ME8493 Thermal Engineering- I

Unit 1 Gas power cycles

1. **For a given compression ratio otto cycle is more efficient than diesel cycle. Justify. (Nov 2013)**

   Area under P-V diagram is more that the diesel cycle. When the area is more, workdone for that cycle is more. So, the efficiency for otto cycle will be higher than diesel cycle.

2. **What is meant by mean effective pressure? (Nov 2013) (May 2016) (Nov 2017) (Nov 2014)**

   It is hypothetical pressure which is acting on the piston during the power stroke.

   Mean effective pressure = workdone /stroke volume

3. **Mention the ranges of compression ratio for SI and CI engine.(May 2013)**

   SI engine 6-10

   CI engine 16-20

4. **What is relative efficiency? (May 2013)**

   It is defined as the ratio between actual thermal efficiency and air standard efficiency

$$\eta_{relative} = \frac{\text{Actual thermal efficiency}}{\text{Air stsnderd efficiency}}$$

5. **What is meant by Air standard efficiency.(May 2014)(Apr 2017)**

   It is defined as the ratio of work done by the cycle to the heat supplied to the cycle.

6. **Define compression ratio and cut off ratio. (May 2014)**

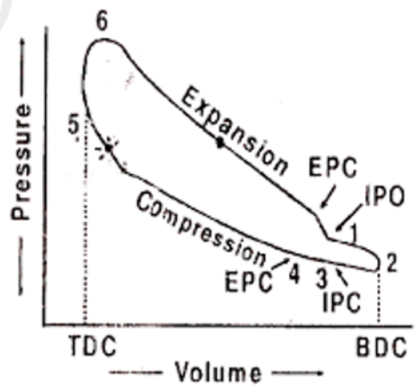
   Compression ratio:

   It is defined as the ratio between total cylinder volumes to the clearance volume.

   Cut off ratio:

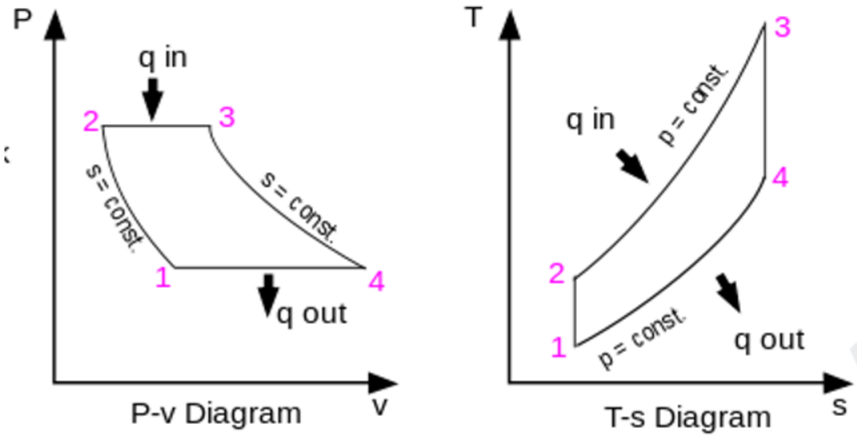
   It is defined as the ratio of volume after the heat addition to volume before the heat addition.

7. **Draw the actual PV diagram of two stroke engine.(Nov 2014)**



Indicator Diagram for a Two Stroke Cycle Petrol Engine.

8. Draw the brayton cycle on p-v and T-s diagram. (May 2015)(Apr 2017)



9. When compression ratio is kept constant , what is the effect of cut off ratio on the efficiency of diesel cycle. (Nov 2015)

When cut off ratio of diesel cycle increases, the efficiency of cycle is decreased when compression ratio is kept constant.

10. Differentiate any three major differences between otto and diesel cycle. (Nov 2015,2016)

S.No	Otto cycle	Diesel cycle
1	Efficiency is less due to low compression ratio	Efficiency is more due to low compression ratio
2	Fuel is admitted into the cylinder during suction stroke	Air alone is admitted in to the cylinder during suction stroke
3	Spark ignition system is used for ignition.	Compression ignition system is used for ignition.

11. What are the assumptions made in the air standard cycle.(May 2016) (Nov 2016) (May 2015)

- The work medium is a perfect gas throughout.
- The working medium does not undergo chemical change through the cycle.
- Kinetic and potential energies of the working fluid are neglected.
- The operation of the engine is frictionless

12. Write down the air standard efficiency for otto and diesel cycle. (Nov 2017)

$$\boxed{\eta_{Otto} = 1 - \frac{1}{(r)^{\gamma-1}}}$$

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

13. Write an expression for mean effective pressure for an Otto cycle interns of compression ratio and other parameters

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

Where,

P_1= initial pressure

r = compression ratio

k = Pressure ratio

γ = Adiabatic index

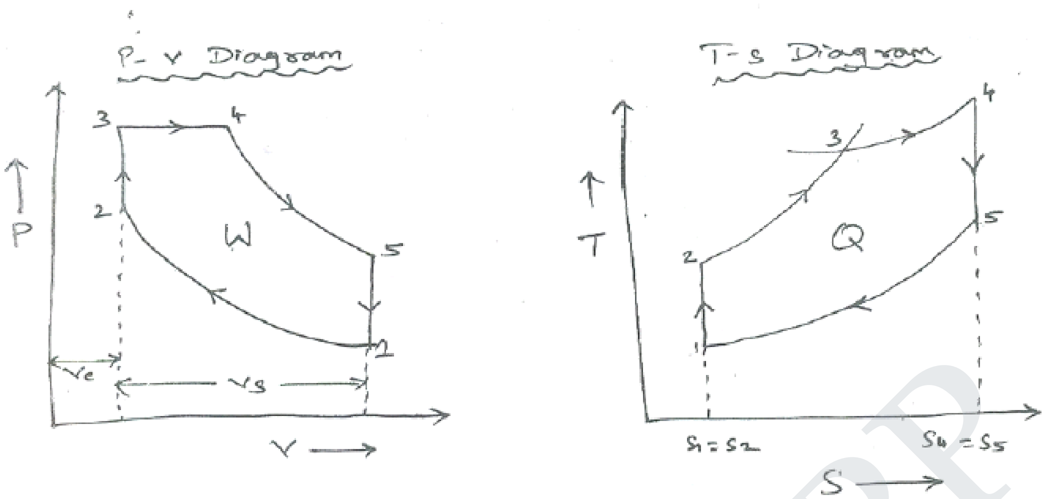
14. For the same compression ratio and heat supplied, state the order of decreasing of Otto, diesel and dual cycle.

$\eta_{Otto} > \eta_{dual} > \eta_{diesel}$

15. What are the effects of introducing regeneration in the basic gas turbine cycle?

- The fuel economy is improved the quantity of the fuel required per unit mass of air is less.
- The work output from the turbine, work required to the compressor will not change.
- Pressure drop will occur during regeneration.
- It increases the thermal efficiency when the low pressure ratio reduces.

16. Sketch the dual cycle on P-V and T-S co-ordinates.



17. Define Expansion ratio.

It is the ratio of volume after the expansion to the volume before expansion.

18. What is the expression for optimum pressure ratio for maximum specific work output in brayton cycle.

$$\text{Optimum pressure ratio, } R_p = \left(\frac{T_3}{T_1}\right)^{\frac{\gamma}{2(\gamma-1)}}$$

19. Is it always useful to have a regenerator a gas turbine power cycle? Why?

It is not always useful to have a regenerator a gas turbine power cycle. Regenerator causes pressure drop of 0.035 to 0.2bar in compressed air and about 0.035bar in exhaust gases. These pressure drop affect to a contained extend the gain in efficiency due to regenerated.

20. Name the factors that affect air standard efficiency of diesel cycle.

- Compression ratio
- Cut off ratio

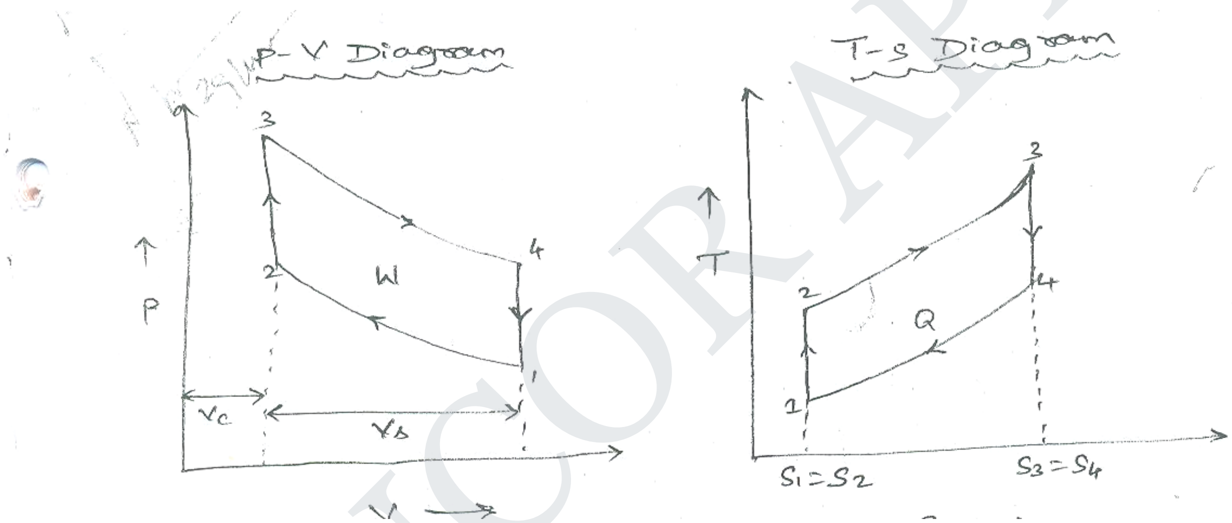
16-MARKS:

DERIVATION:

1. **Derive an expression for air standard efficiency and mean effective pressure of Otto Cycle. (May/June-13)**

This cycle consist of the following four processes.

1. Two reversible adiabatic process or isentropic process.
2. Two constant volume process.



Process 1-2:

1. Process 1-2 is the isentropic compression process.
2. Pressure increases from P_1 to P_2 and temperature increases from T_1 to T_2.
3. Volume decreases from V_1 to V_2.
4. Entropy remains constant.

Process 2-3:

1. Process 2-3 is a constant volume heat addition process.
2. Pressure increases from P_2 to P_3.
3. Temperature increases from T_2 to T_3.
4. Entropy increases from S_2 to S_3 or S_1 to S_3.
5. Volume remains constant.

$$Q_s = m\,C_v\,[T_3 - T_2]$$

Process 3-4:

1. Process 3-4 is an isentropic expansion process.
2. Pressure decreases from P_3 to P_4.
3. Temperature decreases from T_3 to T_4.
4. Volume increases from V_3 to V_4.
5. Entropy remains constant.

Process 4-1:

1. Process 4-1 is a volume heat addition process.
2. Pressure decreases from P_4 to P_1.
3. Temperature decreases from T_4 to T_1.
4. Entropy decreases from S_4 to S_1.

Heat rejected during 4-1, $Q_R = m\,C_v\,[T_4 - T_1]$

Work done during cycle, W = Heat supplied – Heat rejected

$$= Q_S - Q_R$$

$$= m\,C_v\,[T_3-T_2] - m\,C_v\,[T_4-T_1]$$

Efficiency, $$\eta_{Otto} = \frac{Q_S - Q_R}{Q_S}$$

$$= \frac{m\,C_v\,[T_3-T_2] - m\,C_v\,[T_4-T_1]}{m\,C_v\,[T_3-T_2]}$$

$$= 1 - \frac{[T_4-T_1]}{[T_3-T_2]}$$

From p-v diagram,

Total cylinder volume = $V_1 = V_4$

Clearance volume = $V_c = V_2 = V_3$

Stroke volume = $V_s = [V_1-V_2] = [V_4-V_3]$

Compression ratio (r):

Compression ratio, $r = \frac{V_1}{V_2} = \frac{V_4}{V_3}$

Process 1-2,

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

$$T_2 = T_1 \times (r)^{\gamma-1}$$

Process 3-4,

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

$$T_3 = T_4 \times (r)^{\gamma-1}$$

Substitute T_2 and T_3 value in η_{Otto},

$$\eta_{Otto} = 1 - \frac{T_4 - T_1}{T_4 (r)^{\gamma-1} - T_1 (r)^{\gamma-1}}$$

$$= 1 - \frac{T_4 - T_1}{(T_4 - T_1)(r)^{\gamma-1}}$$

$$\boxed{\eta_{Otto} = 1 - \frac{1}{(r)^{\gamma-1}}}$$

Mean effective pressure [p_m]:

Least clearance volume be units i.e., $V_2=V_3=1$

$V_1=V_4= r$

$$\frac{p_4}{p_1} = \frac{p_3}{p_2} = k \text{ (Pressure ratio)}$$

From Pressure 1-2, reversible adiabatic,

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

$$=(r)^{\gamma}$$

$$=\frac{p_3}{p_4}$$

Work done, $$W=\frac{p_3V_3-p_4V_4}{\gamma-1}-\frac{p_2V_2-p_1V_1}{\gamma-1}$$

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

(V_3=V_2=1)

$$=\frac{1}{\gamma-1}\left[(p_3-p_4r)-(p_2-p_1r)\right]$$

$$=\frac{1}{\gamma-1}\left[p_4r\left(\frac{p_3}{p_4r}-1\right)-p_1r\left(\frac{p_2}{p_1r}-1\right)\right]$$

$$=\frac{1}{\gamma-1}\left[p_4r\left(\frac{r^{\gamma}}{r}-1\right)-p_1r\left(\frac{r^{\gamma}}{r}-1\right)\right]$$

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

$$=\frac{p_1r}{\gamma-1}\left(r^{\gamma-1}-1\right)\left(\frac{p_4}{p_1}-1\right) \qquad \left(\therefore \frac{p_4}{p_1}=k\right)$$

Work done $$=\frac{p_1r}{\gamma-1}\left(r^{\gamma-1}-1\right)(k-1)$$

stroke volume $=V_1-V_2$

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

$$=r-1 \qquad (\because V_2=1)$$

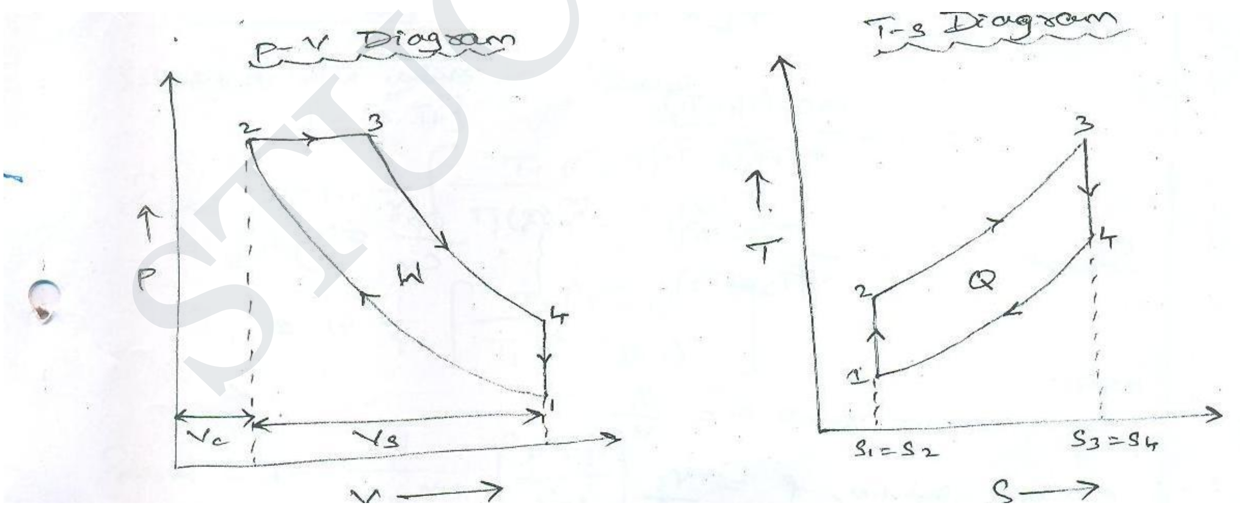
$$p_m = \frac{\textit{Work done}}{\textit{stroke volume}}$$

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

2. Derive an expression for air standard efficiency and mean effective pressure of Diesel Cycle. **(May/June-2013)**

This cycle consist of the following four processes.

1. Two reversible adiabatic process or isentropic process.
2. One constant volume process.
3. One constant pressure process.



Process1-2:

1. Process 1-2 is the isentropic compression process.
2. Air is compressed isentropically P_1 to P_2.
3. Entropy remains constant.

Process2-3:

1. Process 2-3 is a constant pressure heat addition process.
2. Air is heated from T2 to T2 but pressure remains constant.
3. Heat is supplied during the process, Qs = $mc_p [T_3-T_2]$

Process3-4:

1. Process 3-4 is an isentropic expansion process.
2. Air is expands isentropically P_1 to P_2.
3. Temperature decreases from T_3 to T_4.

Process4-1:

1. Process 1-4 is a constant volume heat rejection process.
2. Heat is rejected from air but volume remains constant.
3. Temperature decreases from T_4 to T_1.
4. Heat rejected, $Q_R = mc_v [T_4-T_1]$.

Efficiency of diesel cycle,

$$\eta_{DIESEL} = Q_S-Q_R / Q_S$$

$$= \frac{mCp(T3-T2)-mCv(T4-T1)}{mCp(T3-T2)}$$

$$= 1 - \frac{mCv(T4-T1)}{mCp(T3-T2)}$$

$$\eta_{\text{DIESEL}} = 1 - \frac{(T4-T1)}{\Upsilon\times(T\ 3-T2)}$$

W.K.T,

Compression ratio, $r = v_1/v_2$

Cut off ratio, $\rho = v_3/v_2$

Expansion ratio $= v_4/v_3$

$= v_1/v_3$

$= v_1/v_2 \times v_2/v_3$

$= r \times 1/\rho$

Process1-2,

$T_2/T_1 = (V_1/V_2)^{Y-1}$

$= (r)^{Y-1}$

$T_2 = T_1\ (r)^{Y-1}$

Process2-3,

$V/T = C$

$V_2/T_2 = V_3/T_3$

$T_3/T_2 = V_3/V_2 = \rho$

$T_3 = T_2\times\rho$ (Where, $T_2=T_1(r)^{Y-1}$)

$T_3 = T_1(r)^{Y-1}\rho$

Process3-4,

$T_3/T_4 = (V_4/V_3)^{Y-1}$

$= (r/\rho)^{Y-1}$

$T_4 = T_3/\ (r/\rho)^{Y-1}$

$= T_1(r)^{Y-1}\rho\ /(r/\rho)^{Y-1}$

$= T_1(r)^{\gamma-1}\rho.\ \rho^{\gamma-1}/(r)^{\gamma-1}$

$T_4 = T.\ \rho^{\gamma}$

Substitute the value in efficiency diesel,

$$\eta_{Diesel} = 1 - \frac{1}{\gamma}\left[\frac{T_1\rho^{\gamma} - T_1}{T_1(r)^{\gamma-1}\rho - T_1(r)^{\gamma-1}}\right]$$

$$= 1 - \frac{1}{\gamma}\left[\frac{T_1(\rho^{\gamma} - 1)}{T_1\, r^{\gamma-1}(\rho - 1)}\right]$$

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

Mean effective pressure (P_m):

Work done during the cycle,

$$W = p_2(V_3 - V_2) + \frac{p_3V_3 - p_4V_4}{\gamma - 1} - \frac{p_2V_2 - p_1V_1}{\gamma - 1}$$

$$= p_2V_2(\rho - 1) + \frac{p_3V_2\rho - p_4V_2r}{\gamma - 1} - \frac{p_2V_2 - p_1rV_2}{\gamma - 1}\left[\because \frac{V_3}{V_2} = \rho; \frac{V_4}{V_2} = r\right]$$

$$= \frac{V_2[p_2(\rho - 1)(\gamma - 1) + (p_3\rho - p_4r) - (p_2 - p_1r)]}{\gamma - 1}$$

$$= \frac{V_2\left[p_2(\rho-1)(\gamma-1)+p_2\left(\rho-\frac{p_4}{p_2}r\right)-p_2\left(1-\frac{p_1}{p_2}r\right)\right]}{\gamma-1} \quad [\because p_3 = p_2]$$

$$= \frac{p_2V_2\left[(\rho-1)(\gamma-1)+\left[\rho-\left(\frac{\rho}{r}\right)^{\gamma}\times r\right]-\left(1-\frac{r}{r^{\gamma}}\right)\right]}{\gamma-1}$$

$$\left[\because \frac{p_1}{p_2}=\left(\frac{V_2}{V_1}\right)^{\gamma}=\frac{1}{r^{\gamma}}\right]\left[\because \frac{p_4}{p_2}=\frac{p_4}{p_3}=\left(\frac{V_3}{V_4}\right)^{\gamma}=\left(\frac{\rho}{r}\right)^{\gamma}\right]$$

$$= \frac{p_1V_1r^{\gamma-1}\left[(\rho-1)(\gamma-1)+\left(\rho-\rho^{\gamma}r^{1-\gamma}\right)-\left(1-r^{1-\gamma}\right)\right]}{\gamma-1}$$

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

multiplying V_2 on both side

$$p_2V_2 = p_1 r^{\gamma} V_2 \times \frac{V_1}{V_1}$$

$$p_2V_2 = p_1 \frac{r^{\gamma}}{r} V_1$$

$$p_2V_2 = p_1V_1r^{\gamma-1}$$

$$= \frac{p_1 V_1 r^{\gamma-1} \left(\rho\gamma - \gamma - \rho + 1 + \rho - \rho^{\gamma} r^{1-\gamma} - 1 + r^{1-\gamma}\right)}{\gamma - 1}$$

$$= \frac{p_1 V_1 r^{\gamma-1} \left(\gamma(\rho - 1) - r^{1-\gamma}(\rho^{\gamma} - 1) \right)}{\gamma - 1}$$

Man effective pressure is given by,

$$p_m = \frac{W}{V_1 - V_2} = \frac{p_1 V_1 r^{\gamma-1} \left(\gamma(\rho - 1) - r^{1-\gamma}(\rho^{\gamma} - 1) \right)}{(\gamma - 1) V_1 \left(1 - \frac{1}{r}\right)}$$

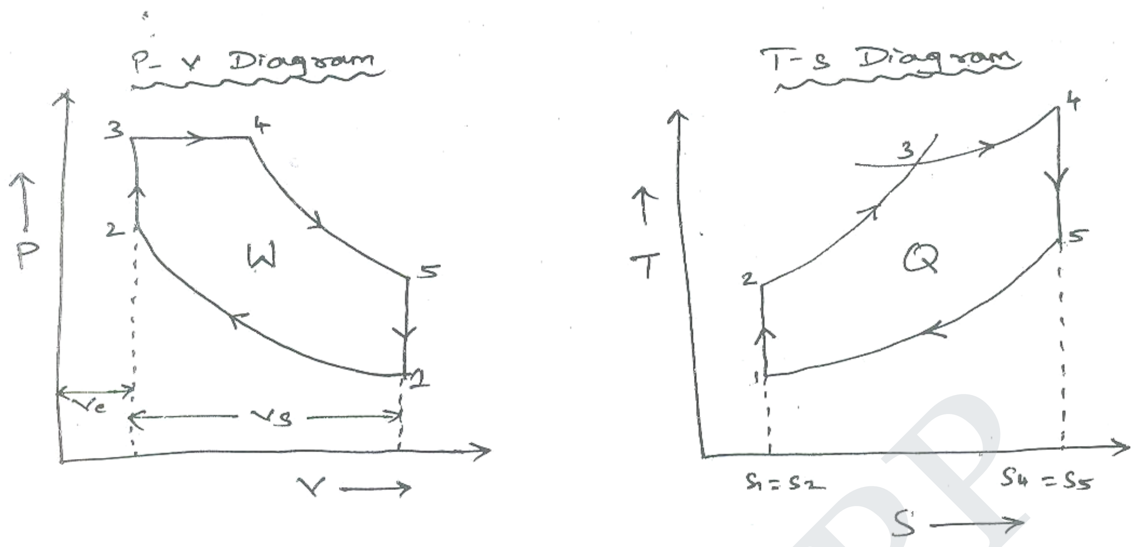
$$= \frac{p_1 r^{\gamma-1} \left(\gamma(\rho - 1) - r^{1-\gamma}(\rho^{\gamma} - 1) \right)}{(\gamma - 1)\left(\frac{r-1}{r}\right)}$$

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

3. **Derive an expression for air standard efficiency and mean effective pressure of Dual Cycle.** **(May/Jun-14)**

This cycle consist of the following process.

1. Two reversible adiabatic process or isentropic process.
2. Two constant volume process.
3. Two constant pressure process.



Process1-2:

1. Process 1-2 is the isentropic compression process.
2. Air is compressed isentropically P_1 to P_2.
3. Entropy remains constant.

Process2-3:

1. Process 2-3 is a constant volume heat addition process.
2. Compressed air is partially heated by constant volume process.
3. Temperature increases from T_2 to T_3.
4. Entropy increases from S_2 to S_3.

Heat supplied during the process, $Q_{s1} = mc_v[T_3-T_2]$

Process3-4:

1. Process 3-4 is a constant pressure heat addition process.
2. Partially heated air is then heated by constant pressure process.
3. Temperature and entropy increases from T_3 to T_4 and S_3 to S_4.

Heat supplied during the process, $Q_{s2} = mc_p[T_4-T_3]$

Process4-5:

1. Process 4-5 is an isentropic expansion process.
2. Air is expands isentropically from P_4 to P_5.
3. Temperature decreases from T_4 to T_5.

Process5-1:

1. Process 5-1 is a constant volume heat rejection process.
2. Heat is rejected from the air volume remains constant.
3. Temperature decreases from T_5 to T_1 and entropy decreases from S_5 to S_1.
4. Heat rejected, $Q_R = mc_v [T_5-T_1]$.

Total heat supplied during heat addition,

$Qs = Qs_1 + Qs_2$

$= mc_v [T_3-T_2] + mc_p[T_4-T_3]$

Air standard efficiency, $\eta = W/Qs = Qs - Q_R / Qs$

$$\eta = \frac{W}{Q_S} = \frac{Q_S - Q_R}{Q_S}$$

$$= \frac{m C_V (T_3 - T_2) + mC_P (T_4 - T_3) - mC_V (T_5 - T_1)}{m C_V (T_3 - T_2) + mC_P (T_4 - T_3)}$$

$$\eta = 1 - \frac{(T_5 - T_1)}{(T_3 - T_2) + \gamma (T_4 - T_3)}$$

W.K.T,

Compression ratio, $\Upsilon = V_1/V_2$

Pressure ratio, $k = P_3/P_2$

Cut off ratio, $\rho = V_4/V_3$

Expansion ratio, $V_5/V_4 = V_1/V_4$

$= V_1/V_2 \times V_2/V_4$

$= V_1/V_2 \times V_3/V_4$

$= \Upsilon / \rho$

Process1-2,

$$T_2/T_1 = [V_1/V_2]^{\Upsilon-1} = r^{\Upsilon-1}$$

$$T_2 = T_1\, r^{\Upsilon-1}$$

Process2-3,

$$P_2/T_2 = P_3/T_3$$

$$T_3 = [P_3/P_2]\, T_2$$

$$T_3 = K\, T_1\, r^{\Upsilon-1}$$

Process3-4,

$$V_3/T_3 = V_4/T_4$$

$$T_4 = [V_4/V_3]\, T_3$$

$$= \rho\, K\, T_1\, r^{\Upsilon-1}$$

Process4-5,

$$T_4/T_5 = [V_5/V_4]^{\Upsilon-1} = [r/\rho]^{\Upsilon-1}$$

$$T_5 = T_4/ [r/\rho]^{\Upsilon-1}$$

$$= T_4\, \rho^{\Upsilon-1} / r^{\Upsilon-1}$$

$$T_5 = T_1.\, K.\, \rho^{\Upsilon}$$

Substitute in efficiency,

$$\eta = 1 - \frac{T_1 k\rho^{\gamma} - T_1}{[T_1(r)^{\gamma-1}k - T_1(r)^{\gamma-1}] + \gamma[T_1(r)^{\gamma-1}k\rho - T_1(r)^{\gamma-1}k]}$$

$$= 1 - \frac{T_1\left[k\rho^{\gamma} - 1\right]}{T_1(r)^{\gamma-1}\left[(k-1) + \gamma k(\rho - 1)\right]}$$

$$\eta_{Dual} = 1 - \frac{1}{(r)^{\gamma-1}}\left[\frac{k\rho^{\gamma} - 1}{(k-1) + \gamma k(\rho - 1)}\right]$$

Note:

When k=1 efficiency of dual reduces to efficiency of diesel.

