is mostly a single cylinder engine.
iv. Fluctuation of speed during a cycle is high. Hence a fly-wheel of heavier mass is necessary on the crank shaft of a stationary engine.	iv. Fluctuation of speed during a cycle is less. Hence a fly-wheel of lighter mass is necessary on the crank shaft of stationary engine.
v. Engine is heavy.	v. Engine is light.
vi. Engine design is complicated.	vi. Engine design is simple.
vii. There is a separate exhaust port for exhaust of the burnt gas	vii. There is no one single exhaust port like 4-stroke cycle engine.
viii. There is no chance of wastage of useful gas through the exhaust port.	viii. There is a chance of wastage of the useful gas through the exhaust port.
ix. It is water cooled.	ix. It is air cooled.
x. More loss of mechanical energy takes place due to friction on parts whose number is many. Hence mechanical efficiency is less.	x. Less loss of mechanical energy takes place to friction on parts whose number is not many. Hence mechanical efficiency is more.

Q. Write the difference between Petrol Engine & Diesel Engine.2015

Ans:

I.C. ENGINE	STEAM ENGINE
i. In I.C. engine the combustion of fuel takes place inside the engine cylinder ii. It is a high speed engine. iii. Thermal efficiency is higher than that of steam engine (35 to 40 %) iv. Product of combustion of fuel with air is used as the working medium. v. Working pressure and temperature within the cylinder are high. vi. It can be started instantaneously. vii. It is heavy and occupies more space per KW power generated.	i. In steam engine the combustion of fuel takes place outside the engine. ii. It is a low speed engine. iii. Thermal efficiency is very low (13 to 18 %) iv. Steam is used as the working medium. v. Working pressure and temperature within the cylinder are less. vi. It cannot be started instantaneously. vii. It is lighter and occupies less space per KW power generated.

Q. What is Internal combustion engine.2016,2017/2.a

Ans:An engine in which combustion of fuel takes place inside engine cylinder is known as internal combustion engine. Example : I.C. Engine,bike engine,machine engine

Q. Define octane number and certain number with example ?

Ans:Octane number:-2015

- The knocking tendency of a fuel in S.I. Engine is generally expressed by octane number.
- The percentage by volume of iso-octane in a mixture of iso-octane and normal heptane which exactly matching the knocking intensity of a given fuel, under standard operating condition i.e. rating termed as octane number of rating of fuel.

Ex: If a mixture of 50 % iso-octane and 50 % heptane match the fuel under test then the octane number rating is 50.

Cetane Number:-

- Knocking tendency is also found in compression ignition (C.I. engine)
- The knocking in C.I. ignition engine due to sudden ignition and abnormal rapid combustion in the fuel chamber.
- Such a situation occurs because of an ignition lag in the combustion of the fuel between the time of ignition and actual burning.
- The property of ignition lag is generally measured in a term of cetane number.
- It is defined as the percentage by volume of a cetane in a mixture cetane and alpha methyl-naphthalene that produce same ignition lag as the fuel being tested.
- In the mixture of cetane is 50 % and Alfa methyl naphthalene is 50 % then the rate of cetane no. is 50 %.

Q. What is hydrocarbon fuel.2016

Ans: A fuel which contains hydrogen and carbon as its main constituents is known as hydrocarbon fuel.

Example methane (CH_4), ethane (C_2H_6) etc.

Q. make a comparison between otto cycle and diesel cycle ?2017/3.b

Ans: Difference Between Otto Cycle and Diesel Cycle

- The Otto cycle was given by German scientist Otto, in 1876 and diesel cycle was discovered by Dr. Rudolph Diesel in 1893.

- In Otto cycle the heat addition is takes place at constant volume where as in diesel cycle heat is added at constant pressure.
- Petrol engines work on Otto cycle and diesel engines work on diesel cycle.
- In Otto cycle at the time of heat addition, the piston is at TDC where as in diesel cycle when the piston is in backward stroke, the heat addition begins and last at a portion of piston stroke.
- The Otto cycle has less compression ratio (7:1 to 10:1) but in diesel cycle the compression ratio is high (11:1 to 22:1). In Otto cycle as well as in diesel cycle heat rejection takes place at constant volume.
- The efficiency of Otto cycle is less as compared with the Diesel cycle.

Q: what do you mean by stoichiometric combustion? 2017/4.a

Ans : Stoichiometric combustion is by thermodynamic definition the theoretical combustion of every drop of fuel when mixed with the correct amount of air (a basic mixture of oxygen and nitrogen gases) to yield exhaust products of only CO₂ and H₂O.

However, such combustion is ideal and in reality doesn't occur since the burning in furnaces, automobiles and jet-engines is always incomplete and less than 100% due to engineering design limitations.

Q: explain in brifly about the heating value of a fuel and its quality ?2017/4.c

Ans : CALORIFIC VALUE OF FUELS

When fuels are burnt, heat is produced. The amount of heat produced by different types of fuels on burning is expressed in terms of calorific value. **Calorific value** of a fuel may be defined as the amount of heat produced on complete burning of 1 gm of fuel. S.I. unit of calorific value of fuels is **kilojoule per gram (KJ/g)**. For example, when one gram of wood is burnt completely it produces 17

kilojoules heat. Therefore, the calorific value of wood is 17 KJ/g. in similar manner, when 1 gm of kerosene oil is burnt completely it produces 48 kilojoules heat. So, the calorific value of kerosene oil is 48 KJ/g.

the calorific value of different types of fuels is given in following table.

Higher calorific value (HCV) = It is the total heat liberated in KJ or Kcal by the complete combustion of 1 Kg of fuel.

Lower calorific value (LCV) = It is the difference of Higher calorific value and heat absorbed by water vapors.

$$\text{LCV} = (\text{HCV} - x \cdot 588.76) \text{ Kcal/Kg}$$

Where 'x' is the fraction of water vapors.

Table of calorific value of fuels

Serial No.	Fuel	Calorific value
1.	Hydrogen	150 KJ/g
2.	Methane	55 KJ/g
3.	LPG	50 KJ/g
4.	Kerosene oil	48 KJ/g
5.	Charcoal	33 KJ/g
6.	Wood	17 KJ/g

Significance of Calorific Value

It becomes clear from table given above that different fuels have different calorific values, i.e. different fuels produce different amounts of heat on burning. The calorific value of fuels helps us to decide that which fuel is good for us. This is done by comparing the calorific values of fuels with each other. Usually, a fuel having higher calorific value is considered to be a good fuel.