When k=1 and η=1 efficiency of dual reduces to efficiency of OTTO.

Mean effective pressure,

Work done,

$$W = p_3(V_4 - V_3) + \frac{p_4V_4 - p_5V_5}{\gamma - 1} - \frac{p_2V_2 - p_1V_1}{\gamma - 1}$$

$$= p_3V_3(\rho - 1) + \frac{p_4\rho V_3 - p_5 rV_3 - p_2V_3 - p_1 rV_3}{\gamma - 1}$$

$$\left[\begin{array}{l} \because \rho = \dfrac{V_4}{V_3}; V_4 = \rho V_3; V_2 = V_3 \\ V_5 = V_1 \text{ multiply and divided by } V_2 \\ V_5 = V_1 \times \dfrac{V_2}{V_2} = rV_2 = rV_3 \\ \dfrac{V_1}{V_2} = r \Rightarrow V_1 = rV_2 = rV_3 \end{array}\right]$$

$$= \frac{p_3V_3(\rho-1)(\gamma-1) + p_4V_3\left(\rho - \frac{p_5}{p_4} r\right) - p_2V_3\left(1 - \frac{p_1}{p_2} r\right)}{\gamma - 1}$$

By substituting the values in above equation,

$$\frac{p_5}{p_4} = \left(\frac{V_4}{V_5}\right)^{\gamma} = \left(\frac{\rho}{r}\right)^{\gamma}$$

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

($p_3=p_4$)

$$\therefore W = \frac{V_3\left[p_3(\rho-1)(\gamma-1) + p_3\left(\rho - \rho^{\gamma} r^{1-\gamma}\right) - p_2\left(1 - r^{1-\gamma}\right)\right]}{\gamma - 1}$$

$$= \frac{p_2V_2\left[k(\rho-1)(\gamma-1) + k\left(\rho - \rho^{\gamma} r^{1-\gamma}\right) - \left(1 - r^{1-\gamma}\right)\right]}{(\gamma - 1)}$$

$$= \frac{p_1V_1 r^{\gamma-1}\left[k\rho\gamma - k\rho - k\gamma + k + k\rho - k\rho^{\gamma} r^{1-\gamma} - 1 + r^{1-\gamma}\right]}{(\gamma - 1)}$$

$$\left[\because p_2V_2 = p_1V_1 r^{\gamma-1}\right]$$

$$W = \frac{p_1V_1 r^{\gamma-1}\left[k\gamma(\rho-1) + (k-1) - r^{1-\gamma}\left(k\rho^{\gamma} - 1\right)\right]}{(\gamma - 1)}$$

Mean effective pressure :

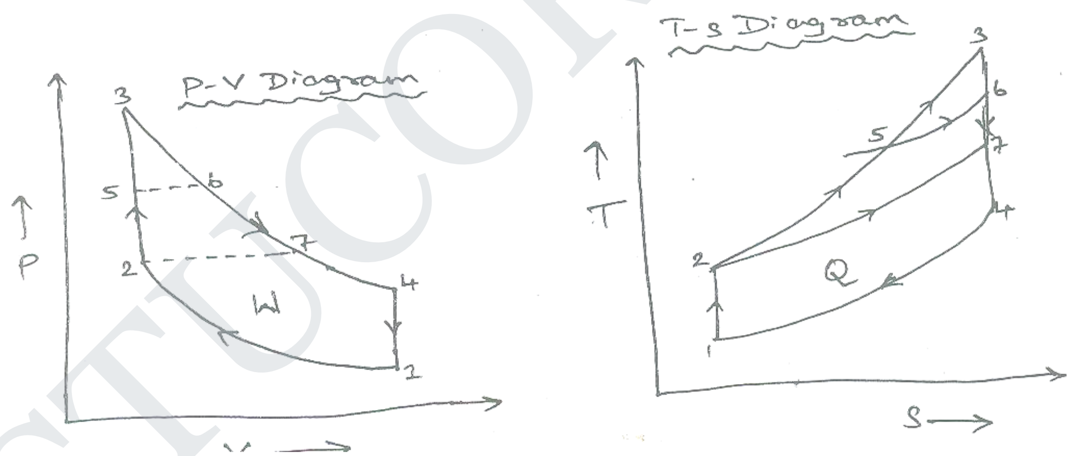
$$p_m = \frac{W}{V_1 - V_2} = \frac{p_1 V_1 r^{\gamma-1}\left[k\gamma(\rho-1)+(k-1)-r^{1-\gamma}\left(k\rho^{\gamma}-1\right)\right]}{(\gamma-1)\,V_1\left(1-\frac{1}{r}\right)}$$

$$= \frac{p_1 r^{\gamma-1}\left[k\gamma(\rho-1)+(k-1)-r^{1-\gamma}\left(k\rho^{\gamma}-1\right)\right]}{(\gamma-1)\left(\frac{r-1}{r}\right)}$$

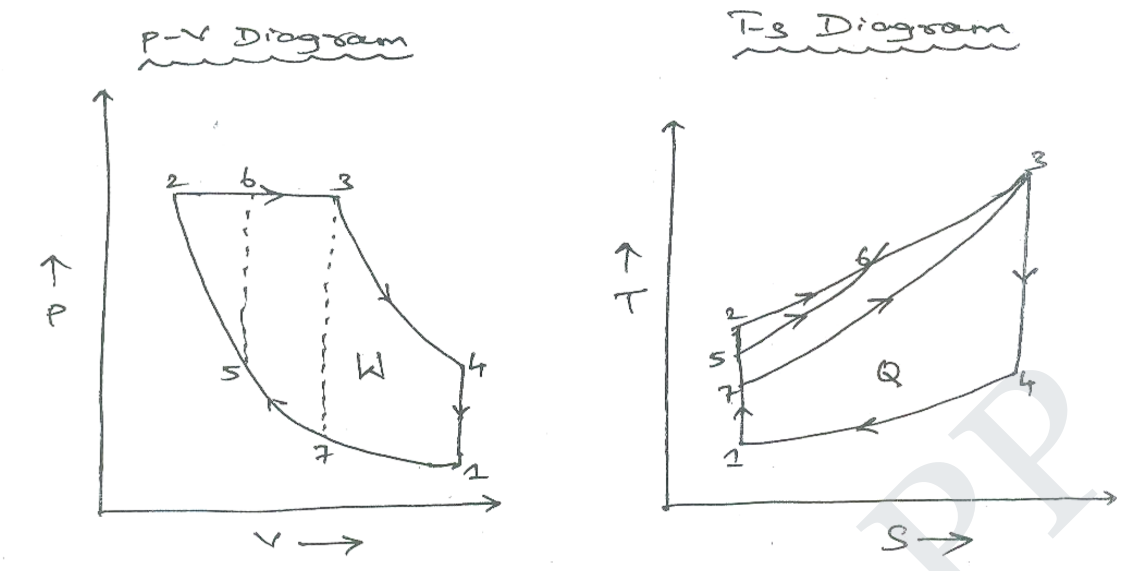
$$p_m = \frac{p_1 r^{\gamma}\left[k\gamma(\rho-1)+(k-1)-r^{1-\gamma}\left(k\rho^{\gamma}-1\right)\right]}{(\gamma-1)(r-1)}$$

4. Comparisons of Efficiencies of Otto, Diesel and Dual Cycle.

Case 1: For same compression ratio and heat rejection.

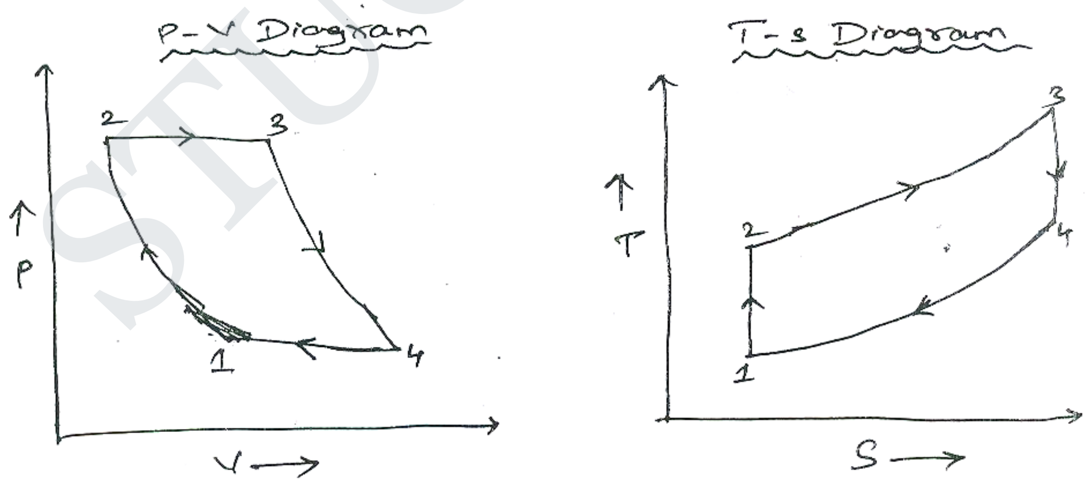


Case 2: For the same maximum pressure and temperature.



BRAYTON CYCLE OR JOULE CYCLE:

It consists of two reversible adiabatic process and two constant pressure process.



Process 1-2: Isentropic compression process

1. Air is compressed in the compressor isentropically from P_1 to P_2
2. Pressure increases from P_1 to P_2 and temperature increases from T_1 to T_2.
3. Volume reduces from V_1 to V_2.
4. Compressor work, $W_c = mc_p[T_2-T_1]$

Process 2-3: constant pressure heat addition process.

1. Compressed air is passed through the combustion chamber where fuel is injected and burned at constant pressure P_2 and temperature increases from T_2 to T_3.
2. Heat addition, $Q_s = mc_p\,[T_3-T_2]$

Process 3-4: Isentropic expansion process.

1. High temperature air is then expanded isentropically in the turbine to the ambient pressure.
2. Temperature falls from T_3 to T_4.
3. Turbine works, $W_T = m\,C_p\,[T_3-T_4]$

Process 4-1: Constant pressure heat rejection process,

1. Air is then returned to its original position after passing through cooler where it cools at constant pressure process.
2. Heat rejected, $Q_R = m\,C_p\,[T_4-T_1]$

Efficiency, $\eta = W/\,Q_s$

$$= Q_s - Q_R\,/\,Q_s$$

$$= m\,C_p\,[T_3-T_2] - m\,C_p\,[T_4-T_1]\,/\,m\,C_p\,[T_3-T_2]$$

$$= 1- [T_4-T_1]\,/\,[T_3-T_2]$$

w.k.t,

$$\text{Compression ratio, } r = V_1/V_2 = V_4/V_3$$

$$\text{Pressure ratio, } R_p = P_2/P_1 = P_3/P_4$$

Process1-2,

$$T_2/T_1 = [V_2/V_1]^{Y-1}$$

$$= r^{Y-1}$$

$$T_2 = T_1\, r^{Y-1}$$

Process3-4,

$$T_3/T_4 = [V_4/V_3]^{Y-1}$$

$$= r^{Y-1}$$

$$T_3 = T_4\, r^{Y-1}$$

Also,

$$T_3/T_4 = [P_3/P_4]^{Y-1/Y}$$

$$T_3 = T_4\, (R_p)^{Y-1/Y}$$

Substitute T_2 and T_3 in efficiency of brayton.

$$\eta = 1- 1/(R_p)^{Y-1/Y}$$

$$= 1 - 1/r^{Y-1}$$

Work ratio = Net work transfer / Positive work transfer

$$= m\, C_p\, [T_3-T_4] - m\, C_p\, [T_2-T_1] / m\, C_p\, [T_3-T_4]$$

$$= 1- [T_2-T_1] / [T_3-T_4]$$

$$= 1 - \frac{T_1(R_p)^{Y-1/Y} - T_1}{T_3 - T_3/(R_p)^{Y-1/Y}}$$

$$= 1 - T_1/T_3 \times (R_p)^{Y-1/Y}$$

PROBLEMS:

5. **A six cylinder petrol engine has a compression ratio 5%. The clearance volume of each cylinder is 110 cc. It operates on a four stroke constant volume cycle and the indicated efficiency ratio referred to air std. efficiency is 0.56 at the speed of 2400 rpm. It consumes 10 kg of fuel per hour. The calorific value of fuel is 44000 KJ/kg. Determine the average indicated mean effective pressure.**

Given data:

$r = 5$

$V_c = 110$ cc

Efficiency = 0.56

$N = 2400$ rpm

$m_f = 10$ kg/hr

$C_v = 44000$ KJ/kg

$Z = 6$

Solution:

Compression ratio,

$$r = \frac{V_s + V_c}{V_c}$$

$5 = V_s + 110/110$

$V_s = 440$ cc

Air standard efficiency,

$$\eta = 1 - \frac{1}{r^{\gamma - 1}}$$

$= 1 - 1/ (5)^{1.4 - 1}$

$= 47.47$

Relative efficiency,

$$\eta = \frac{\eta_{actual}}{\eta_{airstd}}$$

$0.56 = \eta_{actual} / 47.47$

$\eta_{actual} = 26.58\%$

Actual efficiency = $\frac{Work\ done}{Heat\ input}$

$0.2658 = W/ (10/3600) (44000)$

$W = 32.49$ KW

Net work output,

$$W = \frac{p_m V_s N Z}{60}$$

$2.49\times10^{3} = p_m \times 440\times10^{-6} \times (1200/60) \times 6$

$p_m = 6.15$bar

6. **One kg of air is taken through an (a) OTTO cycle, (b) DIESEL cycle. Initially the air is at 1 bar 290k. The compression ratio for both cycles is 12 and heat addition is 1.9 MJ in each cycle. Calculate the air standard efficiency and mean effective pressure for both the cycle.(Nov/Dec-11) (May/Jun-14) (Nov-14)**

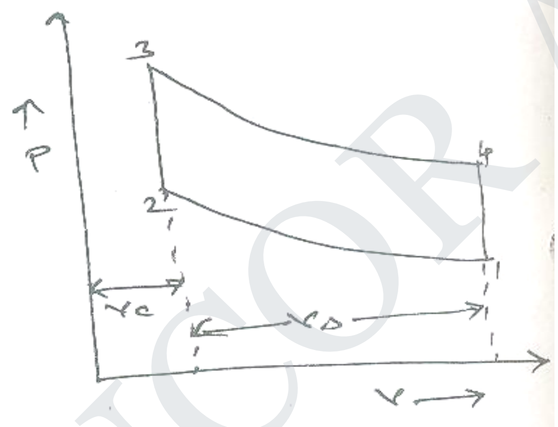
Given data:

P_1 = 1bar = 100KN/m^2

T_1 = 290 K

r = 12

Q_S = 1.9 MJ = 1.9 × 10^3 KJ



Solution:

a. **OTTO cycle:**

Process1-2: Isentropic compression

$$\frac{P_2}{P_1} = \left(\frac{V_2}{V_1}\right)^{\gamma} = (r)^{\gamma}$$

$$= 100\ (12)^{1.4}$$

$$P_2 = 3242.3\ \text{KN/m}^2$$

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

$T_2 = 290\ (12)^{1.4-1}$

$T_2 = 783.55$ K

Heat supplied,

$Q_s = m\ C_v\ [T_3 - T_2]$

$1900 = 1 \times 0.718\ [T_3 - 783.55]$

$T_3 = 3429.79$ K

Process 2-3: Constant volume process

$$\frac{P_2}{P_3} = \frac{T_2}{T_3}$$

$P_3 = P_2 \times (T_3/T_2)$

$= 3242.3 \times (3429.79/783.55)$

$P_3 = 14196.7 KN/m^2$

Air standard efficiency,

$$\eta = 1 - \frac{1}{r^{\gamma-1}}$$

$= 1 - 1/(12)^{1.4-1}$

$= 62.98\%$

Pressure ratio,

$$K = \frac{P_3}{P_2}$$

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= 14196.7/ 3242.3

= 4.378

Mean effective pressure,

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

= 100 × 12 [4.378 – 1/ 1.4] [$(12)^{1.4-1}$ – 1/ 12 - 1]

= 1567.93 KN/m^2

b. DIESEL cycle:

Process 1-2: Isentropic compression

$$\frac{T_2}{T_1} = (r)^{\gamma-1}$$

T_2 = [$(12)^{1.4-1}$ × 290]

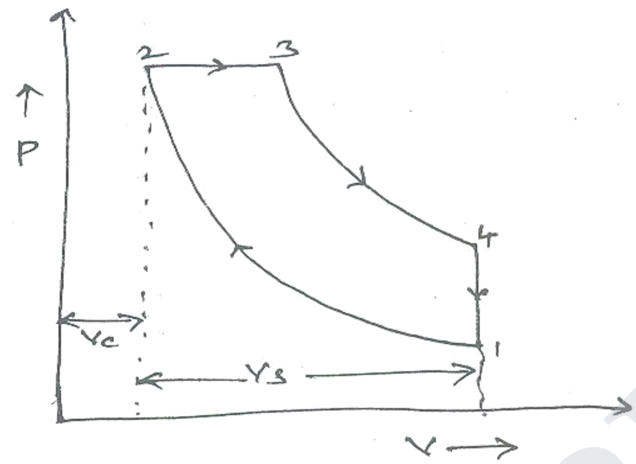
= 783.56 K

Process 2-3: Constant pressure heat addition

$Q_s = m\, C_p\, [T_3 - T_2]$

$1.9 \times 10^3 = 1 \times 1.005 \times [T_3 - 783.56]$

T_3 = 2674 K



Cut off ratio, $\rho = \frac{V_3}{V_2} = \frac{T_3}{T_2}$

= 2674/783.56

ρ= 3.413

Air standard efficiency, $\eta_{Diesel} = 1 - \frac{1}{\gamma (r)^{\gamma-1}} \left(\frac{\rho^{\gamma} - 1}{\rho - 1} \right)$

$= 1 - 1/1.4(12)^{1.4-1}$ $[3.413^{1.4} – 1/3.413 - 1]$

= 49.68 %

Mean effective pressure,

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

$= 100 \times 12^{1.4}$ $[1.4(3.413 - 1) - (12)^{1-1.4} \times (3.413^{1.4} - 1)] / (1.4 - 1)(12-1)$

= 1241 KN/m^2

7. **An air std. DUAL cycle has a compression ratio of 16 and compression begins at 1 bar and 50°C. The maximum pressure is 70 bar. The heat transferred to air at constant pressure is equal to heat transferred at constant volume. Find the temperature at a cardinal point, cycle efficiency and mean effective pressure. Take C_p = 1.005 KJ/KgK and C_v = 0.718 KJ/KgK. (Nov/Dec-11,12,May/June-13)**

Given data:

r = 16

P_1 = 1 bar

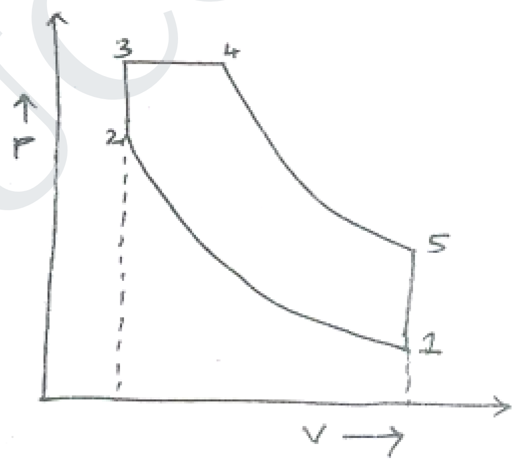
T_1 = 50°C = 323K

P_3 = 70 bar

$Q_S = Q_{S2}$

C_p= 1.005 KJ/KgK

C_v = 0.718 KJ/KgK



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Solution:

Specific volume, $v_1 = \dfrac{RT_1}{p_1}$

= (287 × 323)/100000

= 0.92701 m^3/kg

Process1-2: Isentropic compression

$$p_2 = (r)^{\gamma} \times p_1$$

= $16^{1.4}$ × 1

= 48.5bar

$$\frac{T_2}{T_1} = (r)^{\gamma-1}$$

= $16^{1.4\text{-}1}$ × 323

= 979 K

Specific volume, $v_2 = \dfrac{RT_2}{p_2}$

= (287 × 979)/ (48.5 × 100000)

= 0.05794 m^3/kg

Process2-3: constant volume heat addition process.

$$\frac{P_2}{P_3} = \frac{T_2}{T_3}$$

T_3 = [70/48.5] 979

= 1413 K

$Q_{s1} = m\, C_v\, [T_3\text{-}T_2]$

$= 1(0.718)\ [1413\text{-}979]$

$= 311.612$ KJ/Kg

Process 3-4: constant pressure heat addition process.

$Q_{s2} = m\, C_p\, [T_4\text{-}T_3]$

$311.12 = 1.005\ [T_4 – 1413]$

$T_4 = 1723$ K

W.K.T,

$$\frac{V_4}{V_3} = \frac{T_4}{T_3}$$

$V_4 = [1723/1413]\ 0.05794$

$= 0.070652\ m^3/kg$

Expansion ratio,

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

$= 0.070652/0.92701$

$= 0.096215$

Process 4-5: Isentropic expansion process

$$p_5 = \left(r_e\right)^{\gamma}\ p_4$$

$= [0.076215]^{1.4}\ [70]$

$= 1.9063$ bar

$$T_5 = (r_e)^{\gamma-1} T_4$$

$= [0.076215]^{1.4\text{-}1} [1723]$

$= 567$ K

Cut off ratio,

$$\rho = \frac{V_4}{V_3}$$

$= 0.070652/0.05744$

$=1.2194$

pressure ratio,

$$k = \frac{p_3}{p_2}$$

$=70/48.5$

$=1.4433$

Cycle efficiency

$$\eta_{Duel} = 1 - \frac{1}{(r)^{\gamma-1}}\left[\frac{k\rho^{\gamma}-1}{(k-1)+\gamma k(\rho-1)}\right]$$

$$= 1 - \frac{1}{(16)^{1.4-1}}\left[\frac{1.4433(1.2194)^{1.4}-1}{(1.4433-1)+(1.4\times1.4433)(1.2194-1)}\right]$$

$= 66.34$ %

Net heat supplied to the cycle,

$Q_s = Q_{s1} + Q_{s2}$

$= 311.612 + 311.612$

$= 623.224$ KJ/Kg

Net work done of the cycle,

$$W = Q_s \times \eta$$

$$= 623.224 \times 0.6634$$

$$= 413.45 \text{ KJ/Kg}$$

The mean effective pressure,

$$p_m = \frac{W}{V_1 - V_2}$$

$$= 413.45/(0.92701-0.05794)$$

$$= 4.75 \text{ bar}$$

8. **Air enters a Brayton cycle at 100kpa, 300k. The compression ratio is 8:1. The maximum temperature in the cycle is 1300k. Find 1.Air standard efficiency, 2.compresssor and turbine work and 3. Work ratio. (Nov-14)**

Given data:

P_1 = 100 kpa

T_1 = 300 K

r = 8

T_3 = 1300 K

Solution:

Process 1-2:

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

$T_2 = (8)^{1.4-1} \times 300$

$= 689.2$ K

Process 3-4:

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

$T_4 = 1300/(8)^{1.4-1}$

$= 565.85$ K

Compressor work, $W_C = C_P [T_2 - T_1]$

$= 1.005[689.2-300]$

$= 391.145$ KJ/Kg

Turbine work, $W_T = C_P [T_3 - T_4]$

$= 1.005[1300-565.85]$

$= 734.82$ KJ/Kg

Air standard efficiency,

$$\eta = 1 - \frac{1}{(r)^{\gamma-1}}$$

$= 1-1/ (8)^{1.4-1}$

$= 56.47\%$

Unit 2 Internal combustion engines

1. **What are the advantages of four stroke cycle engine over two stroke cycle? (May 2015)**

Advantages:

1. Higher volumetric efficiency
2. Thermal efficiency is higher
3. Emission is less.

2. **What do you meant by short circuiting in two stroke engine? (Nov 2013)**

In two stroke engines, all the burnt gases are not exhausted. Some portion of it will remain in the cylinder. When the piston moves to BDC, the some amount of fresh air fuel mixture from crankcase enters in to the cylinder to sweep out the burnt gases. The process of sweeping out the exhaust gases with the help of fresh air fuel mixture is known as short circuiting.

3. **Name the four stages of combustion in a CI engine. (May 2013)**

- Ignition delay period
- Period of rapid combustion
- Period of controlled combustion
- Period of after burning

4. **What is the effect of supercharging on the power output of the IC engine? (May 2013)**

Supercharging increases the power output of the engine due to the increased induction of air. This makes more oxygen available for combustion.

5. **What is a carburettor? State any two functions of carburettor. (May 2014)**

Carburetor is a device used to mix of petrol and air in correct proportions.

Functions of carburetor

- It maintains a small reserve of petrol in the float chamber at a constant head
- It atomizes and vaporizes the fuel
- It supplies a fine spray of petrol
- It produces a homogeneous mixture

6. **What are the advantages of MPFI system?(Apr 2017)**

1) More uniform A/F mixture will be supplied to each cylinder, hence the difference in power developed in each cylinder is minimum.

(2) No need to crank the engine twice or thrice in case of cold starting as happens in the carburetor system.

(3) Immediate response, in case of sudden acceleration / deceleration.

(4) Since the engine is controlled by ECM* (Engine Control Module), more accurate amount of A/F mixture will be supplied.

7. **What is a unit injection system? (Nov 2013)**

   In this system, each cylinder of the engine is provided with an individual injector, high pressure pump and a metering device.

8. **What is octane number in I.C engine? (Apr 2017)**

   It indicates the ignition quality of gasoline. Higher this number, the less susceptible is the gas to 'knocking' when burnt in a standard spark-ignition engine. Octane number denotes the percentage (by volume) of iso-octane in a combustible mixture (containing iso-octane and normal-heptane) whose 'anti-knocking' characteristics match those of the gas being tested.

9. **What is meant by valve overlapping period? (Nov 2014)**

   Valve overlap is the period during the valve timing where both the intake and exhaust valves are open. Occurring towards the end of the exhaust stroke, the intake valves are opened just before all the exhaust gases are released, providing more time for the intake air to enter the engine.

10. **What do you understand by ignition delay? (Nov 2014)**

    It is a time period between the starting of injection and combustion, during this period, the fuel is atomized, vapourized and mixed with air which is raised to itself ignition temperature.

11. **What are the functions of a flywheel? (May 2015) (Nov 2017)**

    The function of flywheel is to store energy received during the power stroke and to return the energy during the other stroke when the power is not produced.

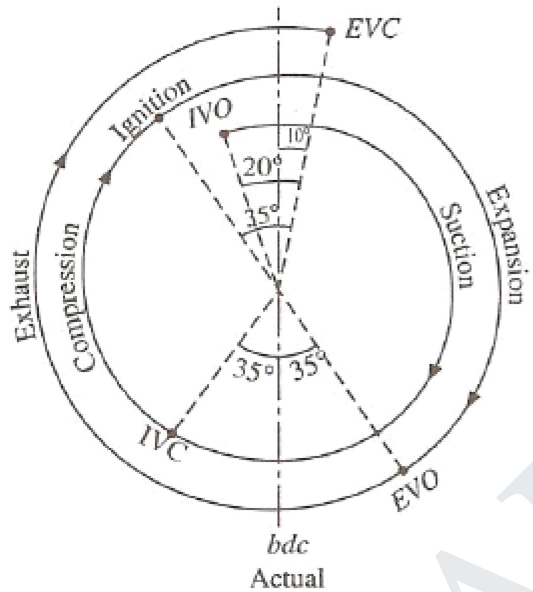
12. **Write the important requirements of fuel injection system (Nov 2015)**

- The beginning as well as the end of injection should takes place sharply.
- The injection of fuel should occur at the correct movement, correct rate and correct quantity as required by the varying engine load.
- The fuel should be injected in a finely atomized condition and should be uniformly distributed inside the combustion chamber.

13. **State the purpose of thermostat in an engine cooling system (Nov 2015)**

    A thermostat is used in the water cooling system to regulate the circulation of water in system to maintain the normal working temperature of the engine parts during the different operating conditions.

14. **Show the valve overlapping period of a typical four stroke petrol engine on valve timing period. (May 2016)**



15. **Define knocking in S.I engine. (May 2016)**

If the temperature of the unburnt mixture exceeds the self ignition temperature of the fuel and remains at or above this temperature during the period of preflame reactions, spontaneous ignition occurs at various pin point locations. This phenomenon is called knocking.

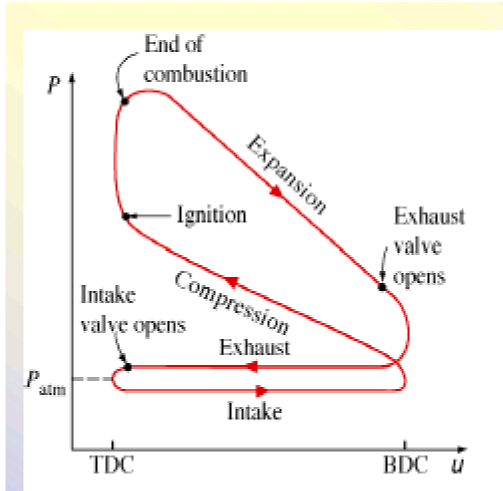
16. What is the antifreeze solutions used in water cooling systems. (Nov 2016)

Water and ethylene glycol
Water and propylene glycol

17. What is meant by motoring test. (Nov 2016)

Motoring test determine the friction power at conditions very near to the actual operating temperatures at the test speed and load.

18. Draw the actual pv diagram of a four-stroke diesel engine and indicate all the processes. (Nov 2017)



19. Define the term brake power. (May 2014)

The power developed at the output shaft (crank shaft) is called the brake power.

B.P=2πNT
N=speed in rpm
T=Torque in KN.m

20. **What are the major losses in an I.C engine?**

- Heat loss due to cooling water.
- Heat loss due to exhaust gases
- Heat loss due to radiation
- Heat loss due to friction

16 marks:

1) Explain with suitable sketch the magneto-ignition system used in petrol engine and state its advantages and disadvantages over battery ignition-system system. (May-06, Dec-11)

The magneto-ignition system generates the ignition current on its own and does not depend on any battery or generator for its supply. This system is used on motor cycles and also used in few vehicles such as tractors and fire engines.

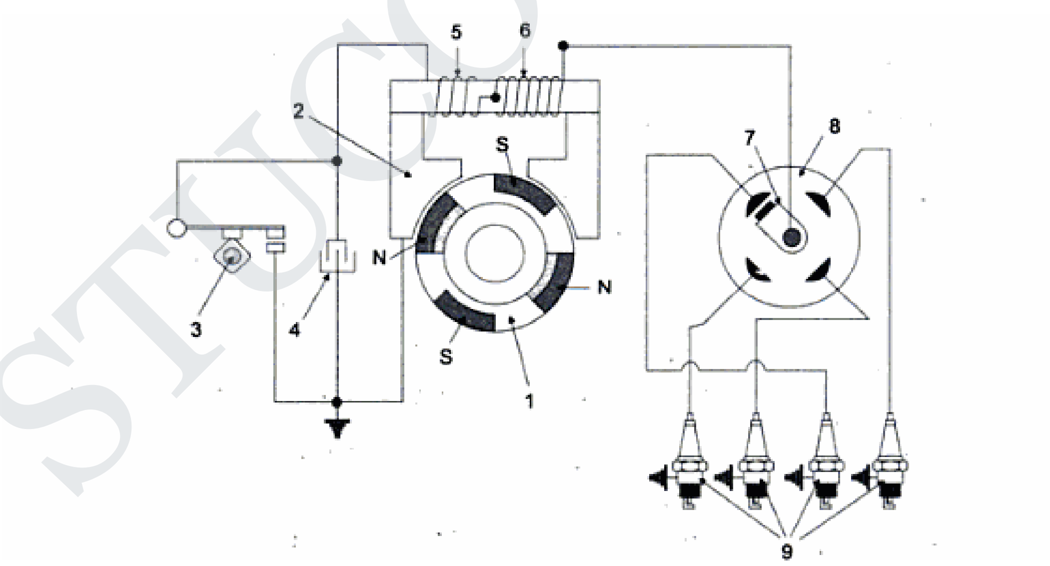
The magneto is of 3 types

1) Rotating magnet type

2) Rotating armature type

3) Polar inductor type magneto

In the rotating magneto type, the magneto revolves and the primary and secondary windings are kept stationary. In the rotating armature type, the armature with the primary and the secondary windings rotates between poles of stationary magnet. In the polar inductor type magneto, the magnet and windings are kept stationary, but the flux field is reversed with the help of the soft iron polar projections called inductors.



1. Rotating magnet; 2. Armature pole piece; 3. Cam;
4. Condenser; 5. Primary coil; 6. Secondary coil; 7. Rotor arm; 8. Distributor; 9. Spark plugs

Fig: 1 Principle of the Rotating Magnet-Type Magneto for 4 Cylinder Engine:

In the fig, the magnet is rotating while the armature pole pieces are stationary. The distributor, rotor arm and four plugs are shown in fig. The primary and secondary coils as well as the condenser are fixed. The contact does not rotate, while the cam rotates.

When the wheel rotates, the magnet also rotates and current is generated. This current first blows through the primary coil. The rotating cam breaks the contact points and due to this sudden discontinuity in the flow of current, high tension current is induced in the secondary coil. The high tension current flows to the distributor. As the distributor arm rotates, the high tension current is distributed by this arm to the spark plugs. Spark is produced in the plugs following the firing order of the engine; the condenser prevents the development of any arcing between the contact breaking points during separation.

A comparison between the battery ignition system and the magneto ignition system is given below

BATTERY IGNITION SYSTEM:

- Batter supplies current to the primary circuit.
- Even, at low speed a good spark is available.
- It the battery is discharged it is difficult to start the engine.
- Starting the engine is easy.
- This system occupies more space.
- Efficiency of the system decreases as the engine speed rises.
- As there is a battery maintenance problems are considerable.
- Used in cars buses and trucks.

MAGNETO IGNITION SYSTEM:

- Magneto generates the current.
- Poor sparking at low speed.
- As, there is no battery such difficulty does not arise.
- Starting of the engine is not so easy.
- This system requires low space.
- Efficiency of the system improves as the engine speed rises.
- As there is no battery, maintenance problem are less.
- Used in, motor cycles, scooters and racing cars.

2. Classify the internal combustion engine.

IC engines are classified are based on:

Number of strokes per cycle

- Four stroke engine
- Two stroke engine

Cycle operations

- Otto cycle engine
- Diesel cycle engine
- Dual combustion cycle engine

Types of fuel used

- Petrol engine
- Diesel engine
- Gas engine

Methods of charging

- Naturally aspirated engine
- Supercharged engine

Types of ignition

- Spark –ignition engine
- Compression ignition engine

Types of cooling

- Air cooling
- Water cooling

Speed

- Low speed engine
- Medium speed engine
- High speed engine

Number of cylinders

- Single
- Two
- Four
- Six
- Eight
- Twelve

Arrangement of cylinders

- Straight or in line engine
- Horizontal engine
- Radial engine
- V – engine
- Opposed cylinder engine

Method of governing

- Quality governing
- Quantity governing

Valve arrangement

- L-head
- I-head
- F-head
- T-head

3. Explain why cooling is necessary in an I.C engine? With neat sketches describe the working of water cooling system used for multi-cylinder. Why should a pump and thermostat be provided in the cooling system of an engine?

As a result of the combustion of fuel in the cylinders of the engine a considerable amount of heat is produced. All heat is not utilized as power at the crankshaft, with only about 20% of the heat being used as power at the crankshaft 35% of the heat is transferred to the cylinder walls which constitutes the power loss.

The heat should be prevented from being transferred to the cylinder walls as it causes the pre-ignition of charge. Further, the lubricant might also burn because of the excessive heat. The burning of the lubricant in turn might lead to seizure of the piston.

While the engine is running, heat should be continuously removed from the engine. For this purpose, various methods of cooling the engine are utilized.

Water cooling system

In a water cooling system, water jackets are provided in the cylinder block and the cylinder head. Water fills up these jackets and the heart from the cylinder is transferred to the water in the jackets thus cooling in the cylinder.

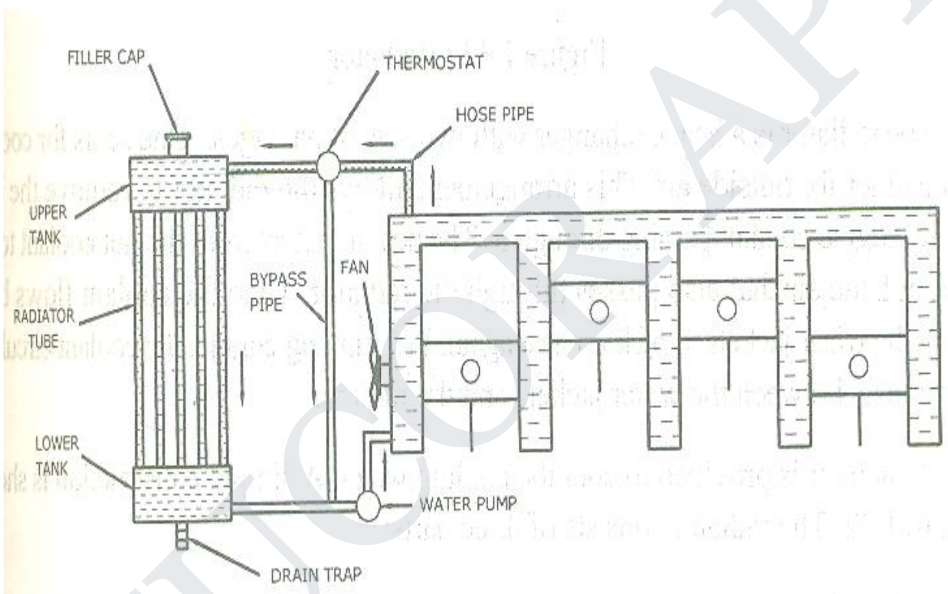


Fig: 2 Water Cooling System

When the water passes through the radiator, it is cooled by the cold air drawn by a fan. The cold water again reaches the cylinder block by means of thermo siphon system. However this method of circulation of water is not effective as the heat dissipated by the engine is so large that it is not possible to cool the engine quickly by the thermo siphon system. To enable faster cooling a pump is introduced in the system between the radiator and the engine block at the lower side. This pump is rotated by the crankshaft by means of a belt. When the pump, water is circulated with some force, in the positive direction. Therefore the heat of engine block is removed quickly without any difficulty.

Water pump

A pump is used in the water cooling system for increasing the velocity of the circulating water .Water pump is rotated by the crankshaft through a v-belt.

Thermostat

It consists of a metallic part, which either expands or contracts when it comes in contact with hot or cold water. When the valve comes in contact with cold water, it closes. When the water is hot, the valve rises above its seat and hot water passes through the valve to the radiator. The principle of braking up and mixing the fuel with the air is called carburetion.

4. Explain the working principle of Simple carburetor with a neat sketch..

Functions of carburetor

- It maintains a small reserve of petrol in the float chamber at a constant head
- It atomizes and vaporizes the fuel
- It prepares a mixture of petrol and air in correct proportions
- It supplies a fine spray of petrol
- It produces a homogeneous mixture

Simple carburetor

The main components of simple carburetor are: float chamber, float, nozzle, venture, throttle valve, inlet valve, and metering jet. In the float chamber, a constant level of the petrol is maintained by the float and a needle valve.

The float chamber is ventilated to atmosphere. This is used to maintain atmospheric pressure inside the chamber. The float which is normally a metallic hollow cylinder rises and closes the inlet valve as the fuel level in the float chamber increases to certain level.

The mixing chamber contains venture, nozzle, and throttle valve the venture tube is fitted with the inlet manifold. This tube has a narrow opening called venture. The nozzle keeps the same level of petrol as that of the level in the float chamber. The mixing chamber has two butterfly valves. One is to allow air into the mixing chamber known as choke valve. The other is to allow air –fuel mixture to the engine known as throttle valve.

Working

During the suction stroke, vacuum is created inside the cylinder. This causes pressure difference between the cylinders and d outside the carburetor. Due to this, the atmospheric air enters into the carburetor. The air flows through the venturi. The venturi increases the velocity of air enters into the carburetor. The flows through venturi. The venturi increases the velocity of air and reduces the pressure. This provides the partial vacuum at the tip of the nozzle. Because of this vacuum, the fuel comes out from the nozzle in the form of fine spray. These fine fuel particles mix with the incoming air to form air –fuel mixture. Thus, it gives homogeneous mixture of air- fuel to the engine.

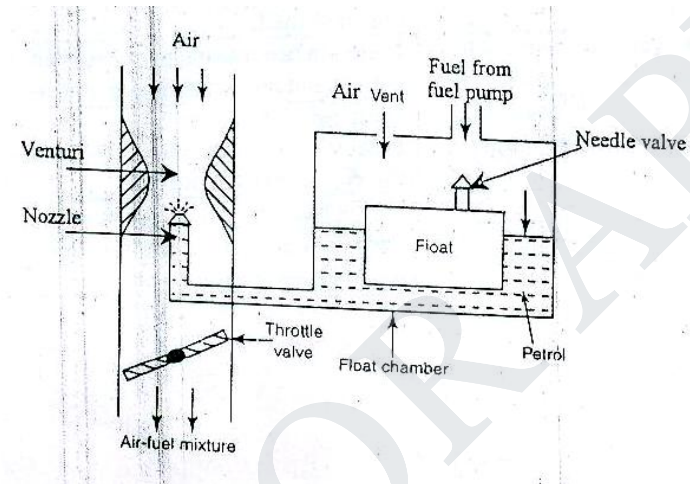


Fig:3 Simple Carburettor

5. Compare four stroke and two stroke cycle engines.(Dec-11)

FOUR STROKE ENGINE:

- Power is developed for every two revolutions of the crankshaft
- Consists of valves, camshafts and tappets.
- For the same size, power is less for same number of revolutions.
- There is one working stroke for every two revolutions of the crankshaft.
- There are many moving parts and hence there is more friction and less mechanical efficiency.
- The exhaust gases are fully burnt and leave as the exhaust. Therefore has more output.
- Engine is water cooled.
- Used in cars and commercial vehicles.
- The engine uses less lubricating oil.

TWO STROKE ENGINE:

- Power is developed for every one revolutions of the crankshaft.
- Consists only of ports with no valves, camshaft and tappets.
- For the same size, power is more for the same of revolutions.
- There is no working stroke for every revolution of crankshaft.
- There are few moving parts and hence there is less friction and more mechanical efficiency.
- Some amount of fresh charge mixes with the exhaust and leaves the exhaust. Therefore the engine has less output.
- Engine is air cooled.
- Used in motor cycles, scooters and small boats.

6. With a neat diagram explain the working of battery ignition system.(May/June-12 ,Nov/Dec-13)

The ignition system starts the combustion process in a spark – ignition close to the end of the compression stroke.

Types of ignition system

- Battery ignition system
- Magneto ignition system
- Electronic ignition system

Battery ignition system or coil ignition system

Passenger cars, light trucks and some motorcycle are fitted with battery ignition system.

A battery ignition system consists of a battery, ammeter, switch, ignition coil, condenser, cam, contact breaker points, distributor and spark plugs. The positive terminal of the battery and condenser and one terminal of each spark plug are all earthed to the metal body of the engine.

The primary ignition circuit consists of the battery, ammeter, switch, primary winding and the contact breaker points which are connected to earth. A condenser is connected to the contact breaker points in parallel. One of the condenses is connected to the contact breaker points and the other end is earthen.

The secondary ignition circuit constitutes the secondary winding, distributor and spark plugs, which are returned to earth. High tension voltage of about 25000v to 30000v is required to jump the gap plug and produce the spark. The ignition coil is used to step up the battery voltage ranges from 6v to 12v high tension voltage. The spark produced by the high tension voltage ignites the mixture of air and fuel in the combustion chamber of the cylinder.

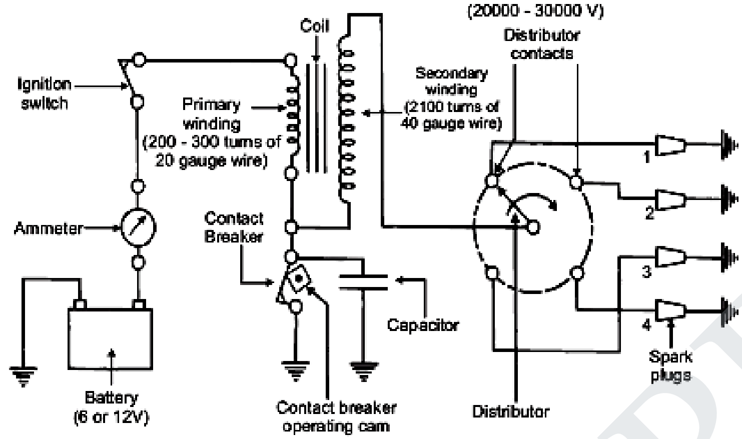


Fig: 4 Battery Ignition System

The rotation of the distributor rotor sends the current to four segments. These segments in turns send the current to the spark's plug.

The condenser protects the breaker point by reducing the arcing at the breaker points. For the ignition system of four –cylinder engine, the cam of the contact breaker has four projections which are called lobes. For every revolution of the cam, the primary circuit is completed and broken four times.

When the ignition switch is turned on, current passes from the battery through the primary winding and magnetic field is produced in the coil. When the cam opens the contact breaker points, the magnetic field collapses and the current is induced in the secondary coil. The voltage is stepped by the secondary coil to 30000v. The distributor supplies this high voltage to the proper spark plug. The voltage produces a spark in the spark plug which ignites the combustible mixture of air and fuel in the cylinder.

7. Explain the pressure feed lubrication system with neat diagram?(May-11,14)

The supply of lubricating oil between the moving parts of motor vehicles is called lubrication.

Significance of lubricants

- To reduce friction
- To reduce wear
- To provide cooling effect
- To provide cleaning action

- To provide cushioning effect
- To provide sealing

There are five system of lubrication

- Petrol system
- Splash system
- Pressure- feed system
- Combined splash and pressure feed system
- Dry sump system

PRESSURE FEED SYSTEM:

In the pressure feed system, oil is forced is forced with sufficient pressure to enable it to reach even the smallest clearances.

The clearance between the surfaces of the rotating parts of the engine is generally less than 0.001mm.The value of clearance is same for the engine parts moving to and fro. The splashed oil does not have enough force to reach inside such small spaces. Therefore oil is forced with sufficient pressure so that it reaches small clearance.

An oil pump is used in the pressure feed –system. The oil pump is operated by the crankshaft and is placed in the oil pump. Oil is pumped from the oil sump with sufficient pressure through the oil lines.

The leaves through the outlet of the pump and first reaches the oil distributor. Pipes from the distributor convey the lubricating oil to the various parts of the engine.

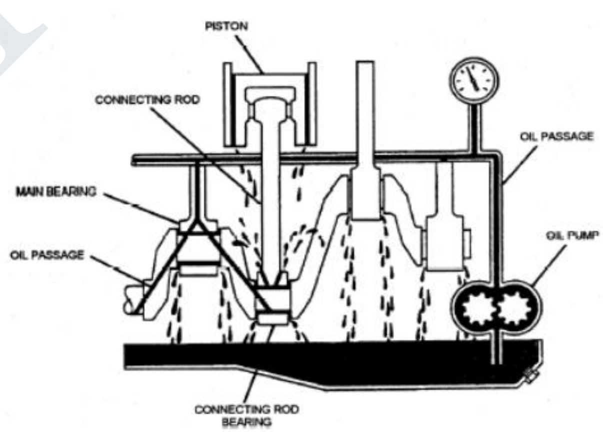


Fig: 5 Pressure Lubrication System

One of the pipes leading from the distributor, supplies oil to main bearings of the crankshaft. Through the holes drilled through the crankshaft and crankpin bearings, oil passes through the main bearings into the crank-arms. The oil finally reaches the crankpin bearings. A hole is drilled in the central portion of the connecting rod. Once the lubricating oil reaches the crankpin bearings, it is passed through the holes in the connecting rod. Finally it reaches the gudgeon bearings, from where it splashed under the pressure from the hole of the connecting rod and gudgeon pin bearings. The oil lubricates the cylinder walls from where the oil drips into the sump.

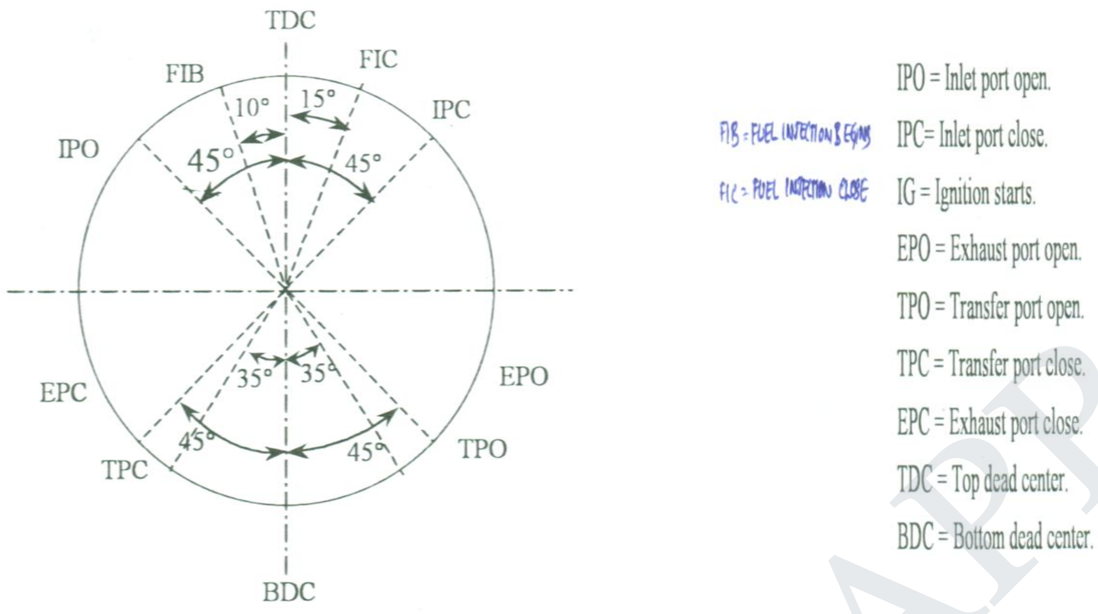
Another pipe supplies oil from the oil distributor under pressure to the timing gears and chain. Once the timing gears are well lubricated, oil returns to the oil sump.

Figure shows the pressure-feed lubricating system in a complete form for a four cylinder in-line engine an oil pump takes the lubricating oil from the wet sump through the strainer. This oil then passes through the filter and reaches the main oil line at a pressure of 200 to 400kpa and lubricates various parts of the engine.

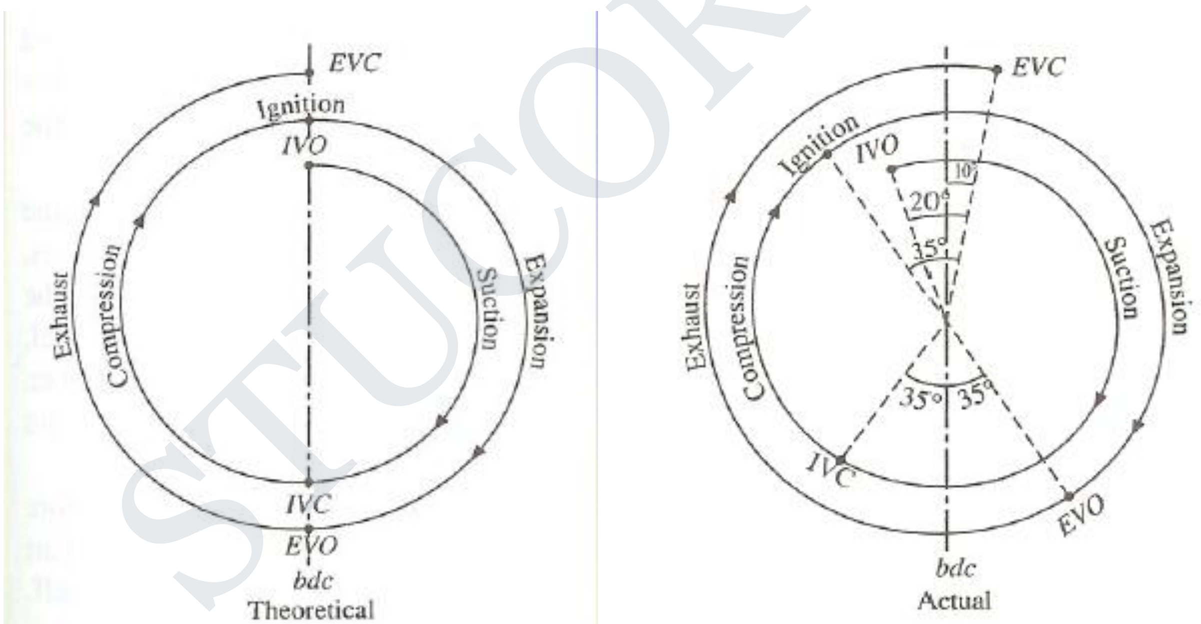
7. Explain the main difference between a 2-stroke and 4- stroke cycle engine. (MAY/JUNE 2012)`

S:NO	PETROL ENGINE	DIESEL ENGINE
1	During the suction stroke , air fuel mixture is drawn from carburettor.	During the suction stroke , air is only drawn from the atmosphere.
2	Carburettor is used to mix the air and fuel in required proportion.	Fuel injector is required to inject the fuel into cylinder in atomized form.
3	Spark plug is required to ignite the fuel air mixture.	Fuel is ignited automatically by high pressure and temperature air.
4	It is operated by Otto cycle or Constant volume cycle.	It is operated by Diesel cycle or constant pressure cycle.
5	Compression ratio varies from 6to8.	Compression ratio varies from 12to18.
6	The starting is easy due to low compression ratio.	The starting is little difficult due to higher compression.
7	Running cost is high because of high cost of fuel.	Running cost is less because of lower cost of fuel.
8	For the same power, less space is required.	For the same power, more space is required.