1) Case of Hydrogen Gas

Hydrogen gas has the highest calorific value of 150 KJ/g among all

the fuels. So, hydrogen gas is considered to be an extremely good fuel. However, hydrogen gas is not used as a fuel in homes and industries. The main reasons for this are:

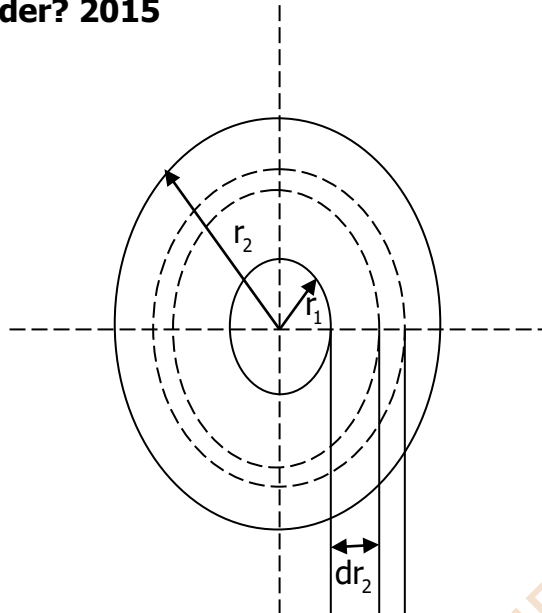
1. Hydrogen gas is highly combustible and it burns with explosion when lighted.
2. The storage and transportation of hydrogen gas from one place to another is very difficult.
3. The cost of production of hydrogen gas is very high. So, it is an expensive fuel.

2) **Case of Methane and Butane**

Almost all the fuels consist of atoms of hydrogen and carbon. Since, the calorific value of fuels depends on the percentage of hydrogen present in them so the fuels which have higher percentage of hydrogen will have higher calorific value as compared to those fuels which have lower percentage of hydrogen. The percentage of hydrogen present in methane is 25% whereas the percentage of hydrogen present in butane is 17%. Due to this reason, methane has higher calorific value as compared to butane.

CHAPTER: 4

Q. Write down the expression of heat conduction through a hollow cylinder? 2015



$$A = 2\pi rL$$

hollow cylinder length L

$$Q = r.A. \frac{dT}{dr}$$

$$Q = k \times 2\pi rL \times \frac{dT}{dr}$$

$$= 2k\pi rL \times \frac{dT}{dr}$$

$$\Rightarrow \frac{dr}{r} = \frac{-2k\pi L dT}{Q}$$

$$\Rightarrow \int_{r_1}^{r_2} \frac{1}{r} dr = \frac{-2k\pi L}{Q} \int_{T_1}^{T_2} dT$$

$$\Rightarrow \ln r \Big|_{r_1}^{r_2} = \frac{-2k\pi L T}{Q} \Big|_{T_1}^{T_2}$$

$$\Rightarrow \ln \left(\frac{r_2}{r_1} \right) = \frac{-2k\pi L}{Q} (T_2 - T_1)$$

$$\Rightarrow \ln \left(\frac{r_2}{r_1} \right) = \frac{2k\pi L}{Q} (T_1 - T_2)$$

$$\Rightarrow Q = \frac{2k\pi L (T_1 - T_2)}{\ln \left(\frac{r_2}{r_1} \right)}$$

Consider a hollow cylinder made of material having constant thermal conductivity and insulated at both ends.

Let r_1 and r_2 = inner and outer radius of cylinder

T_1 and T_2 = Temp. of inner and outer surface.

K = constant thermal conductivity

Consider an element at radius 'r' and thickness 'dr' for length of hollow cylinder through which heat is transmitted.

Q. Write down the expression of heat conduction through hollow sphere.2012

Ans: $Q = -K \times A = d\pi/dr$

$$A = 4 \pi r^2$$

$$Q = -K \times 4\pi r^2 \times dT/dr$$

$$\frac{dr}{dr^2} = -\frac{k4\pi}{Q} dt$$

$$\int_{r_1}^{r_2} \frac{dr}{dr^2} = \int_{r_1}^{r_2} \frac{-k4\pi}{Q} dt$$

$$\Rightarrow \int_{r_1}^{r_2} r^{-2} dr = \frac{-k4\pi}{Q} \int_{T_1}^{T_2} dT$$

$$\Rightarrow \left[\frac{r}{-2+1} \right]_{r_1}^{r_2} = \frac{-k4\pi}{Q} T_2$$

$$\Rightarrow -\frac{1}{r} \Big|_{r_1}^{r_2} = \frac{-k4\pi}{Q} (T_2 - T_1)$$

$$\Rightarrow 1 - \left(\frac{1}{r_2} - \frac{1}{r_1} \right) = + \frac{4k\pi}{Q} (T_2 - T_1)$$

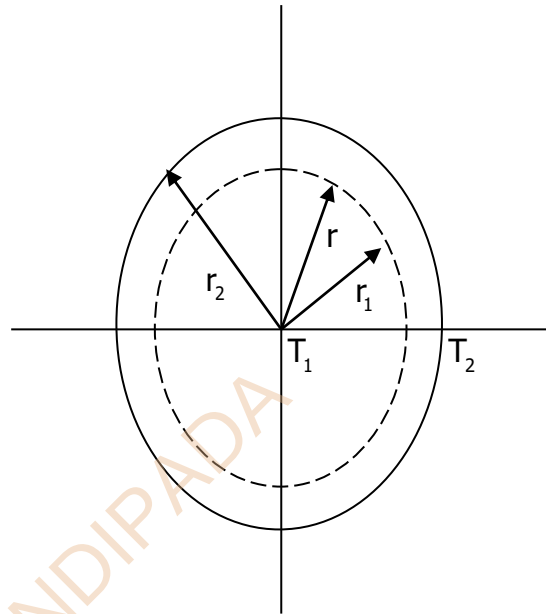
$$\Rightarrow \frac{1}{r_1} - \frac{1}{r_2} = \frac{4k\pi}{Q} (T_2 - T_1)$$

$$\Rightarrow \left(\frac{r_1 - r_2}{r_1 r_2} \right) Q = 4\pi k (T_1 - T_2)$$

$$\Rightarrow Q = \frac{4k\pi(T_1 - T_2)}{\left(\frac{r_2 - r_1}{r_1 r_2} \right)}$$

$$Q = \frac{(T_1 - T_2)}{\left(\frac{r_2 - r_1}{r_1 r_2} \right) rk\pi}$$

$$Q = \frac{4k\pi(T_1 - T_2)(r_1 r_2)}{r_2 - r_1}$$



Let : r_1 and r_2 are the inner and outer radius of the sphere.

T_1 and T_2 = the temp. of inner and outer radius

K = constant thermal conductivity.