8. **Draw the port Timing diagram of two stroke cycle diesel engine. (May/June-2013)**



9. Draw the valve timing diagram for 4- stroke cycle spark ignition system. (May/June-2012)



10. **Explain the construction and working of a fuel injector with a neat sketch.** (May/June-2013,14)

- The function of the fuel injection system is to provide the right amount of fuel at the right moment and in a suitable condition for the combustion process.

- There must therefore be some form of measured fuel supply, a means of timing the delivery and the atomisation of the fuel.
- The injection of the fuel is achieved by the location of cams on a camshaft. This camshaft rotates at engine speed for a two-stroke engine and at half engine speed for a four-stroke.
- There are two basic systems in use, each of which employs a combination of mechanical and hydraulic operations. The most common system is the jerk pump; the other is the common rail.
- A typical fuel injector is shown in Figure , It can be seen to be two basic parts, the nozzle and the nozzle holder or body.
- The high-pressure fuel enters and travels down a passage in the body and then into a passage in the nozzle, ending finally in a chamber surrounding the needle valve.
- The needle valve is held closed on a mitred seat by an intermediate spindle and a spring in the injector body. The spring pressure, and hence the injector opening pressure, can be set by a compression nut which acts on the spring.
- The nozzle and injector body are manufactured as a matching pair and are accurately ground to give a good oil seal. The two are joined by a nozzle nut.
- The needle valve will open when the fuel pressure acting on the needle valve tapered face exerts a sufficient force to overcome the spring compression. The fuel then flows into a lower chamber and is forced out through a series of tiny holes.
- The small holes are sized and arranged to atomise, or break into tiny drops, all of the fuel oil, which will then readily burn. Once the injector pump or timing valve cuts off the high pressure fuel supply the needle valve will shut quickly under the spring compression force.
- •All slow-speed two-stroke engines and many medium-speed fourstroke engines are now operated almost continuously on heavy fuel. A fuel circulating system is therefore necessary and this is usually arranged within the fuel injector.
- During injection the high-pressure fuel will open the circulation valve for injection to take place. When the engine is stopped the fuel booster pump supplies fuel which the circulation valve directs around the injector body.
- Older engine designs may have fuel injectors which are circulated with cooling water.

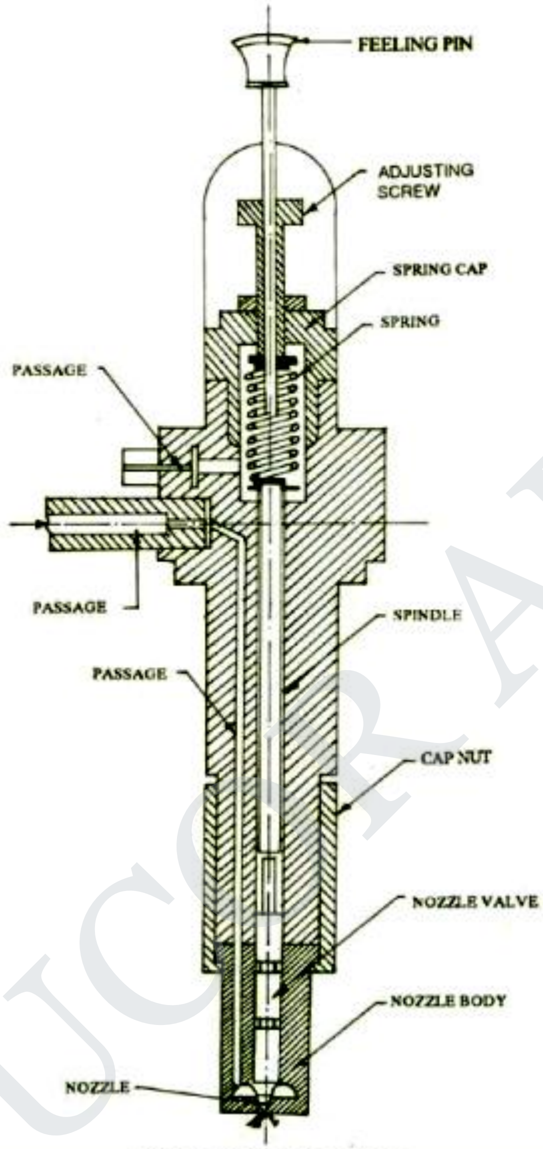


Fig. Fuel injector

16 MARKS: PROBLEMS

1) A four stroke petrol engine has a piston displacement of 2210 cm/cube. The compression ratio is 6.4, the fuel combustion is 0.13 kJ/min.The calorific value of fuel is 45000 kJ/kg.The brake power developed while running at 2500 rev/min is 50.25kW.Determine the brake mean effective pressure and the relative efficiency based on brake thermal efficiency. [Dec-07]

GIVEN:

N=N/2

=2500/2

=1250rpm

=20.83 rps

Vs=2210cm/cube=l*a

R=6.4

Fc=0.13kg/min=7.8kg/hr

Cv=45000 kJ/kg

N=2500 rpm

B.P=50.25 kW

Find:

i) BMP=?

ii) Net (relative based on brake thermal) =?

Solution:

As= (1-1/ (6.4)0.4)*100

=52.4%

B.T=B.P*3600/fc*cv

=50.25*3600/7.8*45000

=51.53%

Net relative =0.5153/0.524*100

=98.33%

B.P= BMP lank

=1091.57 kN/m.sq

Result

B.P= BMP lank

=1091.57 kN/m.sq

2) An 4-stroke single cylinder gas engine developsn15.6 kW B.P at 240 rpm. Using the following data, find the relative efficiency of the engine gas consumption=12.57m^3 measured at 1.05 bar and 15°c.

Cv of the gas =25 kJ/litre at 1bar and 0°c **[Dec-2006]**

Cylinder dia =25cm

Stroke of the engine = 50cm

Clearance volume = 4.5 litres

GIVEN:

N=N/2

B.P=15.6 kW

N=240 rpm

V_1=12.57m^3/hr

P_1=1.05bar

T_1=15°c=288K

C_v=25kJ/litre

P_2=1 bar

T_2=0deg=273K

D=25cm=0.25m

L=50cm=0.5m

V_c =4.5litres

=0.0045m^3

FIND:

Relative efficiency=?

SOLUTION:

V_s=3.14/4*d*d*l

=3.14/4*0.25*0.25*0.5

Vs =0.02454m^3

R=v1/v2

=vc+vs/vc

=0.0045+0.02454/0.0045

R=6.45

As= (1-1/(r) r-1)*100

As=52.55%

P1v1/t1=p2v2/t2=v2=p1v1/t1*t2/p2

V_2=1.05*12.57**273/288

V_2=12.51m^3/hr=fc

B.T=B.P*3600/fc*cv=15.6*3600/12.51*25000=17.95%

Relative=B.T/AS

=0.1795/0.5255=34.15%

Result:

Relative=34.15%

3)A four cylinder stroke cycle petrol engine 79mm bore, 132mm stroke develops 28.35 kW brake power while running at 1450 rpm and using a 20% rich mixture if a volume of air into the cylinder when measured at 15.5°c and 760mm of mercury is 70% of the swept volume the theoretical air fuel ratio is 14.8 the heating volume of petrol used is44000 kJ/kg and the mechanical efficiency of the engine is90%find the indicated thermal efficiency, take R=0.287kJ/kgK, the brake mean effective power. [May-06, May-11)

GIVEN:

N=n/2

D=79mm=0.079

L=132=0.132m

B.P=28kW

N=1450 rpm

N=725rpm=n/2

=12.08rps

Cv=44000kJ/kg

Mech=90%

R=0.287kJ/kg.K

Using 20% rich mixture

T=15.5deg c

=288.5 K

Volume of air drawn=70% vs

P=760mm of mercury.

M_a/m_f=14.8

C_v=44000kJ/kg

FIND:

I.T=?

Bmp=?

SOLUTION:

Vs=3.14/4*4*4*l

=3.14/4*0.079*0.0079*0.132

Vs=6.4702*10^{-4} m^3

Volume of air drawn=70/100*vs

=70/100*6.4702*10-4

=4.529*10^{-4} m^3

Pv=mrt

m=pv/rt

P=760 mm of mercury=1.01325 bar

=101.325 kN/m^2.

M=101.325*4.529*10-4/0.287*288.5

=5.542*10-4*725*4

=1.60727 log/min

Ma=96.436 kg/hr

Ma/mf=ma/fc=14.8=fc=ma/14.8

=6.5159kg/hr

=6.5159*1.2

=7.81915kg/hr

Mech=B.P/I.P

I.p=B.P/mech

I.P=28.35/0.9

=31.5 kW

I.T=I.P*3600/fc*cv=3.15*3600/7.81915*44000

I.T=32.96%

ii) B.P=pmb*la*nk

pmb=B.P=28.85/0.470*10-4*12.08*4

906.79 kN/m^2

Pmb=9.067 bar

RESULT:

i) I.T=32.96%

ii) Bmp=9.067 bar.

6. Discuss the construction and working principle of a four stroke engine with neat sketch. (Nov/Dec-13)

<u>Working principle of Four stroke cycle Petrol Engines.</u>

Construction:

- A piston reciprocates inside the cylinder
- The piston is connected to the crank shaft by means of a connecting rod and crank.
- The inlet and exhaust valves are Mounted on the cylinder head.
- A spark is provided on the cylinder Head.
- The fuel used is petrol

(a) Suction Stroke (First Stroke of the Engine)

- Piston moves down from TDC to BDC
- Inlet valve is opened and the exhaust valve is closed.
- Pressure inside the cylinder is reduced below the atmospheric pressure.
- The mixture of air fuel is sucked into the cylinder through the inlet valve

(b) Compression Stroke : (Second Stroke of the piston)

- Piston moves up from BDC to TDC
- Both inlet and exhaust valves are closed.
- The air fuel mixture in the cylinder is compressed.

(c) Working or Power or Expansion Stroke: (Third Stroke of the Engine)

• The burning gases expand rapidly. They exert an impulse (thrust or force) on the piston. The piston is pushed from TDC to BDC

• This movement of the piston is converted into rotary motion of the crankshaft through connecting rod.

• Both inlet and exhaust valves are closed.

(d) Exhaust Stroke (Fourth stroke of the piston)

• Piston moves upward from BDC

• Exhaust valve is opened and the inlet valve is closed.

• The burnt gases are forced out to the atmosphere through the exhaust valve (Some of the burnt gases stay in the clearance volume of the cylinder)

• The exhaust valve closes shortly after TDC

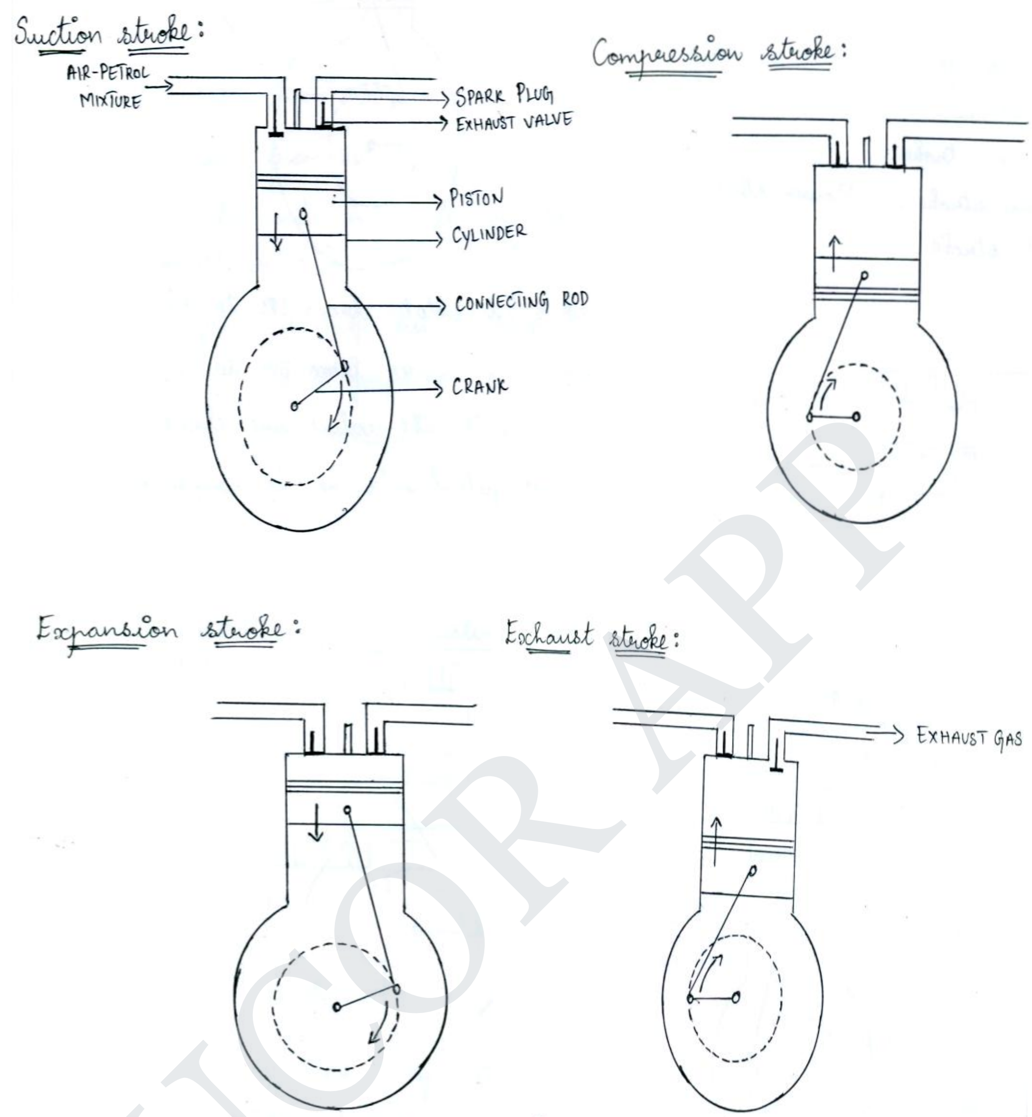
• The inlet valve opens slightly before TDC and the cylinder is ready to receive fresh charge to start a new cycle.

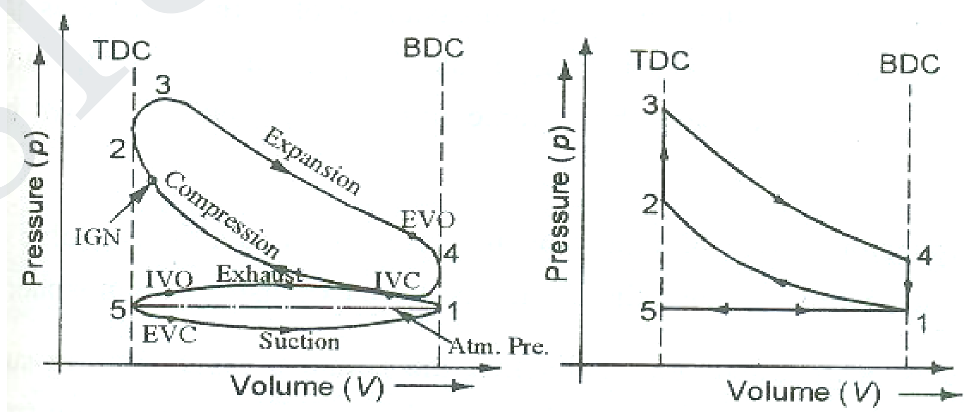
Summary:

• Compression ratio varies from 5 to 8

• The pressure at the end of compression is about 6 to 12 bar.

• The temperature at the end of the compression reaches 250^{o} C to 350^{o} C





(a) Actual cycle (b) Theoretical cycle

<u>Actual cycle & Theoretical cycle for four stroke cycle S.I Engine</u>

Working principle of four stroke cycle diesel Engines.

Construction:

- A piston reciprocates inside the cylinder
- The piston is connected to the crankshaft by means of a connecting rod and crank.
- The inlet and exhaust valves are mounted on the cylinder head.
- A fuel injector is provided on the cylinder head
- The fuel used is diesel.

(a) Suction Stroke (First Stroke of the piston)

- Piston moves from TDC to BDC
- Inlet valve is opened and the exhaust valve is closed.
- The pressure inside the cylinder is reduced below the atmospheric pressure.
- Fresh air from the atmosphere is sucked into the engine cylinder through air cleaner and inlet valve.

(b) Compression stroke (Second stroke of the piston)

- Piston moves from BDC to TDC
- Both inlet and exhaust valves are closed.
- The air is drawn during suction stroke is compressed to a high pressure and temperature

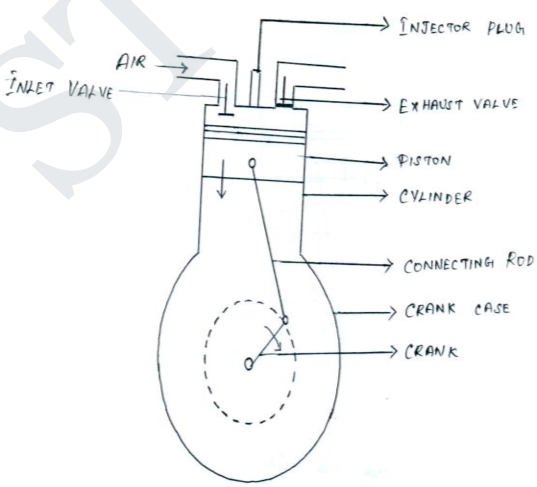
(c) Working or power or expansion stroke (Third stroke of the piston)

- The burning gases (products of combustion) expand rapidly.
- The burning gases push the piston move downward from TDC to BDC
- This movement of piston is converted into rotary motion of the crank shaft through connecting rod.
- Both inlet and exhaust valves are closed.

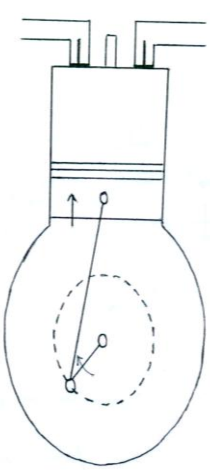
(d) Exhaust Stroke (Fourth stroke of the piston)

- Piston moves from BDC to TDC
- Exhaust valve is opened the inlet valve is closed.
- The burnt gases are forced out to the atmosphere through the exhaust valve. (some of the burnt gases stay in the clearance volume of the cylinder)
- The exhaust valve closes shortly after TDC
- The inlet valve opens slightly before TDC and the cylinder is ready to receive fresh air to start a new cycle.

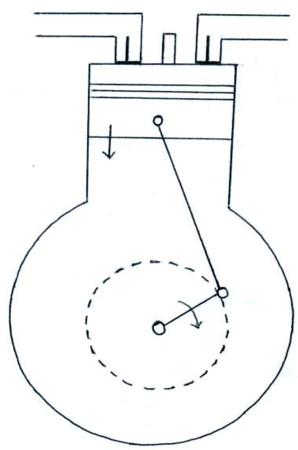
Suction Stroke:

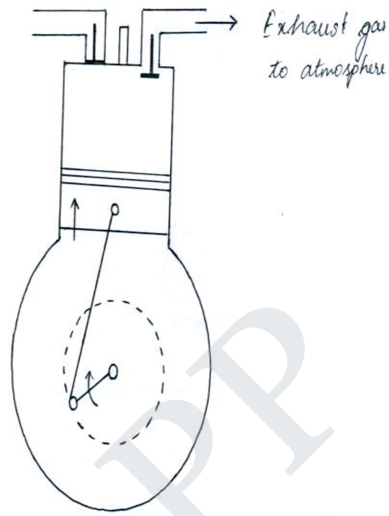


Compression stroke:

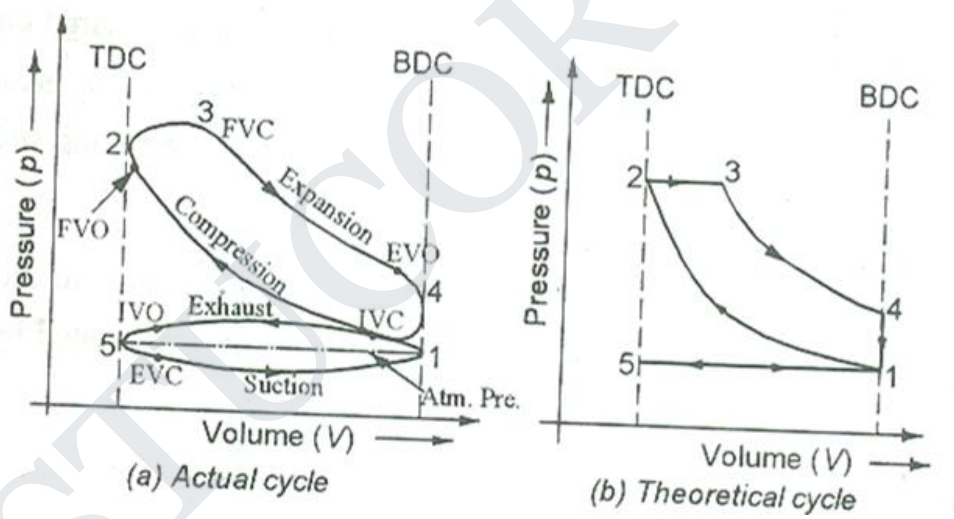


Expansion Stroke **Exhaust Stroke**





Actual cycle& Theoretical cycle for four stroke cycle C.I Engine ::



17. **Explain in detail the multi-point fuel injection system in petrol engines.**

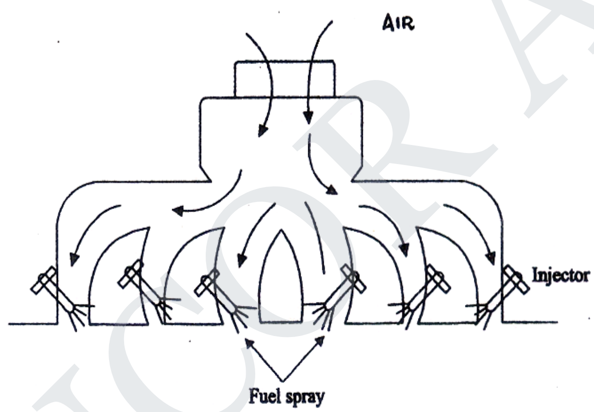
[Anna univ.dec'07, 08, June' 09, dec09,May'13]

A multi-point injection system, also called ***port injection***, has an injector in the port (air-fuel passage) going to each cylinder. Gasoline is sprayed into each intake port and toward each intake valve. Thereby, the term multi-point (more than one location) fuel injection is used. Multipoint fuel injection

(MPFI) locates an injector immediately upstream of each inlet valve, which enables better control of the air/fuel mixture to each cylinder.

HOW MPFI WORKS?

The MPFI system consists of one fuel injector placed near every intake valve and directed towards it, in the fuel intake manifold. Fuel is supplied to the injector through a common rail. The amount of air intake is decided by the car driver by pressing the gas pedal, depending on the speed requirement. The air mass flow sensor near throttle valve and the oxygen sensor in the exhaust sends signal to ECU. ECU determines the air fuel ratio required, hence the pulse width. Depending on the signal from ECU the injectors inject fuel right into the intake valve. The fuel sprayed at high pressure gets atomized into fine particles and get mixed with air. The air fuel mixture is sucked into the engine cylinder and the combustion takes place.



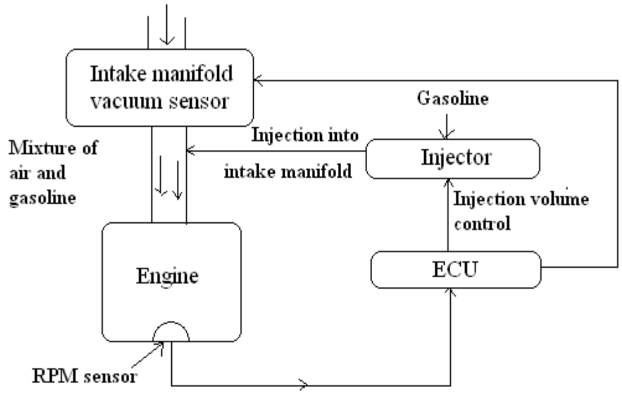
Multi point fuel injection

Types of MPFI System:

1. D-MPFI System
2. L-MPFI System

D-MPFI System:

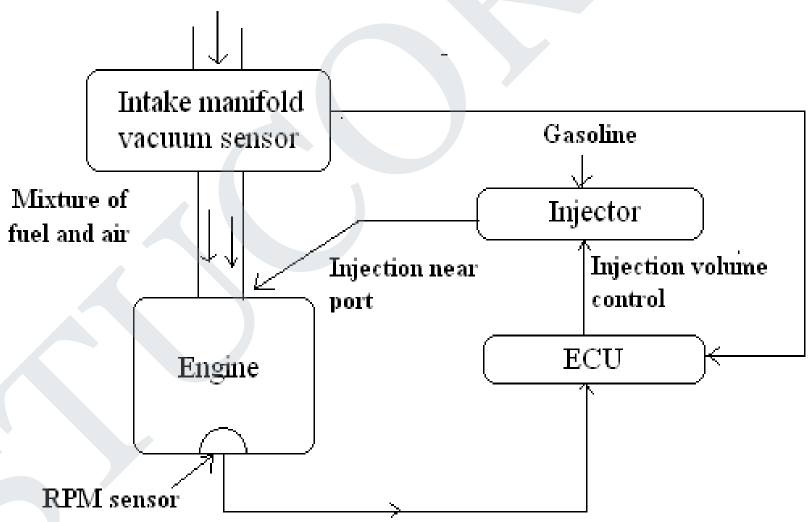
D-MPFI measures the vacuum in the intake manifold. It also senses the volume of air by its density. D-MPFI is also referred to as D-Jetronics, which is a trade mark of Bosch. D-Jetronics is a word created from German word ‘Drunk’ (pressure), and ‘Jetronics’, a word coined by Bosch meaning “injection”.



D-MPFI Gasoline Injection System

L-MPFI System:

L-MPFI directly senses the amount of air flowing into the intake manifold by means of an air flow meter. This system is used on analog circuit electronic fuel injection engines. L-MPFI is also referred to as L-Jetronics. The 'L' comes from the German "Luft" meaning "Air".



L-MPFI Gasoline Injection System

Advantages over Carburetor:

- Improved atomization. Fuel is forced into the intake manifold under pressure that helps break fuel droplets into a fine mist.
- Better fuel distribution. Equal flow of fuel vapors into each cylinder.

- Smoother idle. Lean fuel mixture can be used without rough idle because of better fuel distribution and low-speed atomization.
- Lower emissions. Lean efficient air-fuel mixture reduces exhaust pollution.
- Better cold weather drivability. Injection provides better control of mixture enrichment than a carburetor.
- Increased engine power. Precise metering of fuel to each cylinder and increased air flow can result in more horsepower output.
- Fewer parts. Simpler, late model, electronic fuel injection system have fewer parts than modern computer-controlled carburetors.