Q. A spherical shape vessel of 1.4m dia and 90 mm thick. Find the rate of heat loss if the temp. Difference between inner and outer is 220°C take thermal conductivity is 0.083 watt/mk. 2010

Ans:

Given Data:-

$$D_2 = 1.4 \text{ m}$$

$$R_2 = 0.7 \text{ m}$$

$$\text{Thickness} = 90 \text{ mm} = 0.09 \text{ m}$$

$$T_1 - T_2 = 220^\circ\text{C} = 220 + 273 = 493 \text{ K}$$

$$K = 0.023 \text{ w/km}$$

$$Q = \frac{4k\pi(T_1 - T_2)}{\left(\frac{r_2 - r_1}{r_1 r_2}\right)}$$

$$r_1 = r_2 - \text{thickness}$$

$$r_2 = 0.7 - 0.09$$

$$r_1 = 0.61 \text{ m}$$

$$Q = \frac{4k\pi(T_1 - T_2)}{\left(\frac{r_2 - r_1}{r_2 r_1}\right)} = \frac{4 \times 0.023 \times \pi(493)}{\left(\frac{0.7 - 0.61}{(0.7)(0.61)}\right)}$$

$$= 676.036 \text{ K} = 676.036 - 273 = 403.036^\circ\text{C}$$

Q. A metal piece having an external diameter of 150mm carries a steam at 200°C. The pipe is covered by a 25 mm thick insulating material whose conductivity is 0.21 W/m. If the outer surface is at 100°C, find the amount of heat loss per m/min. 2010

Ans: Given data

$$r_2 = 75 \text{ mm} = 0.075 \text{ m}$$

$$\text{dr} = 25 = 0.025 \text{ m}$$

$$T_2 = 100^\circ\text{C}$$

$$T_1 = 200^\circ\text{C} + 273 = 473 \text{ K}$$

$$K = 0.21$$

$$D_2 = 150 \text{ mm} = 0.15 \text{ m}$$

$$L = 1 \text{ m}$$

$$\begin{aligned} Q &= \frac{2k\pi L (T_1 - T_2)}{\ln\left(\frac{r_2}{r_1}\right)} \\ &= \frac{2 \times 0.21 \times \pi \times 60 (473 - 373)}{\ln\left(\frac{0.075}{0.050}\right)} \\ &= 1952.2 \text{ J} \end{aligned}$$

Q. Water flows inside a tube 45 mm diameter and 3.2 m long at a velocity of 0.78 m/sec. Determine the heat transfer coefficient and rate of heat transfer. If the mean water temperature is 50°C and the wall is isothermal at 70°C. for water at 50°C.

$$K = 0.66, \quad V = 0.478 \times 10^{-6}, \quad \text{Pr} = 2.98 \quad 2015$$

Ans: Given data

$$D = 45 \text{ mm} = 0.045 \text{ m}$$

$$L = 3.2 \text{ m}$$

$$U = 0.78 \text{ m/sec}$$

$$t_F = 50^\circ\text{C}$$

$$t_S = 70^\circ\text{C}$$

$$k = 0.66$$

$$v = 0.478 \times 10^{-6}$$

$$pr = 2.981$$

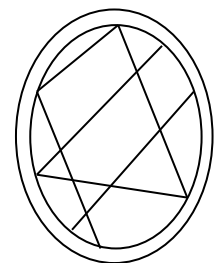
we know that

$$\begin{aligned}
 N_4 &= 0.023 \times Re^{0.8} \times pr^{0.4} \\
 \Rightarrow \frac{hD}{k} &= 0.023 \times \left(\frac{pvD}{\mu} \right)^{0.8} \times (2.981)^{0.4} \\
 \Rightarrow \frac{h \times 0.045}{0.66} &= 0.023 \times \left(\frac{1}{v} \times vd \right)^{0.8} \times (2.981)^{0.4} \\
 \Rightarrow \frac{h \times 0.045}{0.66} &= 0.023 \times \left(\frac{1}{0.478 \times 10^{-6}} \times 0.78 \times 0.045 \right)^{0.8} \times (2.981)^{0.4} \\
 \Rightarrow \frac{h \times 0.045}{0.66} &= 278.08 \\
 \Rightarrow h \times 0.045 &= 278.08 \times 0.66 \\
 \Rightarrow h &= \frac{278.08 \times 0.66}{0.045} = 4078.50 \\
 Q &= h \times A \times (t_s - t_f) = 4078.50 \times 4.52 \times (70 - 50) \\
 &= 368696.4 \\
 Rc &= \frac{suD}{\mu} = \frac{1}{v} \times vD = \frac{1}{0.478 \times 10^{-6}} \times 0.78 \times 0.045 \\
 &= 73430.96
 \end{aligned}$$

Q. Write down the properties of black body.2009

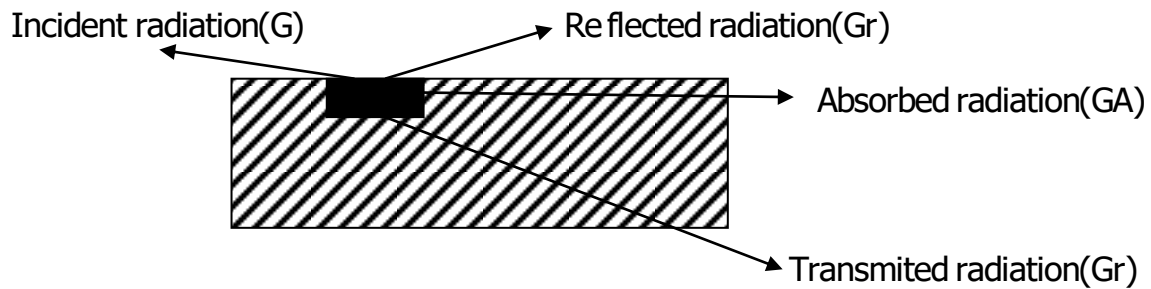
Ans:i. It absorb all the incident radiation on it and does not transmitted or reflected resources off web length and direction.

- ii. It emit maximum amount of thermal radiation at all weave length a at any specified temp. Consider a hole include with a very small hole for passing of incident radiation as shown in the fig. The incident radiant energy pass through the small opening, some of the energy is absorb by inside surface and some reflected who above most of the energy is absorbed in second radiation after absorbing the energy. it strike in the energy the level of heat increases so the on black body by absorbing heat energy to produce high temp.



Q. Derive the Emissivity, absorptivity, Reflectivity and transmittivity.

2008,2017/6.b



$$G = Gr + GA + GT$$

$$\frac{G}{G} = \frac{Gr + GA + GT}{G}$$

$$1 = \frac{Gr}{G} + \frac{GA}{G} + \frac{GT}{G}$$

$$\frac{GA}{G} = \alpha$$

$$\frac{Gr}{G} = p, \quad \frac{GT}{G} = \tau$$

$$\alpha + p + \tau = 1$$

When incident radiation also called as irradiation (Defined as the total incident radiation on a surface from all direction per unit time and per unit surface area expressed in watt/m² and denoted (G). There are three thing is happened reflected back (Gr), Transmitted through (GT) absorbed (GA). Depending upon the characteristics of the body by the conservation of energy principle.

$$G = Gr + GA + GT$$

Deviding both side (G)

$$\frac{G}{G} = \frac{Gr}{G} + \frac{GA}{G} + \frac{GT}{G}$$

$$1 = p + \alpha + \tau$$

$$\alpha + p + \tau = 1$$

where

$$\alpha = \text{Abservity} = \frac{GA}{G}$$

$$p = \text{Re flectivity} = \frac{Gr}{G}$$

$$\tau = \text{Transmitivity} = \frac{GT}{G}$$

Q: state newtons law of cooling ?2017/6.a

Ans: According to Newton's Law of Cooling, the rate of cooling of a body is directly proportional to the difference in temperatures of the body (T) and the surrounding (T_0), provided difference in temperature should not exceed by 30°C.

From the above statement,

$$\frac{dQ}{dt} \propto (T - T_0)$$

Q: state and explain fouriers law of heat conduction ?2017/5.b

Ans: The law of heat conduction is also known as Fourier's law. Fourier's law states that

“the time rate of heat transfer through a material is proportional to the negative gradient in the temperature and to the area.”

Fourier's equation of heat conduction:

$$Q = -kA(dT/dx)$$

Where,

'Q' is the heat flow rate by conduction (W)

'k' is the thermal conductivity of body material ($W \cdot m^{-1} \cdot K^{-1}$)

'A' is the cross-sectional area normal to direction of heat flow (m^2) and

'dT/dx' is the temperature gradient ($K \cdot m^{-1}$).

- Negative sign in Fourier's equation indicates that the heat flow is in the direction of negative gradient temperature and that serves to make heat flow positive.
- Thermal conductivity 'k' is one of the transport properties. Other are the viscosity associated with the transport of momentum, diffusion coefficient associated with the transport of mass.
- Thermal conductivity 'k' provides an indication of the rate at which heat energy is transferred through a medium by conduction process.

Assumptions of Fourier equation:

- Steady state heat conduction.
- One directional heat flow.
- Bounding surfaces are isothermal in character that is constant and uniform temperatures are maintained at the two faces.
- Isotropic and homogeneous material and thermal conductivity 'k' is constant.
- Constant temperature gradient and linear temperature profile.
- No internal heat generation.

Q. Write down the expression of convection heat transfer Newton's law of cooling ?2016

Ans: The rate of equation for the convection heat transfer between a surface and adjacent fluid is presented by Newton law of cooling.

$$Q = h \times A \times (t_s - t_f)$$

Where ,

Q = rate of conductivity of heat transfer.

T_S = Surface temperature

T_F = fluid temperature

H = co-efficient of conductivity of heat transfer.

$$\Rightarrow h = \frac{Q}{A \times (t_s - t_f)} = \frac{w}{m^2 \text{ } ^\circ\text{C}} = w / m^2 \text{ } ^\circ\text{C} \text{ or } w / m \text{ K}$$

The 'h' is related to density, velocity diameter, thermal conductivity etc.

Where N₄ – nusent number = hd/k

Re = Reynolds number = sud/μ

Pr = or ndtl number cpμ/k

$$N_4 = Z \times Re^a \times pr^b \times (D/L)^c$$

$$\Rightarrow N_4 = 0.023 \times Re^{0.8} \times pr^{0.4}$$

Q. A wire 1.5 mm of dia and 150 mm long is submerged in water at atmospheric pressure. A electric current is passed through the wire and increased until the water boil at 100°C under the condition of convection the heat transfer co-efficient is 4500 w/m² °C. Find how much electric power must be supply to the wire to maintain the wire surface at 120°C. 2008

Ans: Given data:-

$$d = 1.5 \text{ mm} = 0.0015 \text{ m}$$

$$L = 150 \text{ mm} = 0.15 \text{ m}$$

$$t_s = 120^\circ\text{C}$$

$$t_f = 100^\circ\text{C}$$

$$h = 4500 \text{ w/m}^2 \text{ } ^\circ\text{C}$$

$$Q = h \times A \times (t_s - t_f)$$

We know that $A = JCDL$

$$\Rightarrow \pi \times 0.0015 \times 0.15 = 7.06 \times 10^{-4}$$

$$\begin{aligned}\Rightarrow Q &= h \times A \times (t_s - t_f) \\ &= 4500 \times 7.06 \times 10^{-4} \times (120 - 100) \\ &= 63.54.\end{aligned}$$

Q. A boiler is made up of iron plates 12 mm thick. If the temperature of outside surface be 120°C and that of inner 100°C. Calculate mass of water evaporated per hour. Assume the area of heating surface as 5m² and thermal conductivity of iron as 84 w/mk. 2015 (s) 4(c)

Ans: $x = 12 \text{ mm} = 0.012 \text{ m}$
 $T_1 = 120^\circ\text{C} = (120 + 273) \text{ K} = 393 \text{ K}$
 $T_2 = 100^\circ\text{C} = (100 + 273) \text{ K} = 373 \text{ K}$
 $t = 1 \text{ hour} = 3600 \text{ second}$
 $k = 84 \text{ W/mK}$

Amount of heat transferred

$$\begin{aligned}Q &= \frac{kA(T_1 - T_2) \times t}{x} = \frac{84 \times 5 \times (393 - 373) \times 3600}{0.012} \\ &= 2520 \times 10^6 \text{ J/h} = 2520 \times 10^3 \text{ KJ/h}\end{aligned}$$

We know that heat required to evaporate 1 kg of water at 100°C is equal to its latent heat i.e. 2260 KJ

$\therefore$ Mass of water evaporated per hour

$$\begin{aligned}&= \frac{\text{total amount of heat transferred}}{\text{Heat required to evaporate 1 kg of water}} \\ &= \frac{2520 \times 10^3}{2260} = 1115 \text{ kg}\end{aligned}$$

Q. A steam pipe 20 m long 100 mm internal diameter and 40 mm thick is covered by a layer of lagging of 25 mm thick. The co-efficient of thermal conductivity for pipe material and lagging are 0.7 w/mk and 0.1 w/mk respectively. If the steam is conveyed at a pressure of 17 bar with 30°C super heat and outside temperature of lagging is 24°C. Determine.. 2015

1. Heat lost per hour

2. The interface temperature

Neglect pressure drop across steam pipe.

Ans: $L = 20 \text{ m}$

$$D_1 = 100 \text{ mm or } r_1 = 50 \text{ mm} = 0.05 \text{ m}$$

$$R_2 = r_1 + \text{pipe thickness} = 50 + 40 = 90 \text{ mm} = 0.09 \text{ m}$$

$$R_3 = r_2 + \text{lagging thickness} = 90 + 25 = 115 \text{ mm} = 0.115 \text{ m}$$

$$K_1 = 0.7 \text{ w/mk}$$

$$K_2 = 0.1 \text{ w/mk}$$

$$\text{Degree of super heat} = 30^\circ\text{C}$$

$$T_3 (24 + 273) \text{ k} = 297 \text{ k}$$

total heat lost per hour

From steam table the temperature of steam corresponding to pressure of 17 bar.

$$T_1 = (204.3 + 273) \text{ k} = 507.3 \text{ k}$$

Total heat lost per second

$$\begin{aligned} A &= \frac{2\pi l(T_1 - T_3)}{\frac{1}{k_1} \times 2.3 \log\left(\frac{r_2}{r_1}\right) + \frac{1}{k_2} \times 2.3 \log\left(\frac{r_3}{r_2}\right)} \\ &= \frac{2\pi \times 20 \times (507.3 - 297)}{\frac{1}{0.07} 2.3 \log\left(\frac{0.09}{0.05}\right) + \frac{1}{0.1} 2.3 \log\left(\frac{0.115}{0.09}\right)} \\ &= \frac{2\pi \times 20 \times 210.3}{8.39 + 2.45} = 2438 \text{ J/s} \end{aligned}$$

$$\begin{aligned}\text{Heat lost per hour} &= 2438 \times 3600 \\ &= 8776800 \text{ J/h} = 8776.8 \text{ kJ/h}\end{aligned}$$