Advantage of M. P. F. I :

- More uniform A/F mixture will be supplied to each cylinder, hence the difference in power developed in each cylinder is minimum. Vibration from the engine equipped with this system is less, due to this the life of engine components is improved.
- No need to crank the engine twice or thrice in case of cold starting as happens in the carburetor system.
- Immediate response, in case of sudden acceleration / deceleration.
- Since the engine is controlled by ECM* (Engine Control Module), more accurate amount of A/F mixture will be supplied and as a result complete combustion will take place. This leads to effective utilization of fuel supplied and hence low emission level.
- The mileage of the vehicle will be improved

Unit III Steam Nozzle and Turbine

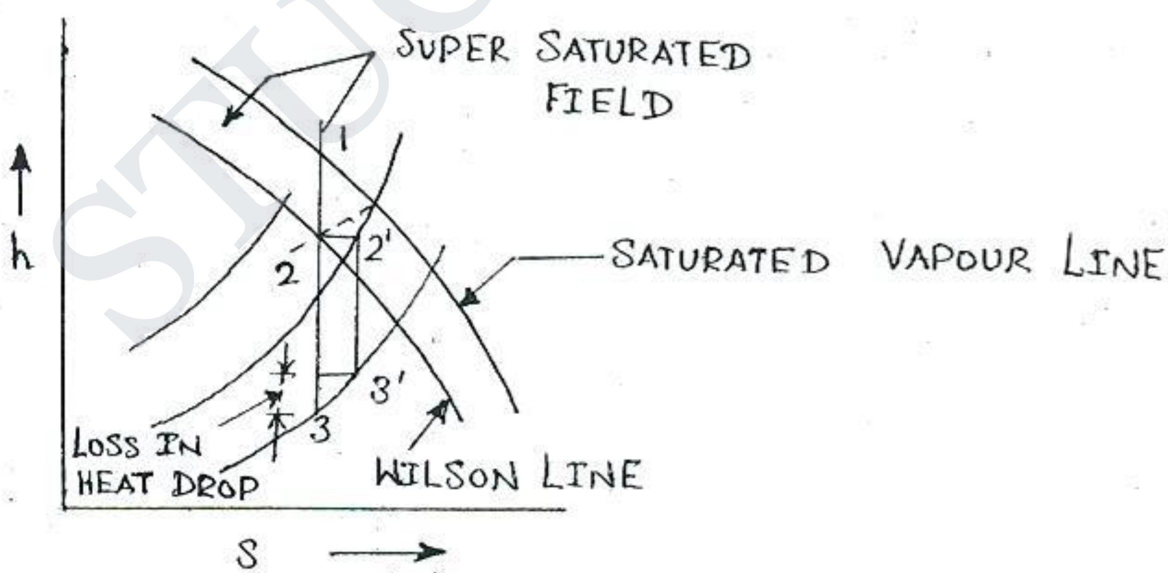
1. **Define coefficient of friction in nozzle. (Nov 2013) (Nov 2014)**
   It is defined as the ratio of the actual enthalpy drop to the is entropy drop to the isentropic enthalpy drop.

2. **Define the term critical pressure ratio. (Nov 2013) (May 2013)(Nov 2017)(Apr 2017)**
   Ratio p_2/p_1 which produces maximum discharge from the nozzle. This ratio is called critical pressure ratio.
   $p_2/p_1 = (2/n+1)^{n/n-1}$
3. **What are the effects of friction on the flow through a steam nozzle. (May 2014)**

- The expansion is no more isentropic and enthalpy drop is reduced.
- The specific volume of steam is increased as the steam become more dry due to its frictional heating.
- The final dryness of fraction of steel is increases on the kinetic energy gets converted into heat due to friction and is absorbed by steam.

4. **What is super saturated flow? (May 2015)**

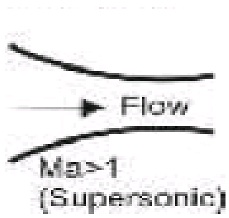
   While analyzing the flow of steam through a nozzle, it was assume the during isentropic expansion process, the steam started to condense as soon as the vapour line was reached, there would be no subsequent change in the condition of steam. This is known as equilibrium flow.
   In actual practice, the does not condense at the Saturation temperature corresponding to the pressure but continues to expand like a gas with fall in temperature even after entering the wet region at point A. This type of flow is called as metastable supersaturated (or) non equilibrium flow.



5. **What is the effect of supersaturation at nozzle. (Nov 2016)**

- There is an increase in entropy and specific volume of steam
- The exit velocity of steam is reduced
- Dryness fraction of steam is improved

6. Draw the shape of a supersonic nozzle. (May 2016)



7. Define degree of reaction. (May 2014) (Nov 2014)

It is defined as the ratio of heat drop in the moving blade to the heat drop in the stage.

8. What is the effect of friction on the flow through a steam turbine (Nov 2015)

- The expansion process will not be isentropic and enthalpy drop will get reduced, which further lead to reduced exit velocity.
- Final dryness fraction will increase
- Specific volume of steam will increase

9. Distinguish between impulse and reaction turbine. (May 2016)

S.No	Impulse turbine	Reaction turbine
1	It consists of nozzles and moving blade.	It consists of fixed blades and moving blades.
2	Pressure drop occurs only in nozzles not is moving blades.	Pressure drop occurs in fixed as well as moving blade.
3	Steam strikes the blade with kinetic energy.	Steam passes over the moving blade with pressure and kinetic energy.

10. **Define diagram efficiency of a steam turbine. (May 2013)**

It is defined as the ratio between work done by moving blades and available energy.

11. Define stage efficiency. (Nov 2016)

It is defined as the ratio between workdone an blade per kg of steam and total energy supplied per kg of steam.

12. Define the term compounding in turbines. (Nov 2017) (Nov 2015)

In a simple turbine, if the steam is expanded from the boiler pressure to condenser pressure in one stage the speed of the rotor becomes tremendously high which leads to practical complications. There are few methods of reducing the speed to lower value, all these methods utilise a multiple system of rotor in series keyed to a common shaft. This is known as compounding.

13. What is pressure compounding? (May 2015)

The pressure is reduced in each stage of nozzle rings and hence this is called as pressure compounding.

14. What are the advantages and limitation of velocity compounded impulse turbine?

Advantages:

- Relatively few number of stages and hence less initial cost.
- Require less space
- The system is reliable and easy to start

Limitation:

- The friction losses are high due to high initial velocity. Hence the efficiency is low.

15. What are the various types of nozzles and their functions?

Convergent nozzle:

In this type of nozzles, the area diminishes from inlet to outlet throat.

Divergent nozzle:

In this type of nozzles, the area increases from inlet to outlet.

Convergent Divergent nozzles:

In this type of nozzles, there is a divergent portion in addition to convergent portion. The divergent part is added to allow higher expansion ratio.

16. What is principle of reaction turbine?

In reaction turbine, the steam expands continuously in both the fixed and moving blades, so its relative velocity does not remains constant. But increases due to the expansion of steam.

17. What is function of governor in steam turbine?

The process of keeping the turbine at constant speed under all condition of load is called governing of turbine.

18. How throttling governing is done?

Steam pressure at inlet to a steam turbine is reduced by throttling process to maintain the speed of the turbine constant at part load.

19. What are the different methods of governing steam turbine?

- Throttle governing
- Nozzle control governing
- By – pass governing
- Combination of throttle, nozzle, and by – pass governing

20. What are the losses in steam turbine?

- Losses in regulating value
- Losses due to mechanical friction
- Losses due to leakage
- Losses due to radiation

16 MARKS:

1. **Dry saturated steam enters a steam nozzle at pressure of 12bar and is discharge to a pressure of 1.5bar. If the dryness fraction of a discharge steam is 0.95. What will be the final velocity of the steam. Neglecting initial velocity of steam.**

Given data:

P_1 = 12bar

P_2 = 1.5bar

X_1 = 1

X_2 = 0.95

To find: C_2

Solution:

From steam table for P_1 = 12bar

$h_1 = h_3$ = 2782.7KJ/Kg

From steam table for P_2 = 1.5bar

h_{f2} = 467.1KJ/Kg, h_{fg2} = 2226.2KJ/Kg

$h_2 = h_{f2} + x_2\, h_{fg2}$

= 467.1 + 0.95 (222.6)

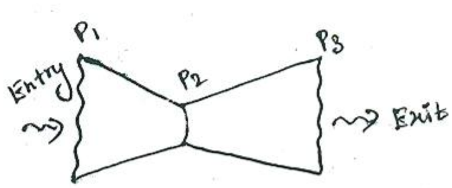
=2581.99KJ/Kg

$C_2 = \sqrt{2\times1000}\,(h_1 - h_2)$

$=\sqrt{2\times1000}\,(2782.7 - 2581.99)$

= 6333.57 m/s

2. **Dry air steam at 10bar is expanded in a nozzle to 0.4bar. The throat area is 7cm^2 and the inlet velocity negligible. Determine the mass flow and exit area. Assume isentropic flow and take the index n = 1.135 for dry saturated steam.**



Given data:

P_1 =10bar;

$X_1 = 1$

$P_3 = 0.4$bar

$A_2 = 7cm^2$

n= 1.135

To find:

$A_{3,}$ m

Solution:

$P2/P1= (2/n+1)^{n/n-1}$

$P2 = (2/1.135+1)^{1.135/0.135} \times 10$

= 5.77bar

From MOLLIER chart,

For P_1 =10bar and $X_1 = 1$

h_1 = 2775 KJ/Kg

h_2 = 2675 KJ/Kg

h_3 =2250KJ/Kg

$X_2 = 0.96$

$X_3 = 0.835$

$C_2 = \sqrt{2\times1000 (h_1 - h_2)}$

$=\sqrt{2\times1000(2776.2 – 2673.77)}$

= 452.6m/s

From steam table, at P2 = 5.77bar, Vg = 0.326

$V_2 = X_2 Vg_2 = 0.96 \times 0.326$

$= 0.31296\ m^3/kg$

$m = A_2C_2/V_2= (7 \times 10^{-4} \times 452.61)/0.31296$

= 1.01235 kg/s

$C_3 = \sqrt{2\times1000 (h_1 – h_3)}$

$=\sqrt{2\times1000(2776.2 – 2250)}$

= 1025.86m/s

From steam table, at P2 = 0.46bar, $Vg_3 = 3.993\ m^3/kg$

$V_3 = X_3 Vg_3 = 0.835 \times 3.993$

$= 3.334\ m^3/kg$

$m = A_3C_3/V_3$

$A_3 = m V_3/C_3 = (1.01235 \times 3.334)/1025.86$

$= 3.29\times 10^{-3}\,m^2$

3. Steam enters a group of convergent –divergent nozzle at 30bar and 275 degree Celsius, the discharge pressure being 0.1bar the expansion is under thermal equilibrium throughout and the loss by friction in divergent section of the nozzle is equivalent to the 10/- of the isentropic enthalpy drop. Calculate the total throat and exit areas to discharge 14kg of steam per second.

Given data:

$P_1 = 30bar$

$T_1 = 275$ degree Celsius

$P_3 = 0.1bar$

Enthalpy drop = 10/-

m = 14kg/s

To find:

A_2, A_3

Solution:

$P_2/P_1= (2/n+1)^{n/n-1}$

For 30 bar pressure T_s = 233.8 degree Celsius <T,

Steam is superheated, n=1.3

$P_2/P_1= (2/n+1)^{n/n-1}$

$P_2 = (2/1.3+1)^{3/1.3-1}\times 30$

= 16.37bar

From MOLLIER chart,

$h_1 = 2930$ KJ/Kg

$h_2 = 2790$ KJ/Kg

$h_3 =2040$KJ/Kg

Convergent section,

$C_2 = \sqrt{2}\times 1000\ (h_1 - h_2)$

$=\sqrt{2}\times 1000(2930 – 2790)$

= 529.15m/s

From steam table, at P2 = 16.32bar,

$V_2 = Vg_2 = 0.122m^3/kg$

$m =A_2C_2/V_2$

$A_2 = m\, V_2 / C_2 = (14 \times 0.122)/529.15$

$= 3.227 \times 10^{-3}\, m^2$

Divergent section,

Enthalpy drop = 10/-

Nozzle coefficient = 0.9

$C_3 = \sqrt{2 \times 1000 \times 0.9 \times (h_1 - h_3)}$

$= \sqrt{2 \times 1000 \times 0.9 \times (2930 - 2040)}$

$= 1265.7 m/s$

From steam table, at P3 = 0.1bar,

$Vg_3 = 14.67\, m^3/kg$

$V_3 = X_3\, Vg_3 = 0.77 \times 14.67$

$= 11.29\, m^3/kg$

$m = A_3 C_3 / V_3$

$A_3 = m\, V_3 / C_3 = (14 \times 11.29)/1265.7 = 0.1294 m^2$

4. Dry saturated steam at 2.8bar is expanded through a convergent nozzle at 1.7bar. The exit area is 3cm^2. Estimate the exit velocity and the mass flow rate, assume isentropic expansion and supersaturated flow exits.

Given data:

$P_1 = 2.8 bar$

$P_2 = 1.7 bar$

$X_1 = 1$

$A_2 = 3 cm^2$

To find: m

Solution:

From steam table, at P1 = 2.8bar,

$h_1 = h_g = 2721.5 KJ/Kg$

$v_1 = v_g = 0.646\, m^3/kg$

Case1: Isentropic expansion,

From MOLLIER chart,

$h_1 = 2725\, KJ/Kg$

$h_2 = 2635\, KJ/Kg$

$C_2 = \sqrt{2 \times 1000\, (h_1 - h_2)}$

$= \sqrt{2 \times 1000 (2725 - 2635)}$

$= 424.26 m/s$

$V_2 = x_2\, g_2 = 0.972 \times 1.003$

$= 1.00203 m^3$

$m = A_2C_2/V_2 = (3 \times 10^{-4} \times 424.26)/1.00203$

$= 0.12702 kg/sec$

$V_2/V_1 = (p1/p2)^{1/n}$

$V_2 = (2.8/1.7)^{1/1.135} \times 0.646$

$= 1.00268\ m^3/kg$

$C_2^2/2 = n/n\text{-}1(p1v1\text{-}p2v2)$

$= \sqrt{2n/n\text{-}1(p1v1\text{-}p2v2)}$

$= \sqrt{(2\times1.135/1.135\text{-}1)(2.8 \times 10^5 \times 0.646 - 1.7 \times 10^5 \times 1.0026)}$

$= 418.66 m/s$

$m = A_2C_2/V_2 = (3 \times 10^{-4} \times 418.66)/1.00268$

$= 0.12526 kg/s$

5. **A convergent-divergent nozzle receives steam at 7bar and 200 °C and expands isentropically into a space of 3bar. Neglecting the inlet velocity, calculate the exit area required for a mass flow of 0.1kg/s when a) The flow is in equilibrium throughout b) The flow is super heated with $Pv^{1.3}$ = C. (Dec-11,May-14)**

Given data:

P_1=7bar

T_1 = 200 degree Celsius

P_3 = 3bar

m= 0.1kg/s

n= 1.3

To find:

A_3 under a) Equilibrium condition, b) Super saturated condition

Solution:

Case 1: Equilibrium condition

From MOLLIER chart,

h_1 = 2845 KJ/sec

x_3 = 0.98

$V_3 = x_3\, g_3 = 0.98 \times 0.606$

$= 0.5938\ m^3/kg$

$C_3 = \sqrt{2\times1000\,(h_1 - h_3)}$

$= \sqrt{2\times1000(2845 - 2680)}$

$= 574.45 m/s$

$m = A_3C_3/V_3$

$A_3 = m\,V_3/C_3 = (0.1 \times 0.5938)/574.45$

$= 103.36 mm^2$

Case 2: Super saturated condition

From super heated steam table at 7bar and 200 degree Celsius

$V_1 = 0.3\ m^3/kg$

$V_3/V_1 = (P_1/P_2)^{1/n}$

$V_3 = (7/3)^{1/1.3} \times 0.3$

$= 0.5756\ m^3/kg$

$C_3^2/2 = n/n\text{-}1(p1v1\text{-}p3v3)$

$= \sqrt{(2\times1.3/1.3\text{-}1)(7 \times 10^5 \times 0.3 - 3 \times 10^5 \times 0.5755)}$

$= 568.71 m/s$

$m = A_3C_3/V_3$

$A_3 = m\,V_3/C_3 = (0.1 \times 0.5756)/568.71$

$= 101.21 mm^2$

16 marks:

1. **Mention the difference between impulse and reaction turbine.(May/June-11,2013)**

Impulse turbine	Reaction turbine
1. It consists of nozzles and moving blade.	1. It consists of fixed blades and moving blades.
2. Pressure drop occurs only in nozzles not is moving blades.	2. Pressure drop occurs in fixed as well as moving blade.
3. Steam strikes the blade with kinetic energy.	3. Steam passes over the moving blade with pressure and kinetic energy.
4. It has constant blade channel area.	4. It has varying blade channel area.
5. Due to more pressure, number of stages required is less.	5. Number of stages required is more due to more pressure drop.
6. Power developed is less.	6. Power developed is considerable.
7. It occupies more space for same power output.	7. It occupies more space for same power.
8. Lower efficiency.	8. High efficiency.
9. Velocity of turbine is more.	9. Velocity of turbine is less.
10. Blade manufacturing is not difficult and this is not costly.	10. Blade manufacturing process is difficult.

2. **A 50% reaction turbine running at 400rpm has the exit angle of the blade as 20 degree and the velocity of steam relative to the blade at the exit is 1.35times the mean speed of the blade. The steam flow rate is 8.33 kg/s and at particular stages the specific volume is 1.281m^3/kg. Calculate for this a) A suitable blade height, assuming the rotor mean diameter 12 times the blade height, b) The diagram work.**

Given data:

α=20 degree

$\rho = V_b / V_{r2} = 1/1.35 = 0.741$

N = 400rpm

m= 8.33kg/s

v= 1.381 m^3/kg

Solution:

$V_{F2} = V_{r2}$ Sin α

= 1.35 V_b Sin 20 = 0.4617 V_b

Mass flow rate, m = πdh V_f / v

8.33= π × 12h × h × 0.4617 V_b / 1.381

8.33= π × 12h × h × 0.4617 (π d N/60) / 1.381

h= 0.138m 138mm

Diagram efficiency, η= α – α /(1 + 2ρcosα - ρ^2)

= 2 – 2 / (1 + 2 × 0.714 × Cos20 - 0.748)

= 91.5%

3. **The following data refers to a single stage impulse turbine**

   Isentropic nozzle entropy drop = 200kJ/kg

   Nozzle efficiency = 90%

   Nozzle angle = 25 °

   Ratio of blade speed of whirl component of steam speed = 0.5 blade coefficient = 0.9. The velocity of steam entering the nozzle 30m/s. Find a) The blade angle at the inlet and outlet if the steam enters the blade without shock and leaves the blade in the axial direction.

   b) Blade efficiency, c) Power developed and axial thrust if the steam flow rate is 10 kg/s.(May-13)

Given data:

h_e = 200kj/kg

η_n = 90%

α = 25 degree

$V_b/V_{w1} = 0.5$; $V_{n2}/V_{r1} = 0.9$

$V_i =$ m/s; $V_2 = V_{f2}$, $V_{w2} = 0$

And β=90 degree for axial discharge

Solution:

Actual enthalpy drop, $h_i - h_e = (h_i - h_e') \times \eta_n$

$$h_i - h_e = 200 \times 0.9 = 180 \text{kj/kg}$$

Exit velocity of nozzle,

$$V_e = \sqrt{2}\,(h_i - h_e) + V_i^2$$

$$= \sqrt{2} \times 1000 \times 180 + 30^2$$

$$= 600.75 \text{m/s}$$

Inlet velocity of steam to the turbine,

$$V_e = V_i = 600 \text{m/s}$$

From ΔBCE, $V_{w1} = V_1 \text{Cos } 25$

$$= 600.75 \text{ Cos } 25$$

$$= 544.76 \text{m/s}$$

$$V_{f1} = V_1 \text{Sin} 25 = 600.75 \text{ Sin } 25$$

$$= 253.9 \text{m/s}$$

$$V_b/V_{w1} = 0.5$$

$$V_b = 544.46 \times 0.5 = 272.23 \text{m/s}$$

$$V_{r1} = \sqrt{}\, V_{f1}^2 + (V_{w1} - V_b)^2$$

$$= \sqrt{253.89^2} + (544.76 - 272.23)^2$$

$$= 372.25 \text{m/s}$$

$$\text{Tan } \theta = V_{f1} / (V_{w1} - V_b)$$

$$= 253.89 / (544.76 - 272.23)$$

$$= 43\ °$$

$V_{r2} = 0.9 \times V_{r1}$

$= 0.9 \times 372.25 = 335.03 m/s$

$\cos \varphi = AB / AD = V_b/V_{r2}$

$= 272.23 / 335.03$

$= 35° 39'$

$V_2 = \sqrt{V_{r2}^2 - V_b^2}$

$= \sqrt{(335.03^2 - 272.03^2)}$

$= 195.28 m/s$

Power developed, $P = m (V_{w1} + V_{w2}) V_b$

$= 10 (544.46) (272.23)$

$= 14.82 Kw$

Blade efficiency, $\eta_b = m (V_{w1} + V_{w2}) V_b / m\, 0.5 V_1^2$

$= (V_{w1} + V_{w2}) V_b / 0.5 V_1^2$

$= (544.46) (272.23) / 0.5 (600.75)^2$

$= 82.14\%$

Axial thrust, $f_y = m (V_{f1} + V_{f2}) = 10 (253.89 - 195.28)$

$= 586.1 N$

4. **The steam supply to an impulse turbine with a single row of moving blades is 3kg/s. The turbine develop 150kw, the blade velocity being 150m/s. The steam flow from a nozzle with a velocity of 450m/s and coefficient of velocity of blade is 0.95. Find the nozzle angle, blade angle at entry and exit, if the steam flows axially after passing over the blade.(Dec-11, May-14)**

Given data:

$m = 3 kg/s$; $V_{r1}/V_{r2} = 0.95$

$V_b = 150 m/s$; $V_1 = 450 m/s$

$P = 150 kw$

$\beta = 10$ degree

$V_{f1} = V_1$

Solution:

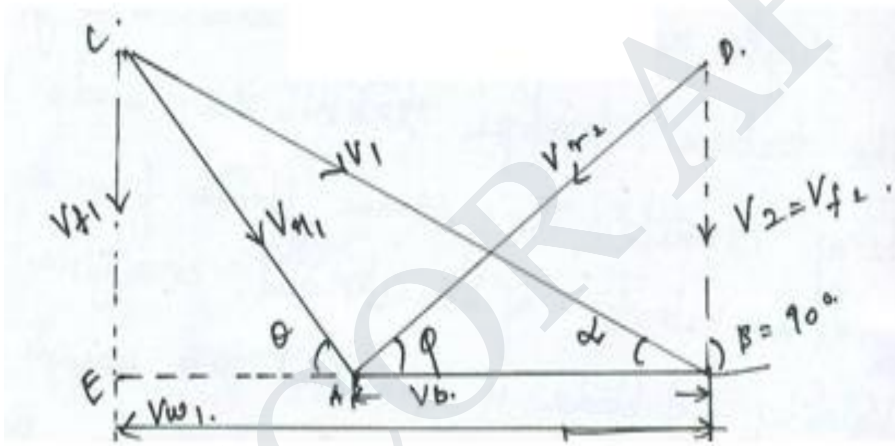
Power developed, $P = m (V_{w1} + V_{w2}) V_b$

$150\times10^3 = 3 (V_{w1}) (150)$

$V_{w1} = 333.33 m/s$

From ΔBCE, $\text{Cos } \alpha = V_{w1} / V_1 = 333.33 / 450$

$\alpha = 42° 12'$



$V_{r1} = \sqrt{V_{f1}^2 + (V_{w1} - V_b)^2}$

$= \sqrt{(333.33 - 150)^2 + 302.31^2}$

$= 353.56 m/s$

$V_{f1} = \sqrt{V_{r1}^2 - V_{w1}^2}$

$= \sqrt{450^2 - 333.33^2}$

$= 302.31 m/s$

From ΔACE, $\text{Tan } \theta = V_{f1} / V_{w1} - V_b = 302.31 / 333.3 - 150$

$= 58° 45'$

But, $V_{r1}/V_{r2} = 0.95$

$V_{r2} = 0.95 \times 353.56$

$= 335.88 m/s$

From ΔADB,

$\cos\varphi = V_b / V_{r2} = 150 / 335.88$

$= 63° 28'$

5. **A steam jets the row blades with a velocity of 350m/s at an angle of 20degree with the direction of motion of the moving blades. If the blade speed is 200m/s, find the inlet and outlet blade angle, no thrust on blades. The velocity of the steam passing over is reduced by 10%, Determine the power developed.**

Given data:

$V_1 = 350 m/s; \alpha = 20°$

$V_b = 200 m/s; m = 1 kg$

$m(V_{f1} + V_{f2}) = 0$

$V_{f1} = V_{f2}$

$V_{r2}/V_{r1} = 0.9$

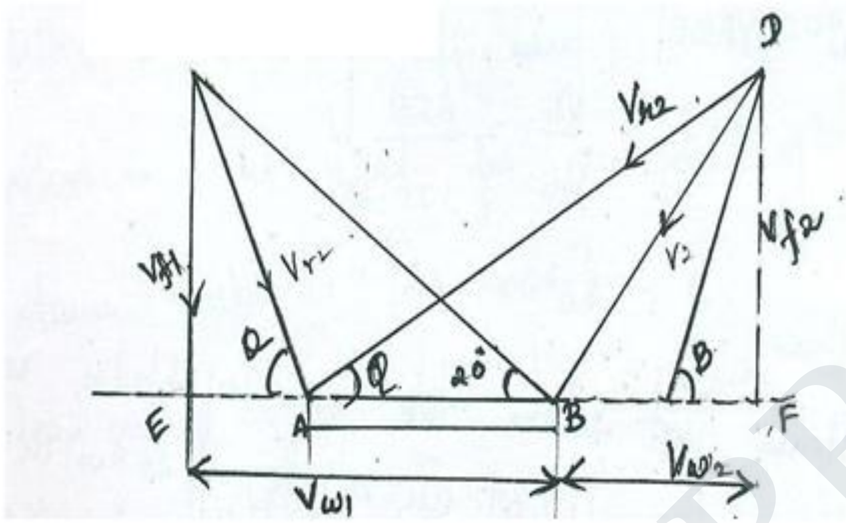
Solution:

$V_{w1} = V_1 \cos 20 = 350 \cos 20 = 328.89 m/s$

$V_{f1} = V_1 \sin 20 = 350 \sin 20 = 119.71 m/s$

$\tan\theta = V_{f1} / (V_{w1} - V_b) = 119.71 / (328.89 - 200)$

$= 42° 53'$



$V_{r1} = \sqrt{V_{f1}^2 + (V_{w1} - V_b)^2} = 175m/s$

$V_{r2}/V_{r1} = 0.9$

$Sin\varphi = V_{f2}/V_{r2}$

$= 119.71 / 158.32$

$= 49°7'$

$V_b + V_{w2} = \sqrt{V_r^2 - V_f^2}$

$200 + V_{w2} = \sqrt{158^2 - 119^2}$

$=96.39m/s$

$P = m\,(V_{w1} + V_{w2})\,V_b = 1 \times 200\,(328.89 - 96.39)$

$= 46.5KJ/kg$

6. **Explain the pressure and velocity compounding diagram of an multi-stage turbines with sketch. (Dec-13) (Nov-14)**

COMPOUNDING OF IMPULSE TURBINES

We already know that, in impulse turbines, the entire pressure drop takes place in nozzles only. If the entire pressure drop from boiler pressure to condenser pressure (say 125 bar to 1 bar) is carried out "in one stage (one set of nozzles) only, then, the velocity of the steam will be extremely high. It will make the turbine rotor to run at very high speeds (upto 30.000 RPM). In practice, such a high speed of a turbine is of no use and will have number of disadvantages. The leaving loss also becomes high. It is usually necessary to reduce the speed by gearing which will be of undue proportions.

So, it is essential to make improvement in the impulse turbine to make it more efficient, practical- to reduce the high speed of the rotor to practical limits. This is achieved by making use of more than one set of nozzles, blades and rotors in series keyed to a common shaft so that either pressure of steam or its velocity is absorbed in stages and in doing so, the speed gets reduced. This also reduces leaving loss. This process of absorbing pressure or velocity of steam in stages to reduce the speed of the turbine rotor is called - compounding.

There are three important methods of compounding:

1. Pressure compounding.

2. Velocity compounding.

3. Pressure - velocity compounding.

1. Pressure Compounding:

In this, the whole expansion of steam is carried out in a number of steps by employing a number of simple impulse turbines in series on same shaft as shown in fig.

We can arrange a number of simple impulse turbines in series on same shaft allowing exhaust steam from one turbine to enter the nozzles of next turbine. Then, each of the simple impulse turbine is termed as - stage of the turbine, each stage containing a set of nozzles and blades. This is equivalent to splitting the whole pressure drop into a series of smaller pressure drops and so it is called - pressure compounding. The total pressure drop of steam doesn't take place in the first set of nozzles but divided equally among all nozzle sets and the pressure remains constant while flowing over the moving blades.

The nozzles are usually fitted into partitions termed as diaphragms which separate one wheel chamber from the next.

The steam from boiler pressure is passed through the first set of nozzles (A number of nozzles are arranged around the circumference of the wheel. All nozzles for one wheel constitute one set of nozzles); where only a small pressure drop occurs with an increase in velocity of steam. While flowing over the first set of moving blades, pressure remains constant but velocity decreases. This constitutes one stage. A stage consists of a set of fixed nozzles and a set of moving blades. A stage itself is a simple impulse turbine.

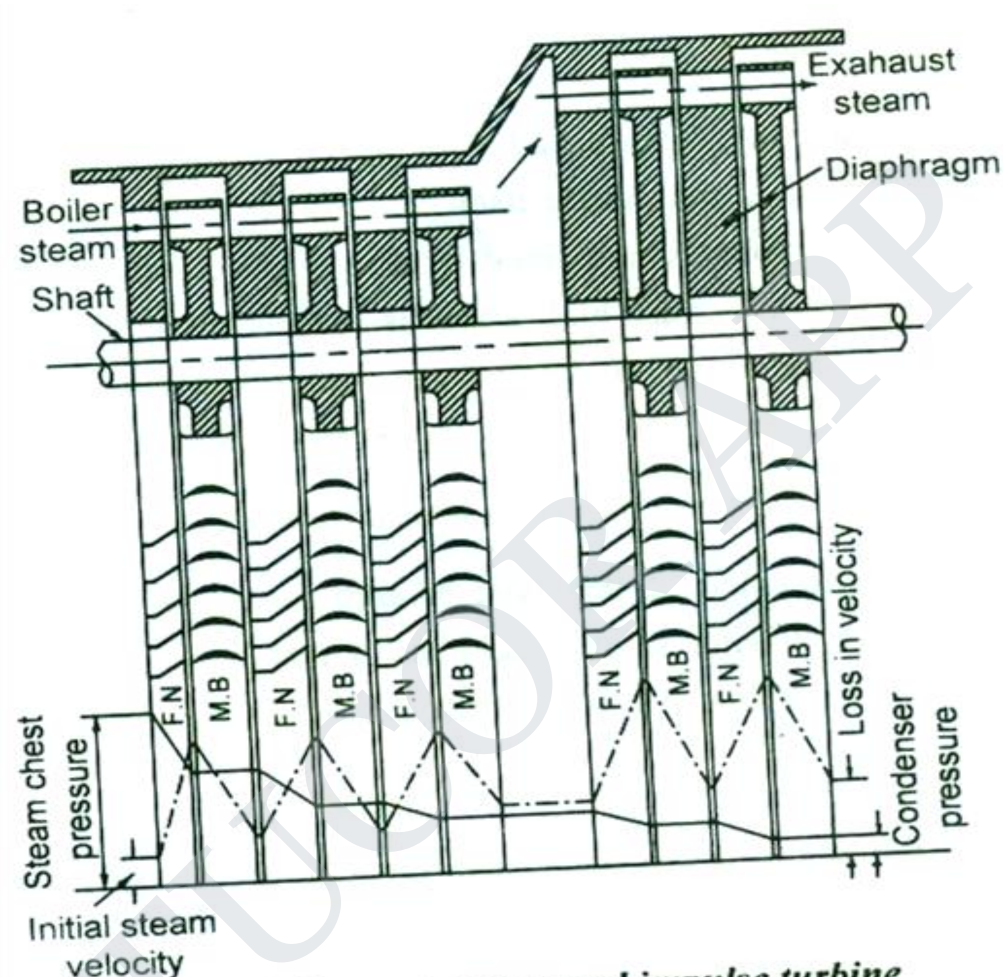


Fig. 3.16. Pressure compound impulse turbine

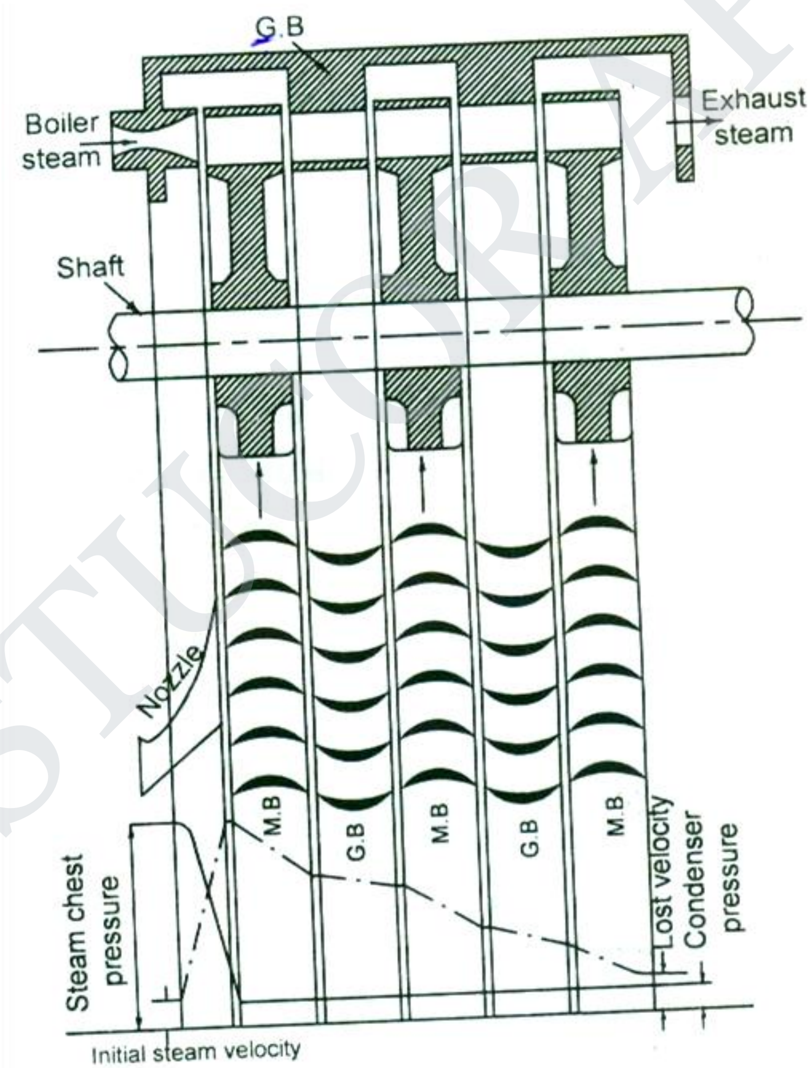
The steam from first set of moving blades enters the second stage - into second set of nozzles where its pressure is further reduced. Consequently, the velocity increase again. Now, the steam enters the second set of moving blades in which pressure remains constant but velocity decreases. This process is repeated in the remaining stages also until condenser pressure is reached.

As pressure drop per stage is reduced, the velocity of steam is reduced which in turn reduces the blade or rotor velocity. The speed of the turbine can be reduced further by increasing number of stages. The leaving velocity of the last stage of the turbine is much less compared to simple impulse or De-lavel turbine.

This is the most efficient type of impulse turbine because the ratio of blade velocity, to steam velocity remains constant. But to obtain very low speed, number of stages required are more and it becomes more expensive. Now-a-days, pressure compounded impulse turbines are not being used. Rateau and Zoelly turbines belong to this group.

2. Velocity Compounding:

In this, the entire pressure drop takes place in one set of nozzles thereafter, the pressure remains constant while the steam flows over the blades. Due to the entire pressure drop, the velocity of steam becomes high, and this velocity is absorbed in steps while steam flows over different sets of moving blades.



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Here, the turbine consists of a set of nozzles and a wheel fitted with two or more rows of moving blades. There are fixed or guide blades arranged between moving blades and set in reverse manner.

The expansion of steam takes place in the set of nozzles from boiler pressure to condenser pressure. The resulting high velocity of steam is utilized by as many sets of rotor blades as necessary.

A portion of initial high velocity of steam is absorbed by the first set of moving blades. The steam from first set of moving blades comes out with a fairly high velocity. It then enters the fixed or stationary or guide blades which change the direction of steam and direct the steam into second set of moving blades; without affecting the velocity appreciably. There is slight drop in velocity in guide blades due to friction. While passing through the second set of moving blades, steam suffers a change of momentum and gives up another portion of its velocity -kinetic energy to the rotor.

The process is repeated and the steam finally enters the condenser from the last set of moving blades.

The entire pressure drop takes place in the nozzles only and no pressure drop occurs in fixed (guide) blades or moving blades. This method of velocity compounding is known as – Curtis principle and Curtis turbine is an example of velocity compounded impulse turbine.

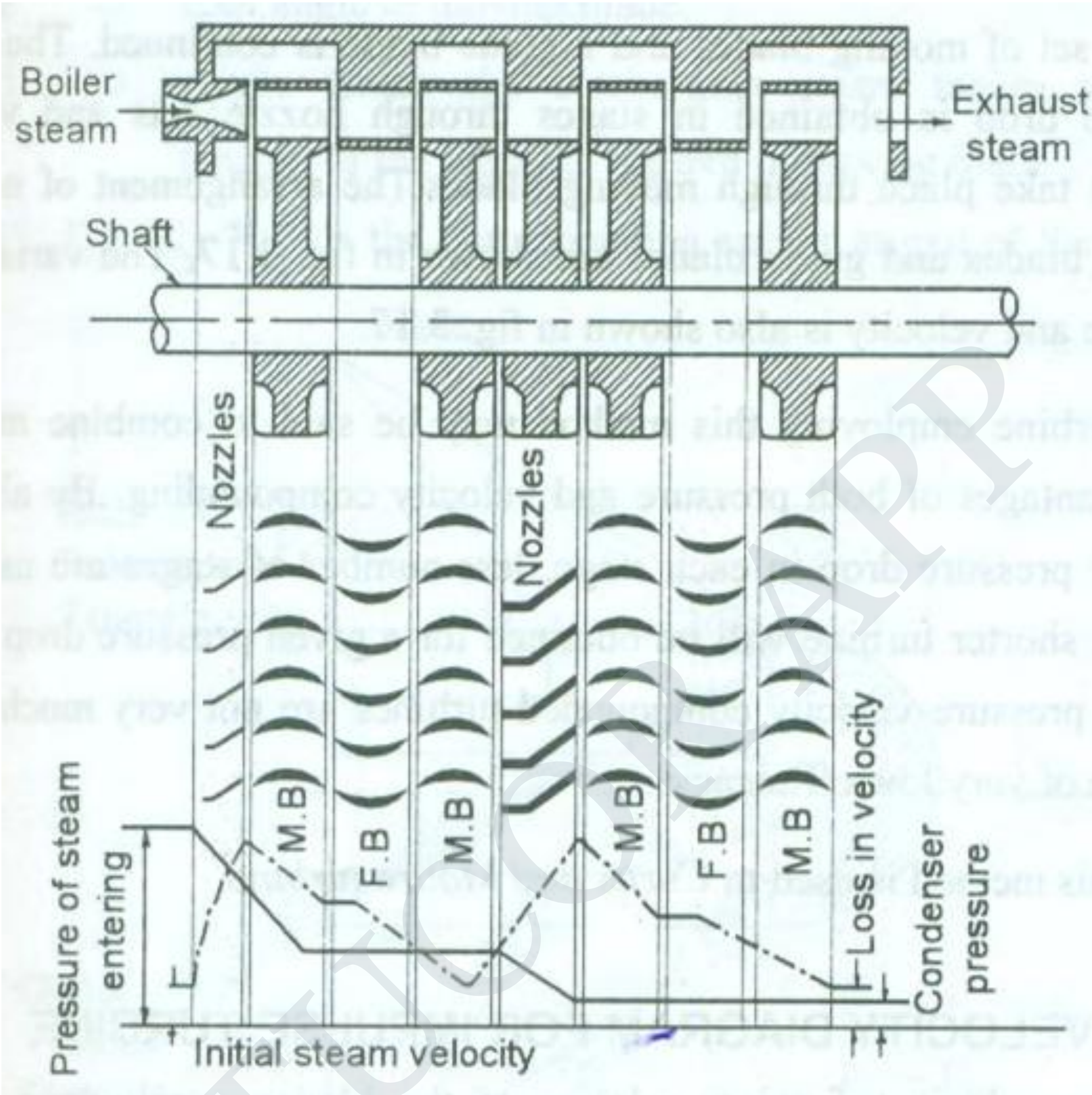
3. Pressure - Velocity Compounding:

In this, both the principles of pressure compounding and velocity compounding are used. Total pressure drop of steam is divided into stages and velocity in each stage is also compounded.

This type allows bigger pressure drop in each stage and hence less number of stages are required. So, for a given pressure drop, this is more compact than a pressure compounded turbine.

In this turbine, each stage has a set of nozzles, two or more rows of moving blades and one or more rows of guide blades both placed alternately. Each stage is separated from adjacent stage by a diaphragm containing a nozzle.

In this turbine, the whole pressure drop takes place in different sets of nozzles, i.e., whole pressure drop doesn't take place on set of nozzles but divided into small drops. So, it is pressure compounded. While flowing over different sets of moving blades in different stages, the velocity is reduced. So, it is velocity compounded. The diameter of this turbine is increased at each stage to allow increasing volume of steam at lower pressures. This type of compounding is used in Curtis turbine.

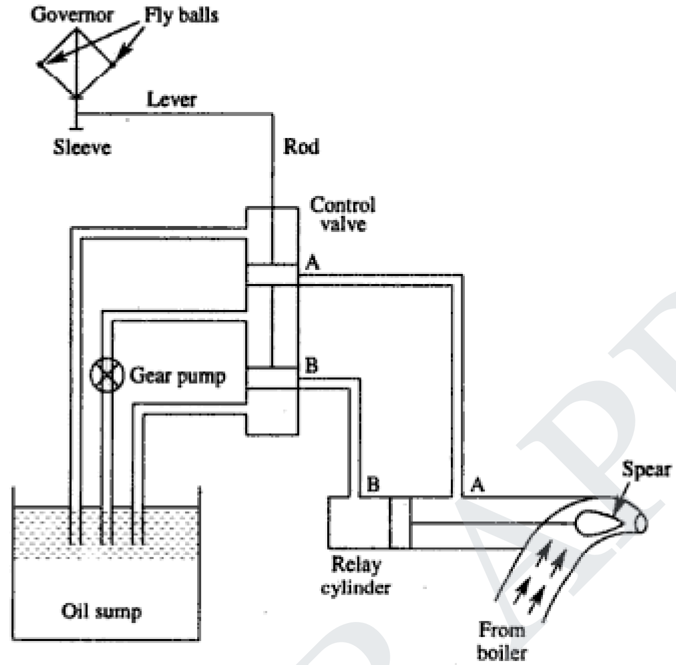


7. **Explain the Governing of Steam Turbine with a neat sketch.**

The method of maintaining the turbine speed constant irrespective of the load is known as governing of tubines.The device used for governing of turbines is called Governor. There are 3 types of governors in steam turbine,

1. Throttle governing
2. Nozzle governing
3. By-pass governing

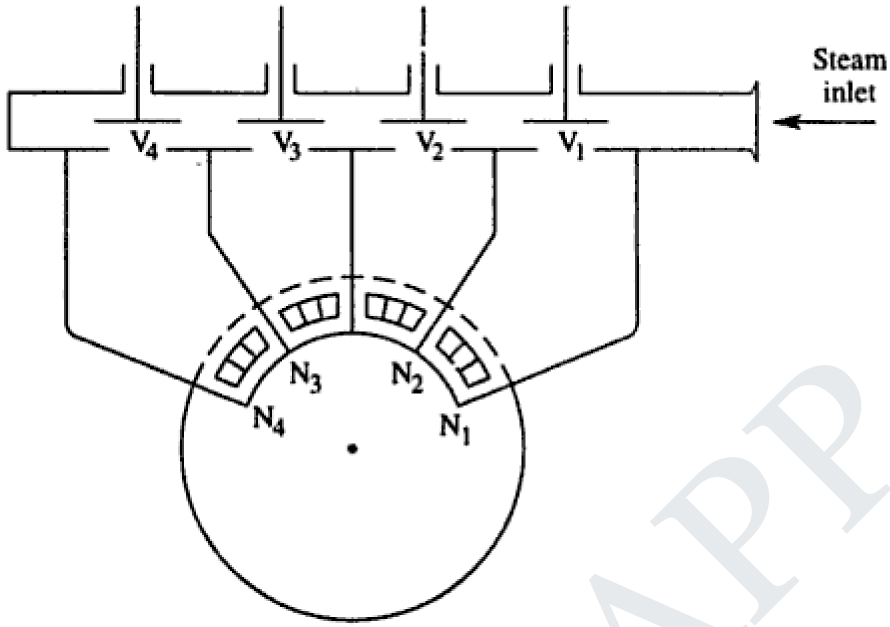
1. Throttle Govering:



Let us consider an instant when the load on the turbine increases. As a result the speed of the turbine decreases. The fly balls of the governor will come down. The fly balls bring down the sleeve. The downword movement of the sleeve will raise the control valve rod. The mouth of the pipe *AA* will open. Now the oil under pressure will rush from the control valve to the right side of the piston in the relay cylinder through the pipe *AA*. This will move the piston and spear towards the left which will open more area of nozzle. As a result the steam flow rate into the turbine increases, which inturn brings the speed of the turbine to the normal range.

2. Nozzle Governing:

A diagrammatic arrangement of nozzle control governing is shown in Fig.
In this nozzles are grouped together in 3 to 5 or more groups and each group of nozzle is supplied steam controlled by valves. The arc of admission is limited to 180° or less. The nozzle control governing is restricted to the first stage of the turbine, the nozzle area in other stages remaining constant. It is suitable for the simple impulse turbine and for larger units which have an impulse stage followed by an impulse reaction turbine.

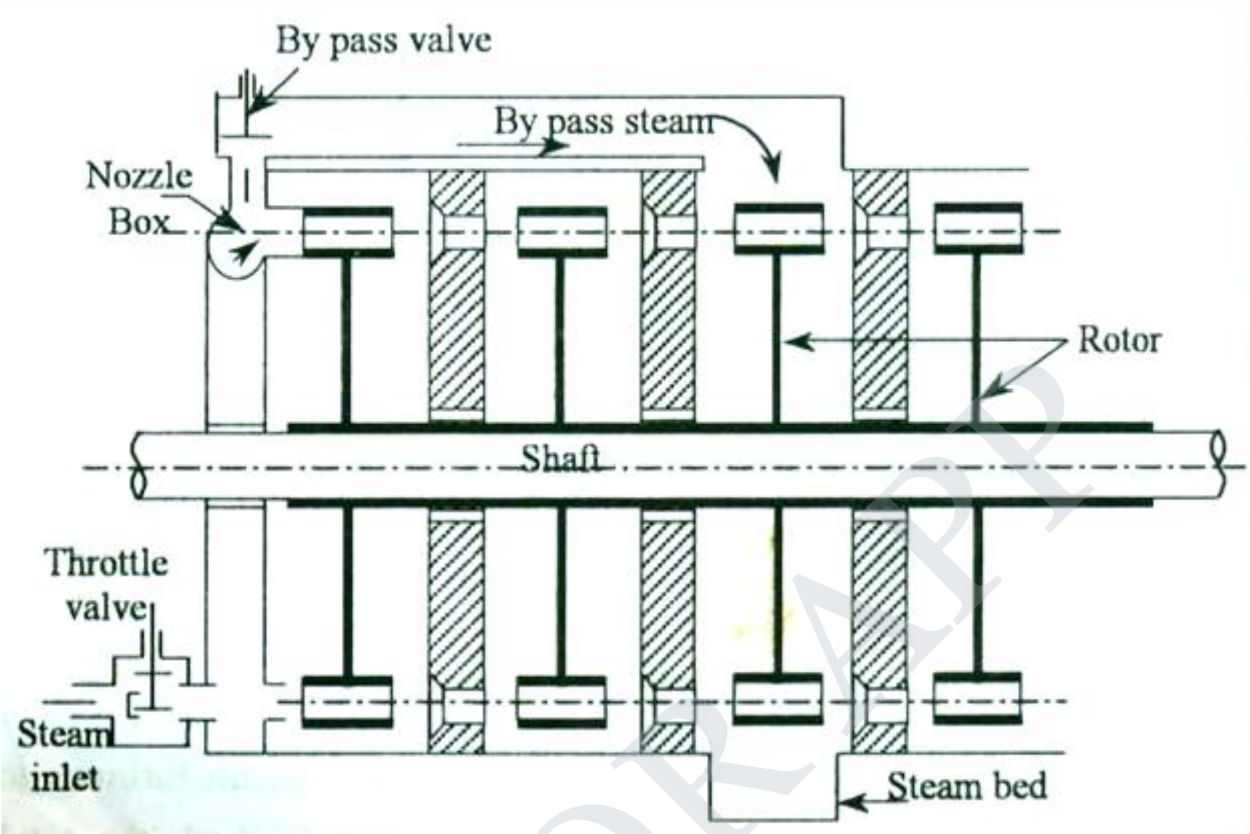


2. By-Pass Governing:

The high pressure impulse turbines generally have a number of stages of small mean diameter of wheel. These turbines are generally designed for maximum efficiency at an economic load which is about 80 per cent of the maximum continuous rating. Due to the small heat drop in the first stage nozzle control governing cannot be efficiently used. Secondly it is desirable to have full admission into high pressure stage at the rated economic load to eliminate the partial admission losses.

In such cases bypass governing is used.

In this arrangement for high loads a bypass line is provided for the steam from the first stage nozzle box into a later stage where work output increases. The bypass of steam is automatically regulated by the lift of the valve. The bypass valve is under the control of the speed of the governor for all loads within its range. In later stages though there is increase in work output, the efficiency is low due to throttling effect.


By pass valve
By pass steam
Nozzle
Box
Rotor
Shaft
Throttle
valve
Steam
inlet
Steam bed

Unit IV Air compresor

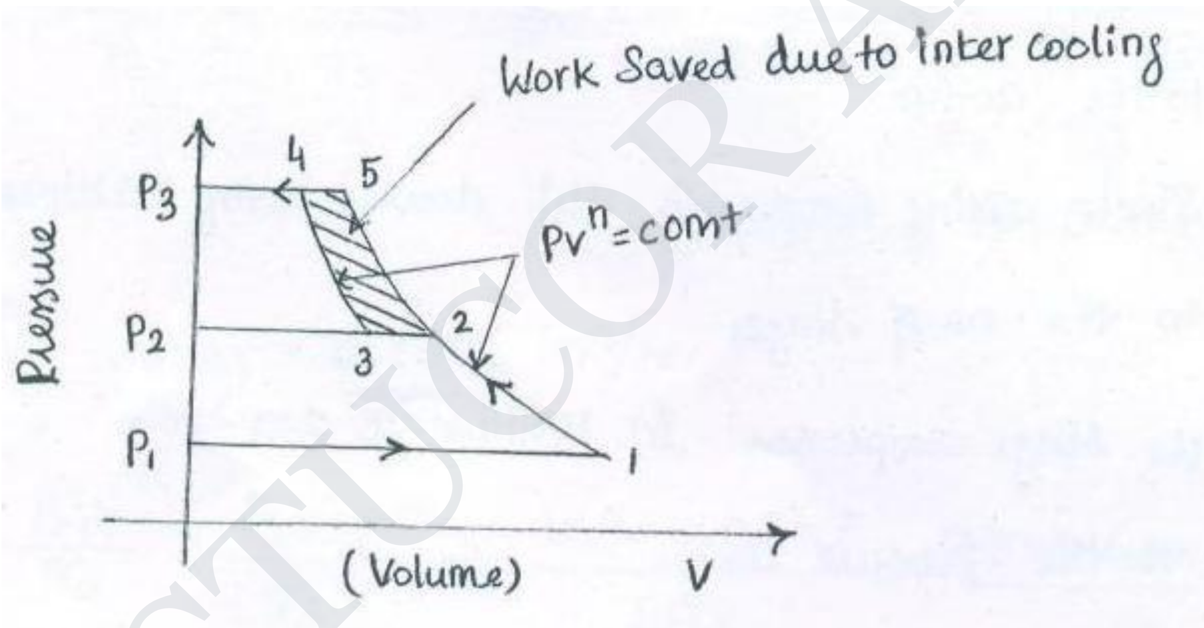
1. **Give the classification of compressor based on movement of piston. (Nov 2013)**
- Reciprocating compressor
- Rotary compressor
2. **What is isothermal efficiency with reference to reciprocating air compressor? (May 2013)**

It is defined as the ratio between isothermal work to the actual work of compressor.

3. **State the principal of working of screw compressor. (May 2013)**

Screw compressors use two meshing helical screws, known as rotors, to compress the gas. Air enters at the suction side and moves through the threads as the screws rotate. The meshing rotors force the gas through the compressor, and the gas exits at the end of the screws.

4. **Draw the P-V diagram of a two stage reciprocating air compressor. (May 2014)**



5. **Define isentropic efficiency of reciprocating compressor. (Nov 2014)**

It is the ratio of isentropic power to the brake power required to drive the compressor.

6. **What is the effect of clearance volume on work of compression? (Nov 2017)**

If clearance volume is considered, actual volume of suction has decreased from the stroke volume. Thus the effect of clearance is to reduce the volume of air actually sucked in per working cycle.

7. **List out the factors limit the delivery pressure in a reciprocating compressor (Nov 2015)**

- The size of the cylinder will be too large for very high pressure
- Due to compression, there will be rise in the temperature of the air. So the delivery pressure is limited, so that rise in temperature of air is not going beyond limit and size of cylinder is not too large.

8. Define volumetric efficiency of an air compressor. (May 2016) (May 2015)

Volumetric efficiency is defined as the ratio of volume of free air sucked into the compressor per cycle to the stroke volume of the cylinder.

9. State the conditions which lower the volumetric efficiency of an air compressor. (May 2016)

- Very high speed
- Leakage past the piston
- Too large a clearance volume
- Obstruction at inlet valve

10. Write the difference between centrifugal and axial compressors. (Nov 2016)

S.No	Centrifugal compressor	Axial compressor
1	Starting torque is low.	Starting torque is high
2	It is not suitable for multistage compression	It is suitable for multistage compression
3	Running cost is low	Running cost is high

11. Define the term Free air delivery (May 2015)(Apr 2017)

Free air delivery: The free air delivered is the actual volume delivered at this state pressure reduced to intake pressure and temperature and expressed in terms of m^3/min.

12. What are the advantages of multistage compression? (May 2015) (Nov 2016)

- It improves the efficiency for the given pressure ratio.
- It reduces the leakage loss considerably.
- It gives the more uniform torque and hence, a smaller size of fly wheel is required.

13. What is meant by intercooler? (May 2014)

The cooler which is placed in between stages is called Intercooler. An intercooler is a simple heat exchanger.

14. What is meant by perfect inter cooling (Nov 2015)

When the temperature of air leaving the inter cooler is equal to the original atmospheric air temperature then the inter cooling known as perfect inter cooling.

15. What is the effect of inter cooling in multi compressor? (Nov 2014)(Nov 2017)

An inter cooler is a simple heat exchanger. It exchanges the heat of compressor air from the low pressure compressor to the circulating water before the air enters to the high pressure compressor. The purpose of inter cooling is to minimize the work compression.