Interface temperature

Let T_2 = Interface temperature

We shall consider the flow of heat (i.e. 2438 J/s) through steam pip

We know that

$$Q = \frac{2\pi kl(T_1 - T_2)}{2.3 \log \left(\frac{r_2}{r_1} \right)}$$

$$\text{or } 2438 = \frac{2\pi \times 0.07 \times 20(507.3 - T_2)}{2.3 \log \left(\frac{0.09}{0.05} \right)}$$

$$= \frac{8.8(507.3 - T_2)}{0.587}$$

$$\text{or } T_2 = 344.6 \text{ K} = (344.6 - 273)^\circ\text{C} = 71.6^\circ\text{C}$$

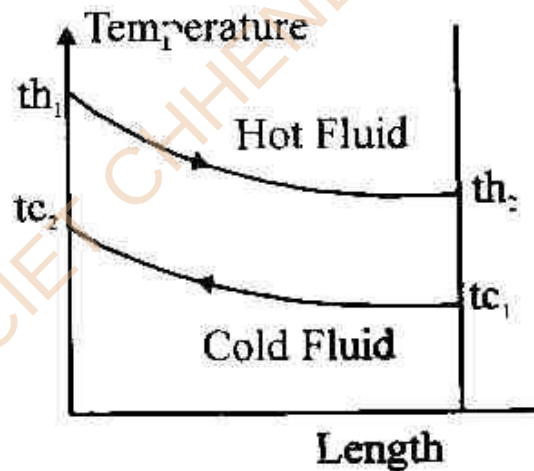
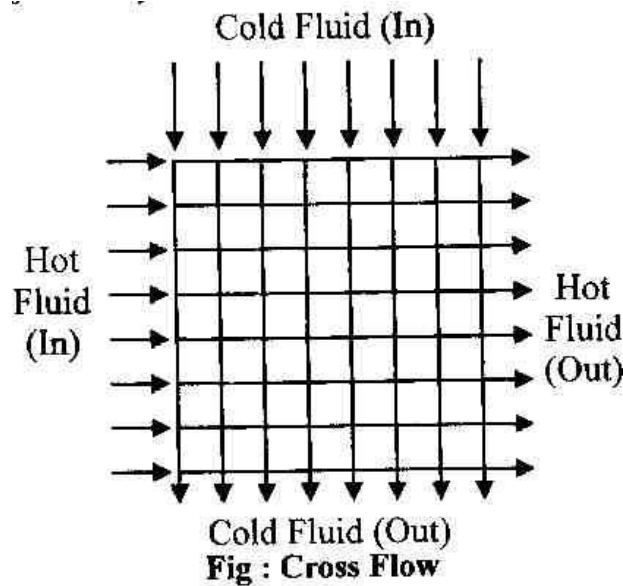


Fig : Counter Flow Heat Exchanger

In cross flow heat exchangers the two fluids (hot and cold) cross one another in space usually at right angles.

Ex.: Automobile radiators, cooling unit of refrigeration system etc.



According to design and constructional features:

- Concentric tubes : In this type two concentric tubes are used, each carrying one of the fluids. The direction of flow may be parallel or counter.
- Shell and tube: In this type the fluids flow through a bundle of tubes enclosed by a shell.
- Multiple shell and tubes passes : In this type heat exchanger the fluid is re-routed through the tubes in the opposite direction.
- Compact heat exchangers : These are special purpose heat exchangers and have a very large transfer surface area per unit volume of the exchanger.

Ex: Plate fin, flattened fin tube exchangers etc.

Q. Heat transfer Radiation.2008

Ans: Radiation heat transfer is defined as the transfer of energy across a system boundary by means of an electro-magnetic mechanism which is caused solely by a temperature difference, whereas the heat transfer by conduction and convection takes place only in the presence of medium, radiation heat transfer does not require a medium. Radiation exchange, in fact occurs most effectively in vacuum. Further, the rate of heat transfer by conduction and convection varies as the temperature difference to the first power, whereas the radiant heat exchange between two bodies depends on the difference between their temperature to the 'fourth power'. Both the amount of radiation and the quality of radiation depend upon temperature.

The dissipation from the filament of a vacuum tube or the heat leakage through the evacuated walls of a thermos flask are some familiar example of heat transfer by radiation.

The contribution of radiation to heat transfer is very significant at high absolute temperature levels such as those prevailing in furnaces, combustion in chambers nuclear explosions and in space applications. The solar energy incident upon the earth is also governed by the laws of radiation. The energy which a radiating surface releases is not continuous but is in the form of successive and separate packet or quanta of energy called photons. The photons are propagated through space as rays.

Q. What is Heat Exchanger ? Discuss about various types of Heat Exchangers.2015

Ans:A heat exchanger may be defined as an equipment which transfers the energy from a hot fluid to a cold fluid, with maximum rate and minimum investment and running costs.

Ex. Condensers and boilers in a steam power plant.

Automobile radiators, oil coolers, chillers, inter coolers, air pre heater etc.

Q. Describe Difference Types of Heat Exchangers:2015,2017/6.c

Ans:Heat exchangers are following types:

(I) According to heat exchange process:

Direct contact or open heat exchangers.

Indirect contact heat exchangers.

(a) Regenerators

(b) Recuperates

In direct contact or open heat exchange the exchange of heat takes place by direct

Mixing of hot and cold fluids and transfer of heat and mass takes place simultaneously.

Ex: Cooling towers, jet condensers

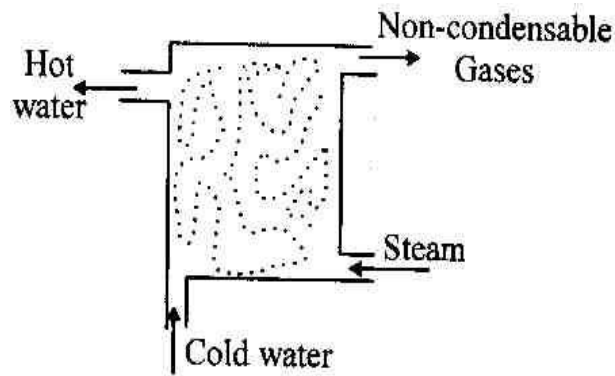


Fig: Direct contact Heat Exchanger

In indirect type heat exchangers, the heat transfer between two fluids carried out by

Transmissions through wall which separates the two fluids.

These are following types:

- (i) Regenerators: Hot or cold fluid pass alternately through a space containing solid particles(matrix).

Ex : I.C. Engines, Gas turbines, Open hearth furnaces etc.

- (ii) Recuperates: Exchange heat on generally either side of dividing wall generally in the form of pipes and tubes.

Ex: Automobile radiators, Oil coolers, air preheaters, economizers etc.

- (iii) According to the direction of fluid motion:

→ Parallel flow or uni direction flow

→ Counter flow

→ Cross flow

In parallel flow heat exchanger, the two fluid streams (hot and cold) travel in the same direction i.e., the two stream enter at one end and leave at the other end.

Ex: Oil coolers, water heaters etc.

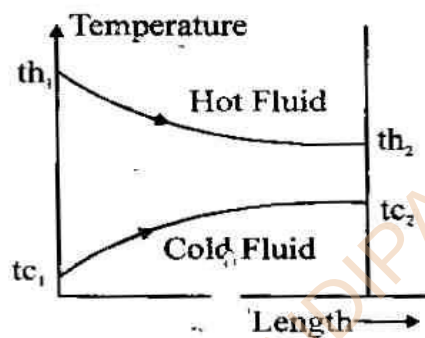
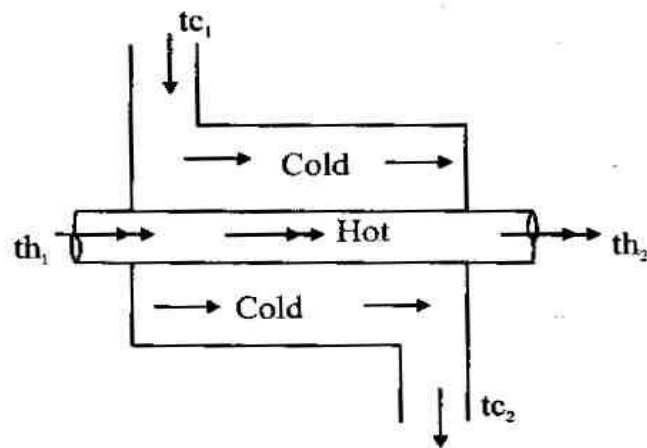
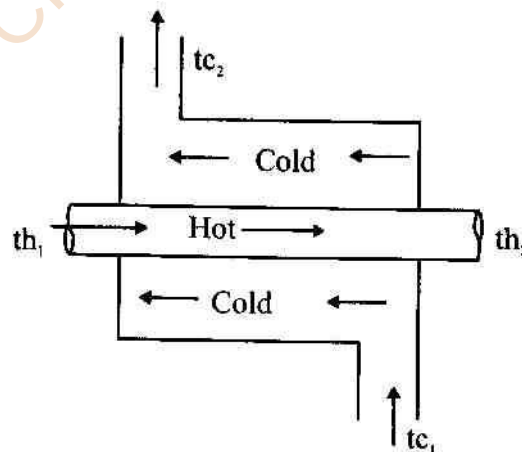


Fig : Parallel Flow Heat Exchanger

In counter flow heat exchangers the two fluids flow in opposite directions. The hot and cold fluids enter at the opposite ends.

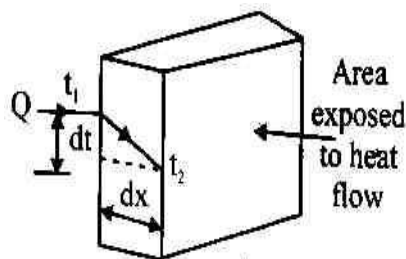
Ex: Air pre heater



Q. Define Fourier's law of heat conduction and Newton's law of cooling.2015

Ans: Fourier's law of heat is an experimental law based on observation and states as follows :

"The rate of flow of heat through a simple homogeneous solid is directly proportional to the area of the section at right angles to the direction of heat flow, and to change of temperature with respect to the length of the path of the heat flow".



Q. Briefly explain Kirchhoff's law related to spectral emissive power to absorptivity.2016

Ans: Kirchhoff's law: The law states that at any temperature the ratio of total emissive power (E) to the total absorptivity (α) is a constant for all substances which are in thermal equilibrium with their environment.

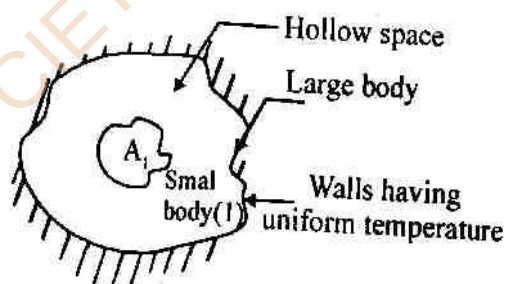


Fig: Kirchhoff's Law

Let us consider a large radiating body of surface area which encloses a small body (1) of surface area and the energy fall on the unit surface of the body at the rate E_b of this energy, generally, a fraction α , will be absorbed by the small body. Thus this energy absorbed by the small body (1) is $\alpha_1 A_1 E_b$, in which α_1 is the absorptivity of the body. When thermal equilibrium is attained the energy absorbed by the body (1) must be equal to the energy emitted, say, E_1 per unit surface. Thus, at equilibrium

$$A_1 E_1 = \alpha_1 A_1 E_b \text{ ----- (1)}$$

Now, we remove body (1) and replace it by body (2) having absorptivity α_2 . The radioactive energy impinging on the surface of this body is again E_b . In this case, $A_2 E_2 = \alpha_2 A_2 E_b \text{ -----(2)}$

By considering generality of bodies, we obtain

$$E_b = \frac{E_1}{\alpha_1} = \frac{E_2}{\alpha_2} = \frac{E}{\alpha} \text{ -----(3)}$$

Also as per definition of emissivity ε , we have

$$\varepsilon = \frac{E}{E_b} \quad \text{or} \quad E_b = \frac{E}{\varepsilon} \text{ -----(4)}$$

By comparing equations (3) and (4) we obtain $\varepsilon = \alpha$

α is always smaller than 1,. Therefore, the emissive power E is always smaller than the emissive power of a black body at equal temperature.

Thus, Kirchhoff's law also states that the emissivity of a body is equal to its absorptivity when the body remains in thermal equilibrium with its surroundings.

Q. Explain shortly various modes of heat transfer.2015,2017/5.a

Ans: Heat transfer which is defined as the transmission of energy from one region to another as a result of temperature gradient takes place by the following three modes :

- (i) Conduction (ii) Convection (iii) Radiation

(i) Conduction :

Conduction is the transfer of heat from one part of a substance to another part of the same substance or from one substance to another in physical contact with it, without appreciable displacement of molecules forming the substance. In solids, the heat is conducted by the following two mechanisms:

By lattice vibration (the faster moving molecules or in the hottest part of a body transfer heat by impacts some of their energy to adjacent molecules).

By transport of free electrons (Free electrons provide an energy flux in the direction of decreasing temperature) For metals, especially good electrical conductors, the electronic mechanism is responsible for the major portion of the heat flux except at low temperature.

In case of gases, the mechanism of heat conduction is simple. The kinetic energy of a molecule is a function of temperature. These molecules are in a continuous random motion exchanging energy and momentum. When a molecule from the high temperature region, it losses energy by collisions. In liquids, the mechanism of heat is nearer to that of gases. However, the molecules are more closely spaced and intermolecular forces come into play.

(ii) Convection:

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

- Convection is possible only in a fluid medium and is directly linked with the transport of medium itself.
- Convection constitutes the macro form of the heat transfer since macroscopic particles of fluid moving in space cause the heat exchange.
- The effectiveness of heat transfer by convection depends largely upon the mixing motion the fluid.

Free Natural convection : Free or natural convection occurs when the fluid circulates by virtue of the natural differences in densities of hot and cold fluids, the denser portions of the fluid move downward because of the greater force of gravity, as compared with the force on the less dense.