16. List the effects of intercooling in a multi stage compression process. (Nov 2013)

- The workdone per day of air is reduced in multistage compression with intercooler

- It improves volumetric efficiencyfor the given pressure ratio
- It provides effective lubrication because of lower temperature range

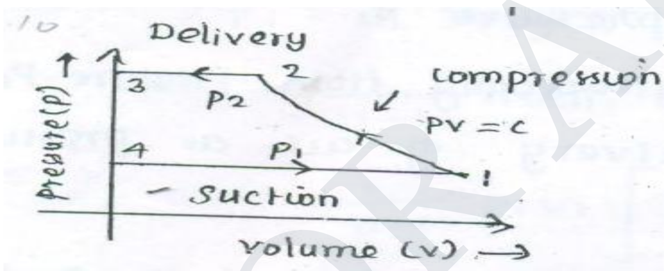
PART-B

16 Marks:

1. **Work done by a single stage reciprocating air compressor without clearance volume. (May-12)**

a) Work done during isothermal compression (pv=c)

The p-v diagram for a single stage acting reciprocating air compressor is shown in figure. The sequence of operation as represented on the diagram is as follows.



Process 4-1: Represents the suction of air at pressure p_1

Process 1-2: Air is compressed isothermally from pressure p_1 to pressure p_2.

Pressure 2-3: Represents the discharge of air at pressure p_2

Work done = Area 1-2-3-4-1

$W = W_{Comp} + W_{Delivery} - W_{Suction}$

$= p_1v_1 \ln [v_1 / v_2] + p_2v_2 - p_1v_1$

For isothermal process, $W_{Comp} = p_1v_1 \ln [v_1 / v_2]$

$= p_1v_1 \ln [v_1 / v_2] + p_2v_2 + p_2v_2$

$= p_1v_1 \ln [v_1 / v_2]$.......... (1)

$p_1v_1 = p_1v_1$

$[v_1 / v_2] = [p_2 / p_1]$

Substitute in (1)

$W = p_1v_1 \ln [p_2 / p_1]$

$Pv = mRT$

$W = mRT_1 [p_2 / p_1]$

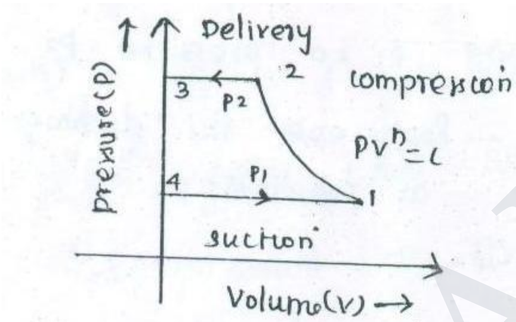
b) Work done during polytrophic compression ($pv^n = c$)

The p-v diagram for a single stage single acting reciprocating air compressor is shown in figure.The sequence of operation as represented on the diagram is as follows.

Process 4-1: Suction of air at pressure p_1.

Process 1-2: Compression of air polytrophically from pressure p_1 to p_2.

Process 2-3: The discharge or delivery of air at pressure p_2



Work done = Area 1-2-3-4-1

$$W = W_{Comp} + W_{Delivery} - W_{Suction}$$

$$= p_2v_2 - p_1v_1 / n-1 + p_2v_2 - p_1v_1$$

$$= \frac{p_2v_2 - p_1v_1 + (n-1)(p_2v_2) - (n-1)(p_1v_1)}{n-1}$$

$$= \frac{p_2v_2 - p_1v_1 + n\,p_2v_2 - p_2v_2 - np_1v_1 + p_1v_1}{n-1}$$

$$= \frac{np_2v_2 - np_1v_1}{n-1}$$

$$W = n / n-1\,[p_2v_2 - p_1v_1]$$

$$(p_1v_1 = mRT_1;\ p_2v_2 = mRT_2)$$

$$W = n / n-1\,[mRT_1 - mRT_2]$$

$$= n / n-1\,mRT_1\,[T_2/T_1 - 1]$$

For polytrophic process,

$$T_2/T_1 = [p_2 / p_1]^{n-1/n}$$

$$W = n / n-1\,mRT_1\,[p_2 / p_1]^{n-1/n}$$

$$= n / n-1\,p_1v_1\,[(p_2 / p_1)^{n-1/n} - 1]$$

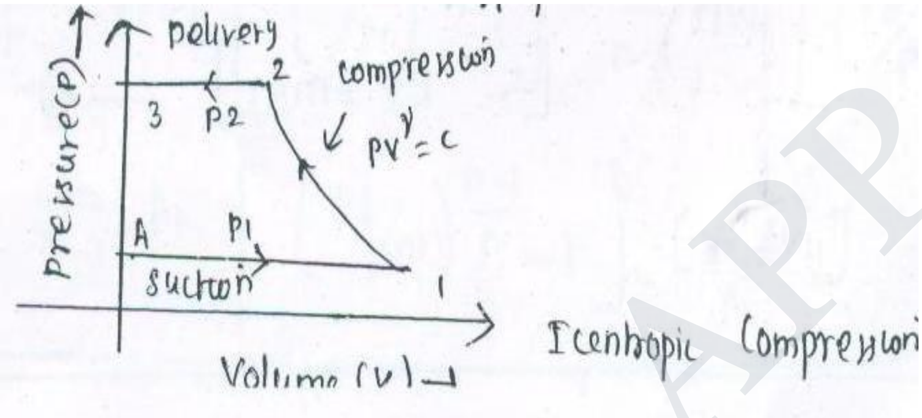
C) Work done during isentropic compression ($pv^{\gamma} = c$)

The p-v diagram for a single stage single acting reciprocating air compressor is shown in figure.

Process4-1: Suction of air at pressure p_1

Process1-2: Isentropic compression of air from pressure p_1 to p_2

Process2-3: Discharge of air pressure p_2



Work done = Area 1-2-3-4-1

$$= p_2v_2 - p_1v_1 / \gamma - 1 + p_2v_2 - p_1v_1$$

$$= \frac{p_2v_2 - p_1v_1 + (\gamma - 1)(p_2v_2) - (\gamma - 1)(p_1v_1)}{\gamma - 1}$$

$$= \frac{p_2v_2 - p_1v_1 + \gamma\, p_2v_2 - p_2v_2 - \gamma\, p_1v_1 + p_1v_1}{\gamma - 1}$$

$$= \frac{\gamma\, p_2v_2 - \gamma\, p_1v_1}{\gamma - 1}$$

$$W = n\, \gamma / \gamma - 1\, [p_2v_2 - p_1v_1]$$

$(p_1v_1 = mRT_1;\ p_2v_2 = mRT_2)$

$$W = \gamma / \gamma - 1\, [mRT_1 - mRT_2]$$

$$= \gamma / \gamma - 1\, mRT_1\, [T_2/T_1 - 1]$$

For polytrophic process,

$$T_2/T_1 = [p_2 / p_1]^{\gamma - 1/\gamma}$$

$$W = \gamma / \gamma - 1\, mRT_1\, [p_2 / p_1]^{\gamma - 1/\gamma}$$

$$= \gamma / \gamma - 1\, p_1v_1\, [(p_2 / p_1)^{\gamma - 1/\gamma} - 1]$$

2. Work done by single stage reciprocating air compressor with clearance volume.

Consider a reciprocating air compressor with clearance volume as shown in figure.

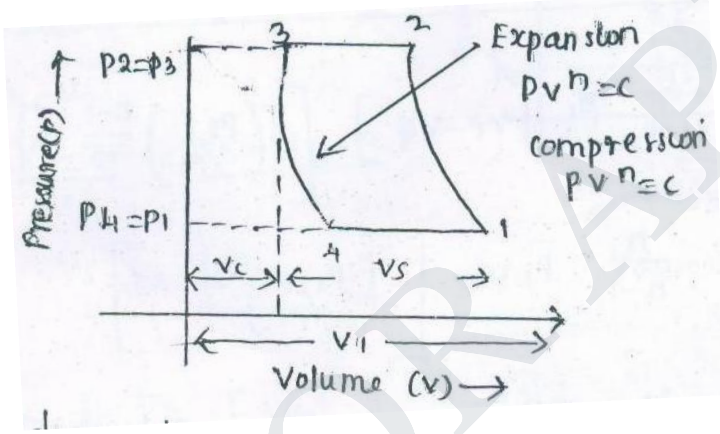
$p_1\, v_1\, T_1$ = initial pressure, volume and temperature of air respectively

$p_2\, v_2\, T_2$ = final pressure, volume and temperature of air respectively

v_c = clearance volume

v_s = stroke volume = $v_1 - v_c$

n = polytrophic index for compression and expansion.



Work done by the compressor per cycle,

W = Work done during compression – Work done during expansion

$= n / n\text{-}1\ p_1v_1 [(p_2 / p_1)^{n-1/n} - 1] - n / n\text{-}1\ p_4v_4 [(p_3 / p_4)^{n-1/n} - 1]$

W.k.t

$p_1 = p_4;\ p_2 = p_3$

$W = n / n\text{-}1\ p_1v_1 [(p_2 / p_1)^{n-1/n} - 1] - n / n\text{-}1\ p_1v_4 [(p_2 / p_1)^{n-1/n} - 1]$

$= n / n\text{-}1\ p_1 [(p_2 / p_1)^{n-1/n} - 1] [v_1 - v_4]$

$= n / n\text{-}1\ p_1\ v_a [(p_2 / p_1)^{n-1/n} - 1]$

Where;

$v_a = v_1 - v_4$ is the actual volume of free air delivered per cycle.

$W = n / n\text{-}1\ mRT_1 [(p_2 / p_1)^{n-1/n} - 1]$

3. Derive an expression for Volumetric efficiency of an air compressor.

(May-14)

Volumetric efficiency:

Volumetric efficiency is defined as the ratio of volume of free air sucked into the compressor per cycle to the stroke volume of the cylinder.

$$\eta_{vol} = \frac{\text{Volume of free air taken per cycle}}{\text{Stroke volume of the cylinder}}$$

$$\eta_{vol} = v_a / v_s$$

From the p-v diagram,

$$v_a = v_s - x$$

$$x = v_4 - v_c$$

$$\eta_{vol} = v_s - x / v_s = v_s - (v_4 - v_c) / v_s$$

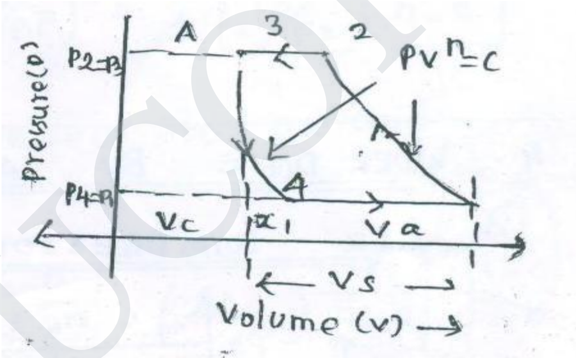
$$= 1 - v_c / v_s [v_4 / v_c - 1] \ldots\ldots\ldots\ldots\ldots(3)$$

Compression and expansion follows, $pv^n = c$

$$p_3 v_3^{\ n} = p_4 v_4^{\ n}$$

$$v_4 / v_3 = (p_3 / p_4)^{1/n}$$

From the p-v diagram, w.k.t,



Volumetric effecency

$$v_3 = v_c;\ p_4 = p_1;\ p_2 = p_3$$

$$v_4 / v_c = (p_3 / p_4)^{1/n}$$

$$v_4 / v_c = (p_2 / p_1)^{1/n}$$

Applying v_4 / v_c value in equation (3)

$$\eta_{vol} = 1 - v_c / v_s [(p_2 / p_1)^{1/n} - 1]$$

Clearance ratio is defined as the ratio of clearance volume to swept volume

Clearance ratio, $c = v_c / v_s$

$$= 1 - c [(p_2 / p_1)^{1/n} - 1]$$

1. **A single cylinder, single stage air compressor has cylinder diameter 160mm and stroke length 300mm. It draws the air into its cylinder at a pressure of 100kpa at 27°C. The air then compressed to a pressure of 650kpa. If the compressor runs at a speed of 2rev/s, determine**
   - **a) Mass of air compressed per cycle**
   - **b) Work required per cycle**
   - **c) Power required to derive the compressor in kW**

Assume the compression process follows pv = constant. (May-12)

Given data:

$D = 160mm = 0.16m$

$L = 300mm = 0.3m$

$p_1 = 100kpa$

$T_1 = 27 + 273 = 300\ K$

$P_2 = 650kpa$

$N = 2\ rev/s$

$pv^Y = c;\ Y=1.4$

Solution:

Work done during isothermal compression

$W = mRT_1 \ln (p_2 / p_1)$

$W = p_1v_1 \ln (p_2 / p_1)$

w.k.t,

$v_1 = \pi/4\ D^2L$

$= \pi/4\ (0.16)^2(0.3)$

$= 6.03 \times 10^{-3} m^3$

Substituting v_1 in work done equation

$W = p_1v_1 \ln (p_2 / p_1)$

$= 100 \times 6.03 \times 10^{-3} \times \ln (650 / 100)$

$= 1.13\ kJ$

Power, $P = W \times N / 60$

$= (1.13 \times 120) / 60$

$= 2.26\ kW$

w.k.t,

$$p_1 v_1 = mRT_1$$
$$m = (100 \times 6.03\times10^{-3}) / (0.287 \times 300)$$
$$= 0.007kg$$

2. **<u>A single cylinder, single acting reciprocating air compressor with a bar of 12cm, and stroke of 16cm runs at 410rpm. At the beginning of compression, the pressure and temperature in the cylinder are 0.98bar and 40°C. The delivery pressure is 6bar. The index of compression is 1.32. The clearance is 6% of stroke volume. Determine the volume of air delivered referred to 1bar and 20°C. What is the compressor power required?</u> (May-13)**

   Given data:

$D = 12cm = 0.12m$

$L = 16cm = 0.16m$

$N = 410rpm$

$p_1 = 0.98bar = 98kpa$

$T_1 = 40 + 273 = 313K$

$p_2 = 6bar = 600kpa$

$n = 1.32$

$v_c = 6\% v_s = 0.06 v_s$

$p_0 = 1bar = 100kpa$

$T_0 = 20 + 273 = 293K$

Solution:

w.k.t,

$$v_s = \pi/4\, D^2 L$$
$$= \pi/4\, (0.12)^2 (0.16)$$
$$= 0.0018\ m^3$$

w.k.t,

$$v_1 = v_c + v_s = 0.06\, v_s + v_s$$
$$= 1.06\, v_s = 1.06 \times 0.0018$$
$$= 1.908 \times 10^{-3}\ m^3$$

Work done on the single stage compressor with clearance volume.

$$W = n / n\text{-}1\ p_1 v_a [(p_2 / p_1)^{n-1/n} - 1]$$

w.k.t,

$$p_3 v_3^n = p_4 v_4^n$$

$$(v_4/v_3)^n = p_3/v_3 = p_2/v_1$$

$$(v_4/v_3)^n = p_2/v_1$$

$$v_4/v_c = (p_2/p_2)^{1/n}$$

$$v_4 = v_c \times (p_2/p_2)^{1/n}$$

$$= 0.06 \times 0.0018\,(600/98)^{1/1.32}$$

$$= 4.26 \times 10^{-4} m^3$$

w.k.t,

$$v_a = v_1 - v_4$$

$$= 1.908 \times 10^{-3} - 4.26 \times 10^{-4}$$

$$= 0.00148\ m^3$$

Substituting v_a value in work done equation.

$$W = 1.32 / 1.32\text{-}1 \times 98 \times 0.00148\,[(600 / 98)^{1.32-1/1.32} - 1]$$

$$= 0.329\ kJ$$

Power, $P = W \times V / 60$

$$= (0.329 \times 410)/60$$

$$= 2.25\ kW$$

w.k.t,

$$p_0 v_0/T_0 = p_2 v_d/T_2$$

$$v_0 = T_0/p_0 \times p_2 v_d/T_2 \ldots\ldots\ldots\ldots. (1)$$

w.k.t,

$$T_2/T_1 = [p_2 / p_1]^{n-1/n}$$

$$T_2 = [p_2 / p_1]^{n-1/n} \times T_1$$

$$= 313 \times (600/98)^{\,1.32-1/1.32}$$

$$= 485.6\ K$$

$$p_1 v_1^n = p_2 v_2^n$$

$$v_2 = v_1 \times (p_1/p_2)^{1/n}$$

$$= 1.908 \times 10^{-3} \times (98/600)^{1/1.32}$$

$$= 0.00048\ m^3$$

w.k.t,

$$v_d = v_2 - v_3$$

$= 0.00048 - 0.06 \times 0.0018$

$= 0.000372\ m^3$

Substituting T_0, p_0, p_2, T_2, and v_d in (1)

$v_0 = (293/100) \times (600/485.6) \times 0.000372$

$= 0.0013\ m^3$

3. <u>A 2kg/s of air enters the LP cylinder of two stage compressor. The overall pressure ratio is 9:1. The air at inlet to the compressor is 100kpa and 35°C .The index of compression in each cylinder is 1.3. Find the inter cooler pressure for perfect inter cooling. Also find the minimum power required and % power saved over single stage compression.</u> (Dec-11)

Given data:

$m = 2kg/s$

$p_3 / p_1 = 9$

$p_1 = 100kpa$

$p_3 = 900kpa$

$T_1 = 35^0C + 273 = 308k$

$n = 1.3$

Solution:

w.k.t,

Inter cooler pressure

$p_2 = \sqrt{p_3\ p_1}$

$= \sqrt{(100 \times 900)}$

$= 300kpa$

Work done for x no. of stage

$W = xn/n\text{-}1\ p_1v_1\ [(p_x + 1/p_1)^{n-1/nx} -1]$ here x=2

$= 2(1.3)/1.3\text{-}1 \times 2 \times 0.287 \times 308\ [(9)^{1.3-1/2\times1.3} - 1]$

Power, $P_1 = 442.13\ kW$

Work done for single stage

$W = n / n\text{-}1\ p_1v_1\ [(p_2 / p_1)^{n-1/n} - 1]$

$W = n / n\text{-}1\ mRT_1\ [(p_2 / p_1)^{n-1/n} - 1]$

$= 1.3 / 1.3 -1 \times 2 \times 0.287 \times 308\ [(9)^{1.3-1/1.3} - 1]$

$= 505.9\ kJ/s$

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Power, p_2 = 505.9 kW

Saving in power = 505.9 – 442.13

= 63.77 kW

% of saving in power = p_2-p_1/p_2

= 63.77/505.9

= 12.6%

4. <u>A single stage single acting compressor delivers 15m^3 of free air per minute from 1bar to 8bar. The speed of compressor is 300rpm assuming that compression and expansion follow the law PV$^{1.3}$=C and clearance is (1/16)th of swept volume ,find the diameter and stroke of the compressor. Take L/D=1.5.The temperature and pressure of air at the suction are same as atmospheric air.</u> (Dec-12)

Given data:

$V_0=15m^3/min$

$P_1=1bar=100kP_a$

$P_2=8bar=800kP_a$

N=300rpm

$PV^{1.3}=C$

N=1.3

$V_C/V_S=1/6$

L/D=1.5

Solution:

$\eta_{vol} = 1-(v_c/ v_s)[(p_2/p_1)^{1/n}-1]$

$= 1-1/16[(8/1)^{1/1.3}-1]$

$=0.753$

$\eta_{vol} = 75.3$ %

w.k.t,

$V_a = V_s\times \eta_{vol} \times 300$

$15 = V_s \times 0.753\times300$

$V_s = 0.0664\ m^3$

$v_s = (\pi/4)D^2\times L$

$= 0.0664$

$(\pi/4)D^2 \times 1.5D = 0.0664$

$D = 0.3834$ m

$L/D = 1.5$

$L = 1.5 \times D$

$= 1.5 \times 0.3834$

$= 0.5751$ m

5. **A three stage air compressor delivers 5.2m^3 of free air /minute. The suction pressure and temperature are 1bar and 30^{0}C. The pressure and temperature are 1.03bar and 20^{0}C at free air condition. The air is cooled at 30^{0}C after each stage of compression. The delivery pressure of the compressor is 150bar.The R.P.M of the compressor is 300.The clearances of L.P, I.P, and H.P cylinders are 5% of the respective strokes. The index of compression and re-expansion in all stages is 1.35.Neglecting pressure losses, find the B.P of the motor required to run the compressor if the mechanical efficiency is 80%.(May-11)**

Given data:

$V_0 = V_a = 5.2$ m$^{3/}$min

$P_1 = 1$ bar $= 100$ kpa

$P_0 = 1.03$ bar $= 103$ kpa

$T_0 = 20^0C = 20+273 = 293$ K

$T_1 = T_2 = T_3 = T_4 = 30^0C = 303$ K

$P_4 = 150$ bar $= 15000$ kpa

$N = 300$ rpm

$C = 5\% = 0.08$,

$\eta_{mech} = 80\% = 0.08$

Solution: Inter cooler pressure,

$p_2/p_1 = (p_4/p_1)^{1/3}$

$= (150/1)^{1/3}$

$p_2/p_1 = 5.31$

$p_2/p_1 = p_3/p_2 = p_4/p_3 = 5.31$

w.k.t,

$v_a = 5.2$ m^3/min $= 5.2/60 = 0.0867$ m^3/sec

Then,

$$p_0 v_0 / T_0 = p_1 v_{a1} / T_1$$

$$103 \times 0.0867 / 293 = 100 \times v_{a1} / 303$$

$$v_{a1} = 0.0923 \text{ m}^3/\text{sec}$$

Similarly,

$$p_0 v_0 / T_0 = p_2 v_{a2} / T_2$$

$$103 \times 0.0867 / 293 = 531 \times v_{a2} / 303$$

$$v_{a2} = 0.0174 \text{ m}^3/\text{sec}$$

Similarly,

$$p_0 v_0 / T_0 = p_3 v_{a3} / T_3$$

$$103 \times 0.0867 / 293 = 2819.61 \times v_{a3} / 303$$

$$v_{a3} = 0.00328 \text{ m}^3/\text{sec}$$

Work done on the compressor,

$$W = n / n\text{-}1\ p_1 va_1 [(p_2 / p_1)^{n-1/n} - 1] + n / n\text{-}1\ p_2 va_2 [(p_3 / p_2)^{n-1/n} - 1] + n / n\text{-}1\ p_3 va_3 [(p_4 / p_3)^{n-1/n} - 1]$$

$$W = 1.35/1.35\text{-}1 \times 103 \times 0.0923 [(5.31)^{1.35-1/1.35} - 1] + 1.35/1.35\text{-}1 \times 531 \times 0.0174 [(5.31)^{1.35-1/1.35} - 1] + 1.35/1.35\text{-}1 \times 2819.61 \times 0.00328 [(5.31)^{1.35-1/1.35} - 1]$$

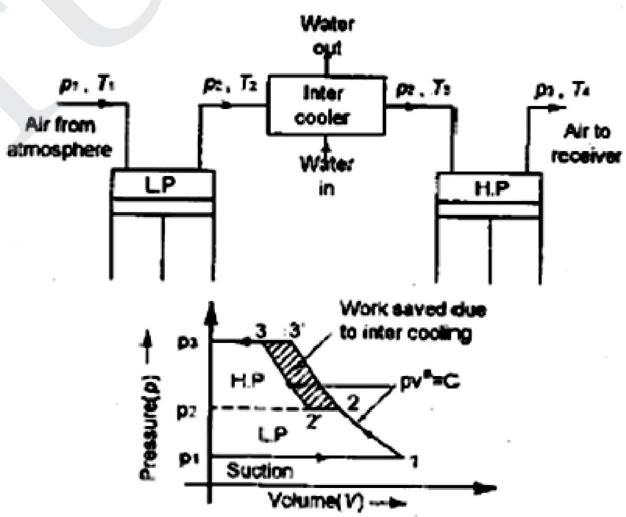
IP = 57.91 kW

$$\eta_{mech} = BP/IP$$

$$BP = \eta_{mech} \times IP = 0.8 \times 57.91$$

Brake power of motor, BP = 46.33 Kw

6. **Explain the construction and working principle of Multi stage compressor and discuss the perfect and in-perfect inter-cooling with neat sketch.** **(Dec-13) (May-14)**



Two stage compression with inter cooler

Assumptions Made In Multistage Compression

1. Suction and delivery pressures remain constant during each stage.
2. The index of compression is same in each stage
3. The inter cooling in each stage is at constant temperature. 4. The mass of air handled by the low pressure and high-pressure cylinders are same.

Advantages of Multistage Air Compressor

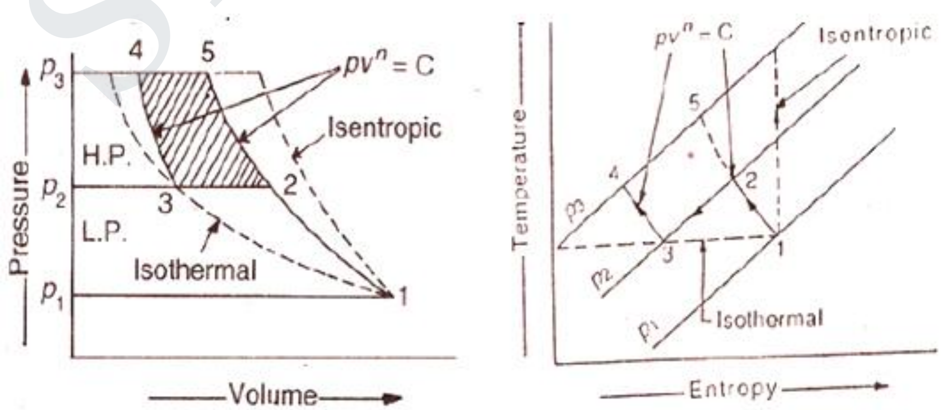
1. Work done per kg of air is reduced in multistage compression with intercooler as compared to single stage compression for the same delivery pressure.
2. Better mechanical balance can be achieved with multistage compressors.
3. It reduces the leakage loss considerably.
4. Volumetric efficiency is improved by increasing number of stag
5. It gives more uniform torque, and hence a smaller size flywheel required.
6. Lower operating temperature permits the use of cheaper in for construction.
7. Better lubrication due to the lesser working temperature.

Intercooling of air in a two-stage reciprocating air compressor:

Efficiency of the intercooler plays an important role in the working of a two-stage reciprocating air compress. Following two types of intercooling are important from the subject point of view:

1. Complete or perfect intercooling:

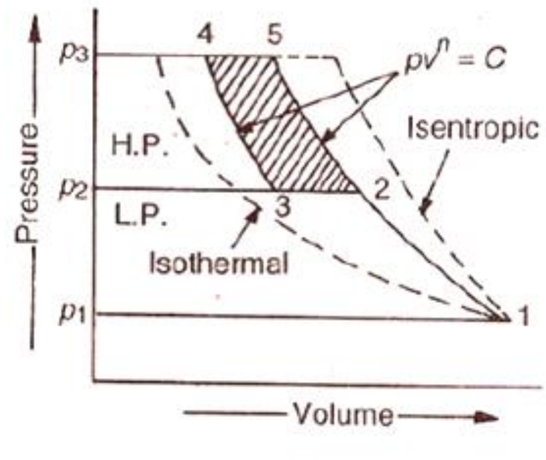
When the temperature of the air leaving the intercooler (i.e. T_3) is equal to the original atmospheric air temperature (i.e. T_1) then the intercooling is known as complete or perfect intercooling. In this case, the point 3 lies on the isothermal curve as shown in below figures:



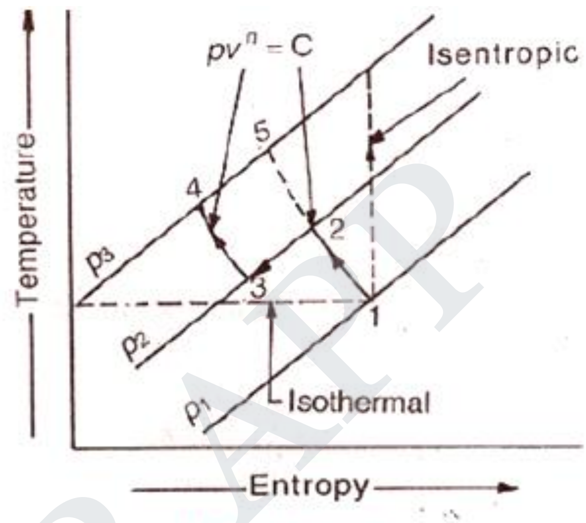
(a) p-v diagram. (b) T-s diagram.