Forced Convection : When the work is done to blow or pump the fluid, it is said to be forced convection.

(iii) Radiation :

Radiation is the transfer of heat through space or matter by means other than conduction or convection. Radiation heat is thought of as electromagnetic waves or quanta an emanation of the same nature as light and radio waves. All bodies radiate heat, so a transfer of heat by radiation occurs because hot body emits more heat than it receives and a cold body receives more heat than it emits. Radiant energy requires no medium for propagation and will pass through vacuum.

Q. State Stefan Boltzmann law.2015

Ans: Stefan Boltzmann law states that the emissive power of a black body is directly proportional to the fourth power of its absolute temperature.

i.e., $E_b = \sigma T^4$

where E_b = Emissive power of a black body.

σ = Stefan-Boltzmann constant.

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

$$E_b = 5.67 (T/100)^4$$

Newton's Law of cooling:

The rate equation for the convective heat transfer (regardless of particular nature) is directly proportional to the temperature difference between a surface and an adjacent fluid is prescribed by Newton's law of cooling.

$$Q = hA (t_s - t_f)$$

Where Q = Rate of conductive heat transfer

A = Area exposed to heat transfer.

t_s = Surface temperature

t_f = Fluid temperature, and

h = Co-efficient of conductive heat transfer.

The units of h are ,

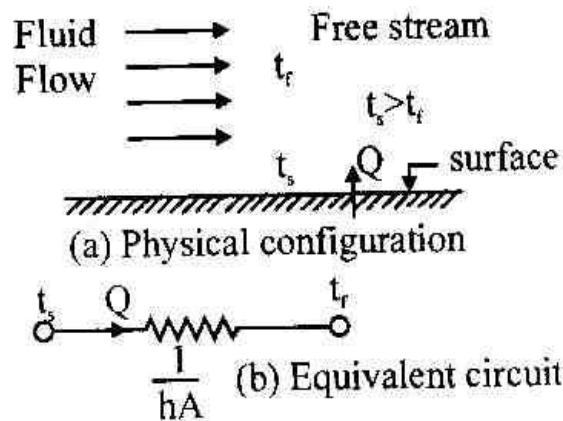
$$h = \frac{Q}{A(t_s - t_f)} = \frac{W}{m^2 \text{ } ^\circ\text{C}} \text{ or } W / m^2 \text{ } ^\circ\text{C} \text{ or } W / m^2\text{K}.$$

The co-efficient of convective heat transfer 'h' (also known as film heat transfer co-efficient) may be defined as "the amount of heat transmitted for a unit temperature difference between the fluid and unit area of surface in unit time.

The value depends on following factors.

- (i) Thermodynamics and transport properties viscosity, density, specific heat etc.)
- (ii) Nature of fluid flow
- (iii) Geometry of the surface

(iv) Prevailing thermal conditions.



Q. Describe Kirchhoff's law ?2015

Ans: The law states that at any temperature the ratio of total emission power (E) to the total absorptivity α is a constant for all substances which are in thermal equilibrium with their environment. Consider a large radiation body of surface area A which contains a small body of surface area A_1 . Let the energy emitted from the unit surface of the body at the rate E_b ; thus this energy is absorbed by small body 1 as $\alpha_1 A_1 E_b$ in which α_1 is absorptivity of the body when thermal equilibrium is at effect the energy absorptivity by small body must be equal to the energy emitted that means E_1 the unit surface so $A_1 E_1 = \alpha_1 A_1 E_b$ when body one is replaced two body to then

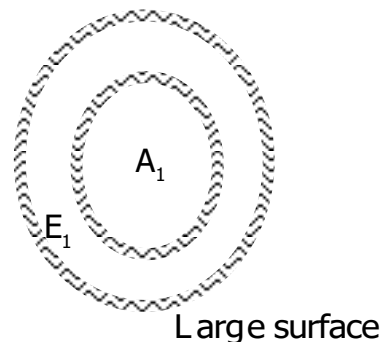
$$A_2 E_2 = \alpha_2 A_2 E_b$$

$$E_b = \frac{E_1}{\alpha_1}$$

$$E_b = \frac{E_2}{\alpha_2}$$

$$E_b = \frac{E}{\alpha}$$

$$E_b = \frac{E_1}{\alpha_1} = \frac{E_2}{\alpha_2} = \frac{E}{\alpha}$$



Thus this law also says that emissivity of the body is equal to the absorptivity when the body remains in thermal equilibrium with its surrounding total emissivity

$$\varepsilon = \frac{E}{E_b}$$

$$E_b = \frac{E}{\varepsilon}$$

$$\alpha = \varepsilon$$

CHAPTER:5

Q. What is the function of refrigerator?2016

Ans: A refrigerator is a reversed heat engine which either cools or maintains the temperature of body (T_1) lower than the atmospheric temperature (T_a). This is done by extracting heat (Q_1) from cold body and delivering it to hot body (Q_2)

Q. what do you mean by refrigeration ? 2017/7.a

Ans: Refrigeration is a process of removing heat from a low-temperature reservoir and transferring it to a high-temperature reservoir. The work of heat transfer is traditionally driven by mechanical means, but can also be driven by heat, magnetism, electricity, laser, or other means. Refrigeration has many applications, including, but not limited to: household refrigerators, industrial freezers, cryogenics, and air conditioning

Q. What is the concept of Refrigerator and heat pump.2015

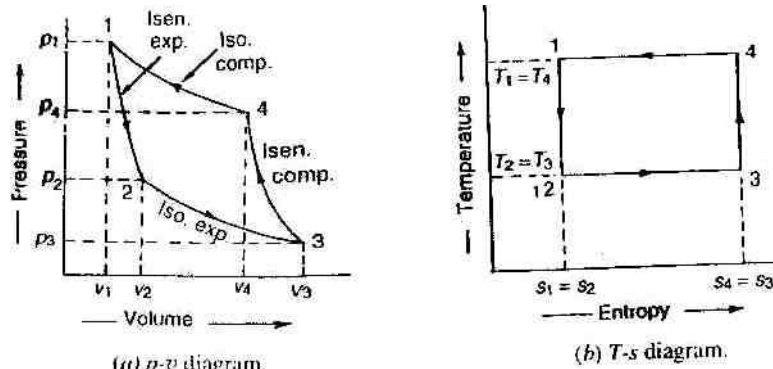
Ans: Refrigerator: A refrigerator is a reversed heat engine which either cools or maintains the temperature of body (T_c) lower than atmospheric temperature. This is done by extracting heat (Q_1) from cold body and delivering it to hot body (Q_2). In doing so work W_R is required to be done on the system

Heat Pump : The performance of heat pump is expressed by the ratio of amount of heat delivered to the hot body (Q_2) to the amount of work required to be done on the system (w_p).

Q. draw the reverse carnot cycle in t-s plot and derive the c.o.p of a refrigerator and heat pump ?2016,2017/7.b

Ans: Refrigerating systems, the Carnot cycle considered is the reversed Carnot cycle. We know that engine working on Carnot cycle has the highest possible efficiency. Similarly a refrigerating reversed system working on the reversed Carnot cycle, will have the maximum possible co-efficient performance. We also know that it is not possible to make an engine working on the Carnot cycle. Similarly, it is also not possible to make a refrigerating machine working on the reversed Carnot cycle. However, it is used as the ultimate standard of comparison.

A reversed Carnot cycle, using air as working medium (or refrigerant) is shown on p-v and T-s diagram (a) and (b) respectively. At point 1, let p_1 , v_1 and T_1 be the pressure, volume temperature of air respectively.



The four stages of the cycle are as follows:

First stage (Isentropic expansion) : the air is expanded isentropically as shown by the curve 1-2 on p-v and T-s diagrams. The pressure of air decreases from p_1 to p_2 , specific volume increases from v_1 to v_2 and the temperature decreases from T_1 to T_2 . We know that during isentropic expansion no heat is absorbed or rejected by air.

Second stage: (Isothermal expansion). The air is now expanded isothermally (i.e. at constant temperature, $T_2 = T_3$) as shown by the curve 2-3 on p-v and T-s diagrams. The pressure of air decreases from p_2 to p_3 and the specific volume increases from v_2 to v_3 . We know that the heat absorbed by the air (or heat extracted from the cold body) during isothermal expansion per kg of air,

$$Q_A = q_{2-3} = T_2(s_3 - s_2) = T_3 (s_3 - s_2)$$

Third stage: (Isentropic compression). The air is compressed isentropically as shown by the curve 3-4 on p-v and T-s diagrams. During this process, the pressure of air increases from p_3 to p_4 specific volume decreases from v_3 to v_4 and temperature increases from T_3 to T_4 . We know that during isentropic compression, no heat is absorbed or rejected by the air.

Fourth stage: (isothermal compression). The air is now compressed isothermally (i.e. at constant temperature, $T_4 = T_1$) as shown by the curve 4-1 on p-v and T-s diagrams. During this process the pressure of air increases from p_4 to p_1 and specific volume decreases from v_4 to v_1 . We know that the heat rejected by the air during isothermal compression per kg of air.

$$Q_R = q_{4-1} = T_4 (s_4 - s_1) = T_1 (s_3 - s_2)$$

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

$$W_R = \text{Heat rejected} - \text{Heat absorbed} = q_R - q_A$$

$$= T_1(s_3 - s_2) - T_3(s_3 - s_2) = (T_1 - T_3)(s_3 - s_2)$$

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

$$(C.O.P.)_R = \frac{\text{Heat absorbed}}{\text{Work done}} = \frac{q_A}{q_R - q_A}$$

$$= \frac{T_3(s_3 - s_2)}{(T_1 - T_3)(s_3 - s_2)} = \frac{T_3}{T_1 - T_3} = \frac{T_2}{T_1 - T_2} \quad \text{---} (T_3 = T_2)$$

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 process 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.

$$(C.O.P.)_P = \frac{\text{Heat rejected}}{\text{Work done}} = \frac{q_R}{q_R - q_A} = \frac{T_1(s_3 - s_2)}{T_1(s_3 - s_2) - T_2(s_3 - s_2)}$$

$$= \frac{T_3}{T_1 - T_2} = \frac{T_2}{T_1 - T_2} + 1 = (C.O.P.)_R + 1$$

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

$$(C.O.P.)_P = \frac{\text{Work done}}{\text{Heat rejected}} = \frac{q_R - q_A}{q_R}$$

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

Q. Air Refrigeration Cycle..2016

Ans: Air can be used as a working medium to produce refrigeration. In air refrigeration isentropic compression and expansion of air play an important role. Let us take a simple example to demonstrate how refrigeration is produced by air.

Let initial pressure of air be 1 bar and initial temperature of air be 20°C or 293 K. Let this air be compressed isentropically five times to 5 bar. If

T_2 = Absolute temperature of air after compression than,

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{1.4-1}{1.4}} \quad \text{or } T_2 = 464.04 \text{ K}$$

Q. Explain the working principle of ideal vapor compression refrigeration with the help of flow diagram and T-S diagram.2016,2015,2017/7.c

Ans: Mechanism of a simple Vapor Compression Refrigeration System :

Figure below shows the schematic diagram of a simple vapor compression refrigeration system. It consists of the following five essential parts:

(i) Compressor :

The low pressure and temperature vapor refrigerant from evaporator is drawn into the compressor through the inlet of suction valve A, where it is compressed to a high pressure and temperature. This high pressure and temperature vapor refrigerant is discharged into the condenser through the delivery or discharge valve B.

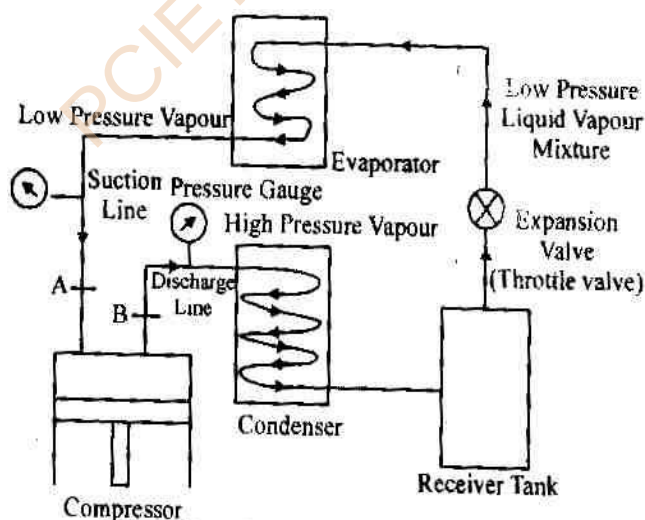


Fig: Simple Vapour Compression

(ii) Condenser:

The condenser or cooler consists of coils of pipe in which the high pressure and temperature vapor refrigerant is cooled and condensed. The

refrigerant, while passing through the condenser, gives up its latent heat to the surrounding condensing medium which is normally air or water.

(iii) Receiver :

The condensed liquid refrigerant from the condenser is stored in a vessel known as receiver from where it is supplied to the evaporator through the expansion valve or refrigerant control valve.

(iv) Expansion valve:

It is also called throttle valve or refrigerant control valve. The function of the expansion valve is to allow the liquid refrigerant under high pressure and temperature to pass at a controlled rate after reducing its pressure and temperature. Some of the liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporized in the evaporator at the low pressure and temperature.

(v) Evaporator :

An evaporator consists of coils of pipe in which the liquid-vapor refrigerant at low pressure and temperature is evaporated and changed into vapor refrigerant at low pressure and temperature. In evaporating, the liquid vapor refrigerant absorbs its latent heat of vaporization from the medium (air, water or brine) which is to be cooled.

Following are the advantages and disadvantages of the vapour compression refrigeration system over air refrigeration system :

Advantages :

- (i) It has smaller size for the given capacity of refrigeration
- (ii) It has less running cost.
- (iii) It can be employed over a large range of temperature.
- (iv) The co-efficient of performance is quite high.
- (v) C.O.P. is quite high as the working of the cycle is very near to that of reversed Carnot cycle.

Disadvantages :

- (i) The initial cost is high.

- (ii) The prevention of leakage of the refrigerant is the major problem in vapor compression system.

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