2. Incomplete or imperfect intercooling:

When the temperature of the air leaves the intercooler (i.e. T_3) is more than the original atmospheric air temperature (i.e. T_1), then the intercooling is known as incomplete or imperfect intercooling. In this case, the point 3 lies on the right side of the isothermal curve as shown in below figure:



(a) p-v diagram.

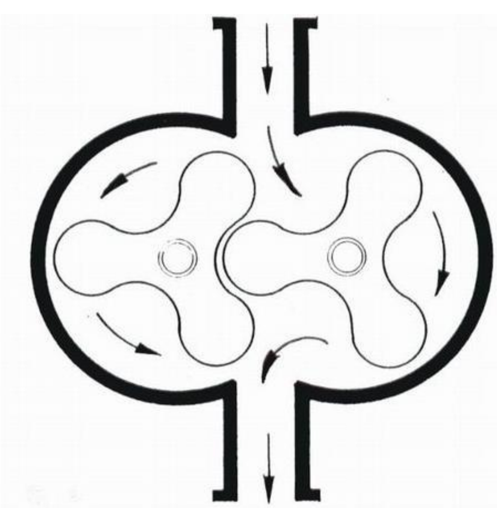


(b) T-s diagram

7. Explain the different types Rotary compressors with neat sketch.

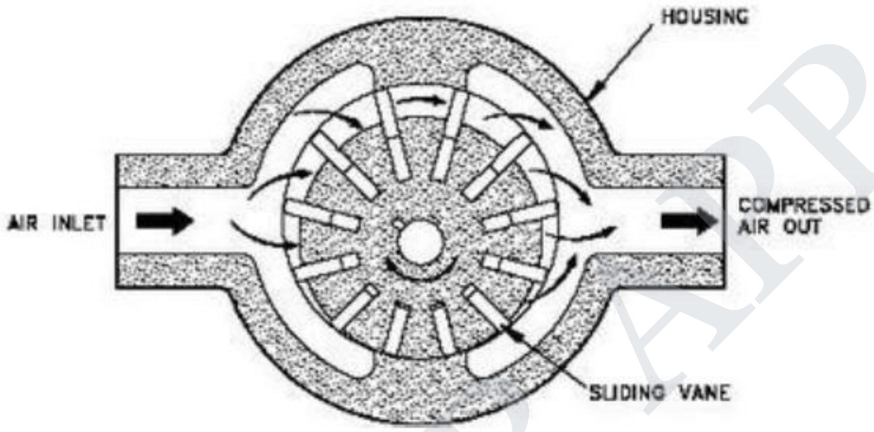
Roots Blower Compressor:

This type is generally called as blower. The discharge air pressure obtained from this type of machine is very low. The Discharge Pressure of 1 bar can be obtained in Single Stage and pressure of 2.2 bar is obtained from Stage. The discharge pressure achieved by two rotors which have separate parallel axis and rotate in opposite directions. This is the example of Positive Displacement Compressor in Rotary Type Air Compressor.



Vane Type compressor:

The rotary slide vane-type, as illustrated in Figure, has longitudinal vanes, sliding radially in a slotted rotor mounted eccentrically in a cylinder. The centrifugal force carries the sliding vanes against the cylindrical case with the vanes forming a number of individual longitudinal cells in the eccentric annulus between the case and rotor. The suction port is located where the longitudinal cells are largest. The size of each cell is reduced by the eccentricity of the rotor as the vanes approach the discharge port, thus compressing the air.



This type of compressor, looks and functions like a vane type hydraulic pump. An eccentrically mounted rotor turns in a cylindrical housing having an inlet and outlet. Vanes slide back and forth in grooves in the rotor. Air pressure or spring force keeps the tip of these vanes in contact with the housing. Air is trapped in the compartments formed by the vanes and housing and is compressed as the rotor turns.

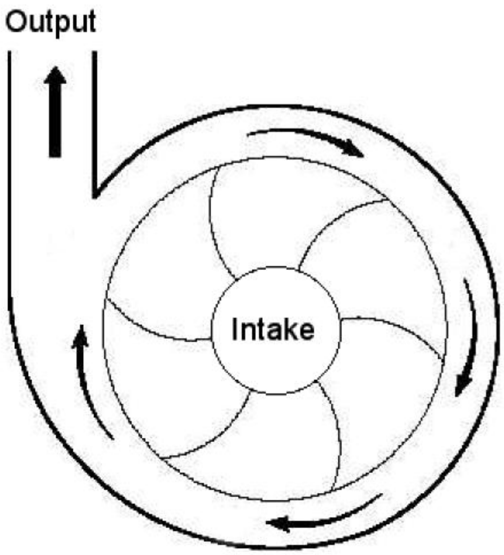
Centrifugal Compressor:

The centrifugal air compressor is a **dynamic** compressor which depends on transfer of energy from a **rotating impeller** to the air. Centrifugal compressors produce high-pressure discharge by converting angular momentum imparted by the rotating impeller (dynamic displacement).

In order to do this efficiently, centrifugal compressors rotate at higher speeds than the other types of compressors. These types of compressors are also designed for higher capacity because flow through the compressor is continuous. Adjusting the inlet guide vanes is the most common method to control capacity of a centrifugal compressor.

By closing the guide vanes, volumetric flows and capacity are reduced. The centrifugal air compressor is an oil free compressor by design. The oil lubricated running gear is separated from the air by shaft seals and atmospheric vents.

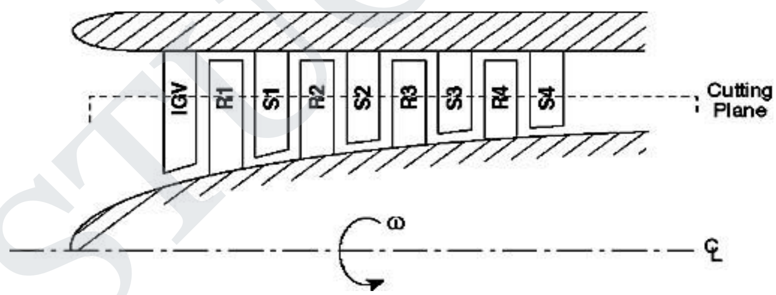
The centrifugal air compressor is a dynamic compressor which depends on a rotating impeller to compress the air. In order to do this efficiently, centrifugal compressors must rotate at higher speeds than the other types of compressors. These types of compressors are designed for higher capacity because flow through the compressor is continuous and oil free by design.



Impeller

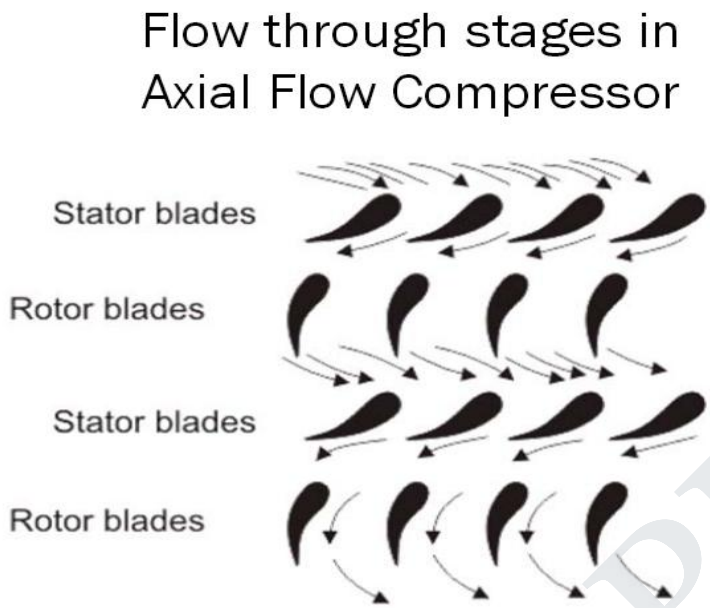
Axial flow compressor: (May-14)

Axial compressors are rotating, aerofoil based compressors in which the working fluid principally flows parallel to the axis of rotation. This is in contrast with centrifugal, axi-Centrifugal and mixed –flow compressors where the air may enter axially but will have a significant radial component on exit.



Axial Flow Compressors– Basic Operation

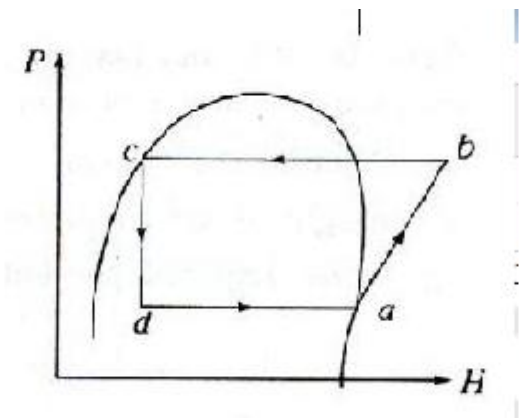
- Axial flow compressor is capable of higher pressure ratio on a single shaft.
- The energy transfer in a single stage is very limited (stage pressure ratio of about 1.2)



- But ease of combining axial flow stages leads to pressure ratios of upto 6/1 or even higher
- Thus axial flow compressor is considered as consisting of many stages
- Single stage is considered as a fan
- For most aircraft & industrial gas turbine, axial flow compressor is used in preference to radial flow type

Unit V Refrigeration and Air conditioning

1. **List out the components in the vapour absorption refrigeration system. (Nov 2013)**
   Heat exchanger, generator, condenser, receiver, expansion valve, evaporator.
2. **Show the simple vapour compression cycle on pressure enthalpy diagram. (May 2016)**



3. **What is the effect of subcooling of the refrigerant on the performance of the vapour compression refrigeration system? (May 2013)**

   It increases the refrigeration effect therefore the COP increases. The mass flow rate of the refrigeration is less than that for the simple saturated cycle. The reduced mass flow rate reduces the piston displacement per minute. Power per tones of refrigeration losses due to reduction in mass flow rate. The increased efficiency may be offering some extent by the rise in the condenser pressure. Work input almost remains same. The heat rejection capacity of the condenser increases.

4. **List two desirable properties of refrigerants. (Nov 2013) (Nov 2014)**

- It should have low boiling point and low freezing point.
- It must have low specific heat and high latent heat.
- It should have low specific volume to reduce the size of the compressor.
- It should have high thermal conductivity to reduce the heat transfer in evaporator and condenser.

5. **State the unit of refrigeration and any two properties of good refrigerant. (May 2014)**
   The capacity of refrigeration is expressed in tonnes of refrigeration (TOR).

6. **What are the requirements of a refrigerant? (Nov 2017)**
   • High evaporating temperature is generally desirable so that heat transmission can occur with lowest possible circulating refrigerant.
   •The refrigerant must be chemically stable at the temperatures and pressures typically expected to be encountered in a refrigeration plant.
   •The refrigerant must not be corrosive or attack normal design materials.

7. Define tonne of refrigeration. (May 2015)

The capacity of refrigeration is expressed in tonnes of refrigeration (TOR).

1 tones of refrigeration = 210 kJ/min (or) = 3.5 kJ/sec (kW)

A tone of refrigeration is defined as the quantity of heat to be removed in order to form one tone of ice at 0oC in 24 hours.

8. Name any three commonly used refrigerants. (Nov 2016)

Chlorofluorocarbons or CFCs, such as R-11, R-12, and R-114

Hydro chlorofluorocarbons or HCFCs, such as R-22 or R-123

Hydro fluorocarbons or HFCs, such as R-134a.

9. Distinguish summer and winter air conditioning (Nov 2015)

In summer air conditioning the air gains both sensible and latent heat. Hence, the conditioning of air is done by both cooling and dehumidification. In winter air conditioning, heating and humidification is done to the air.

10. How does humidity effect the human comfort (Nov 2015)

Humans are very sensitive to humidity as the skin relies on the air to get rid of moisture. The process of sweating is your body’s attempt to keep cool and maintain its current temperature. If the air is at 100 percent relative humidity, sweat will not evaporate in to the air. As a result, we feel much hotter than the actual temperature when the relative humidity is high. If the relative humidity is low, we can feel much cooler than the actual temperature because our sweat evaporates easily, cooling us off.

11. List out the basic elements of an air conditioning system. (May 2016)

Fan, filter, refrigeration unit, humidification or dehumidification system, control system

12. Name the different components of a summer air conditioning system. (May 2013)

- Cooling coil
- Humidifier
- Air damper
- Water eliminator

13. Define relative humidity of air? (Apr 2017)

Relative humidity is the ratio of the mass of water vapour in a certain volume of moist air at a given temperature to the mass of water vapour in the same volume of saturated air at the same temperature.

14. Define RSHF and RTH. (May 2014) (Nov 2014)

Room sensible heat factor is defined as the ratio of the room sensible heat to

The room total heat.

RSHF = RSH / RTH = RSH / (RSH + RLH)

Room total heat(RTH) is the sum of room sensible heat and room latent heat

15. Define the terms gross sensible heat factor and effective sensible heat factor.

(Nov 2017)(May 2015)

Gross sensible heat factor is defined as the ratio of total sensible heat to grand total heat load. Effective sensible heat factor is the ratio of effective room sensible heat to the sum of effective room sensible heat and latent heat.

16. What is meant by ERSHF. (Nov 2016)

Effective room sensible heat factor is defined as the ratio between effective room sensible heat and effective room total heat

17. Define COP of refrigeration

It is defined as the ratio of heat extracted in a given time to the work input.

COP = Ref – effect / Work input

18. How does the actual vapour compression cycle differ from that of the ideal cycle?

- Frequently the liquid refrigerant is sub cooled before it is allowed to enter the expansion value, and usually the gas leaving the evaporator is superheated a few degrees before it enters the compressor.
- Compression usually assumed to be isentropic but actually prove to be neither isentropic nor polytrophic.

19. Define cooling with dehumidification of air in an air-condition system.

The process implies lowering both the air temperature and the humidity ratio. The dehumidification of air only be possible when the temperature of the cooling oil is below the dew point temperature of air.

20. What is humidification and dehumidification?

Humidification:

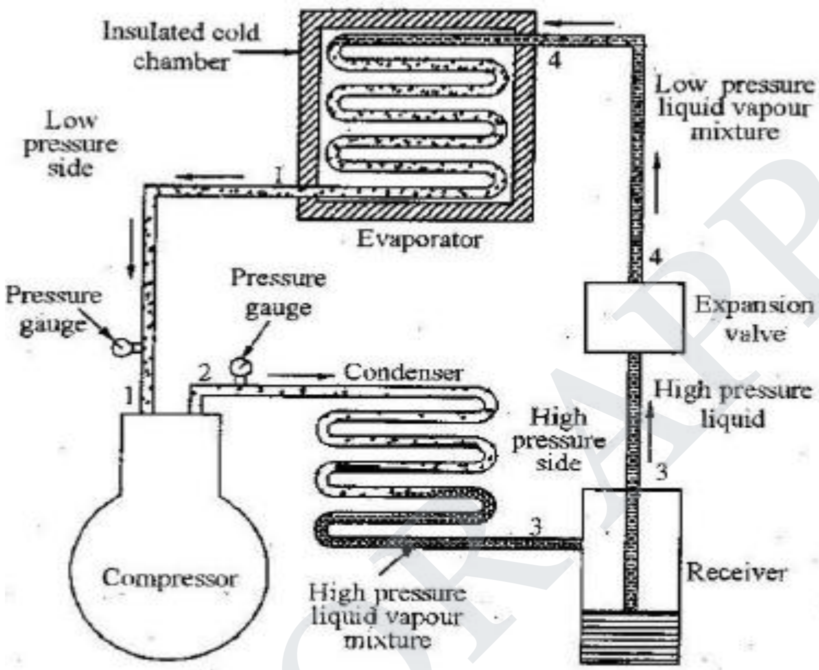
The addition of water vapour to the air is known as humidification.

Dehumidification:

The removal of water vapour to the air is known as dehumidification.

16 MARKS:

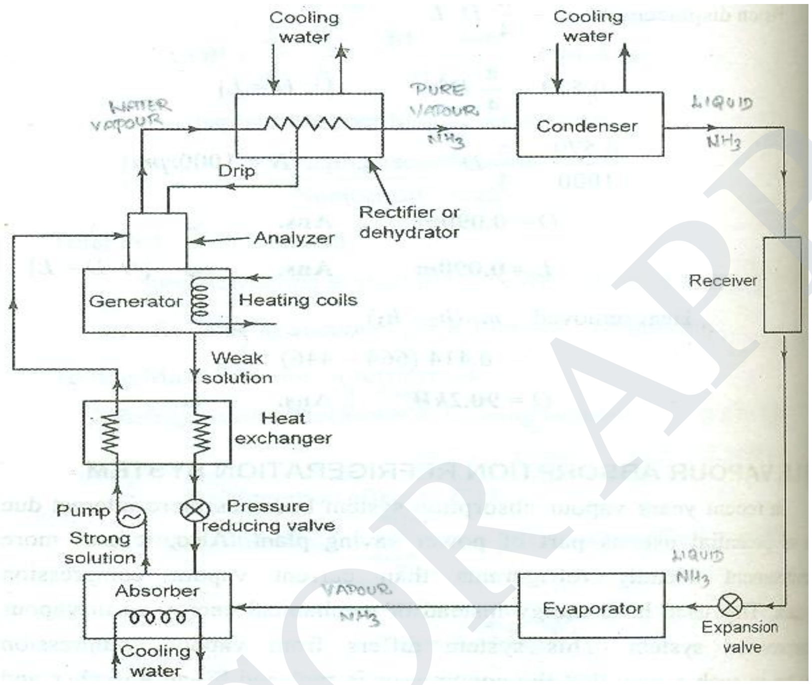
1. Draw a neat sketch of a simple vapour compression refrigeration system and explain its principle of operation.(N/D-2012,13)



- The low pressure refrigerant vapour coming out of the evaporator flows into the compressor. In the compressor, the refrigerant vapour is compressed isentropically.
- The high pressure refrigerant vapour from the compressor is then passed through the condenser vapour refrigerant condenses into high pressure liquid refrigerant.
- The high pressure liquid refrigerant then enters the expansion value through receiver tank. This valve allows the high pressure liquid refrigerant to allow at a controlled rate into the evaporators. While passing through this valve, liquid refrigerant partly evaporates.
- Finally it is passes to evaporator. In the evaporator, the liquid refrigerant absorbs its latent heat of evaporation from the material which is to be cooled. Thus the refrigeration effect is obtained.

COP = Ref – effect / Work input

2. Explain with neat sketch practical Ammonia – water vapour absorbs refrigeration system. Also bring out any four important differences between vapour compressions and vapour absorption refrigeration system. (May-14) **(Nov-14)**

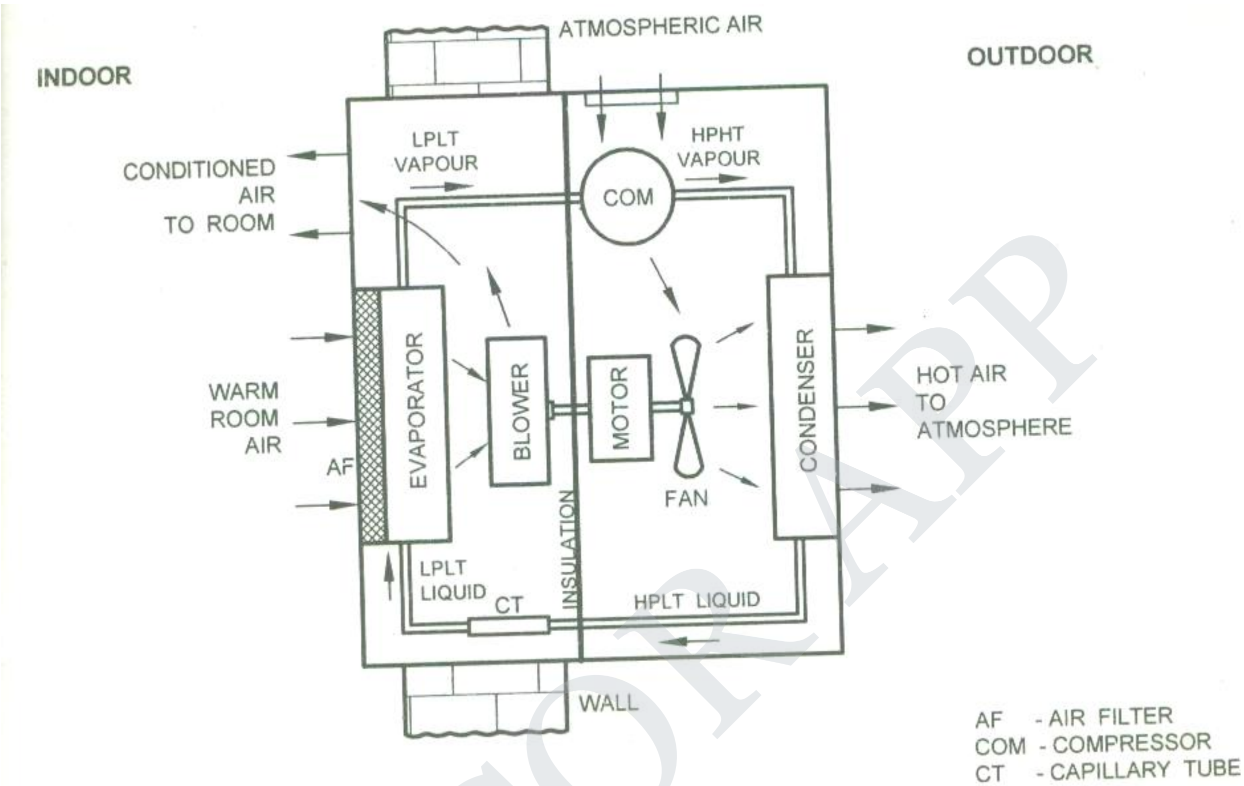


- If the compression in a vapour compression system where replaced with a regenerator, absorber, and heat exchanger.
- The low pressure refrigerant vapour coming from the evaporator is absorber by the weak solution of refrigerant in water.
- Absorption of ammonia lower the pressure in the absorber, which in turn draws more ammonia vapour from the evaporator.
- Water cooling arrangement is employed in the absorber to remove the heat evolved during absorption of ammonia.
- The solution in the absorber is called a strong solution because it is rich in refrigerant.
- The pumpdrawn strong solution from the absorber, built up a pressure up to 10bar and forces the strong solution in the generator through the heat exchanger.

- The strong solution pumped from the absorber to the generator must be heated and the weak solution from the generator to the absorber must be cooled.
- In the generator the strong solution of ammonia is heated by some external source such as gas or steam.
- In heating process, the ammonia vapour is driven out of the solution as a high pressure vapour.
- Ammonia vapour leaving the generator may contain unwanted particles. If this particles is allowed directly to the condenser and expansion valve, it may freeze and choke the pipe line.
- Analyzer and rectifier incorporated in the system before the condenser to remove the water particles contained in the ammonia vapour. The condensate water returned to the analyzer.
- The pure ammonia vapour then passes through the condenser and the ammonia vapour is condensate to liquid ammonia.
- The high pressure liquid refrigerant then enters the expansion valve, the liquid refrigerant partly evaporates.
- The low pressure ammonia vapour leaving the evaporator again enters the absorber and the cycle is repeated.

Vapour compression system	Vapour absorption system
1. Energy supplied is mechanical. 2. Energy supply is low 3. Charging of refrigerant is simple. 4. Space requirement is more. 5. There is more chance of leakage of refrigerant from the system.	1. Energy input is mainly heat. 2. Energy supply is high. 3. Charging of refrigerant is difficult. 4. Space requirement is less. 5. There is no compressor.

3. With the neat sketch explain the room air conditioner.



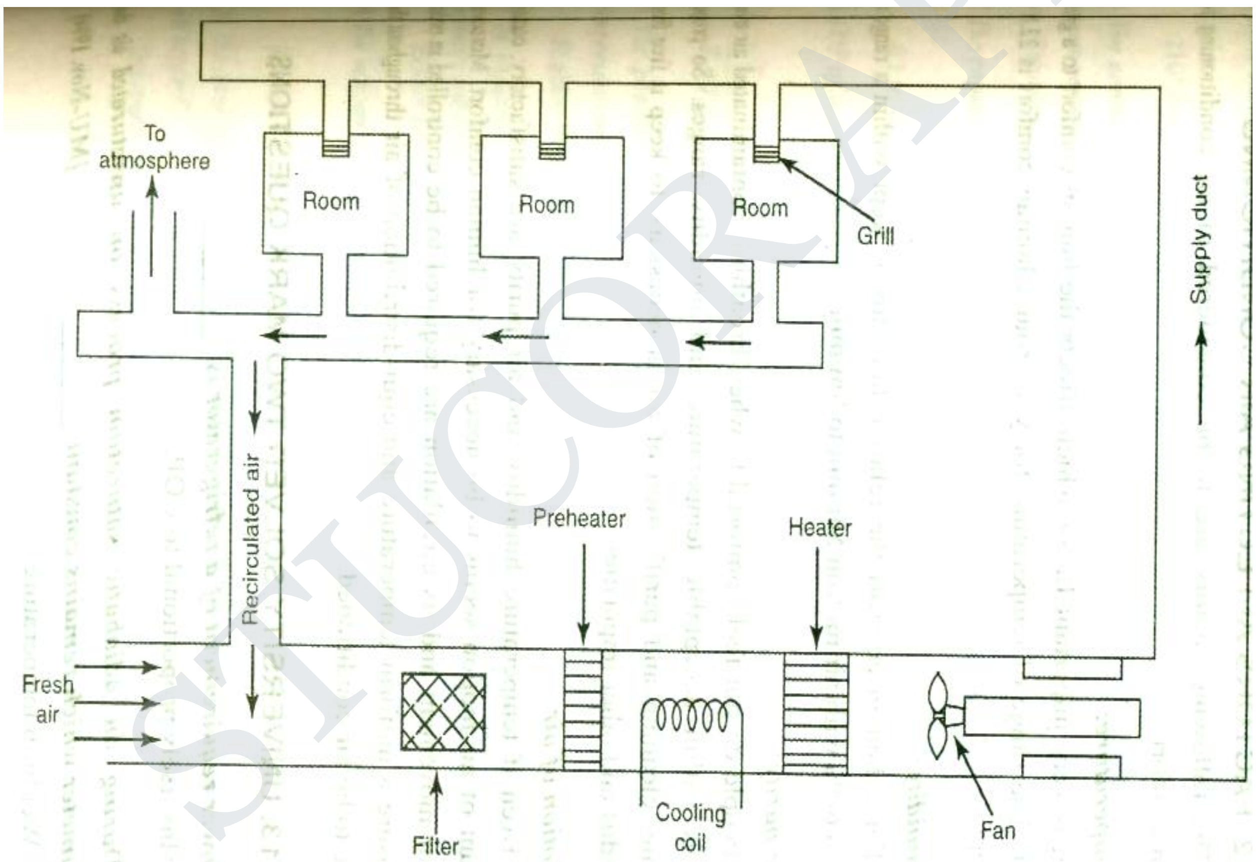
- The low pressure refrigerant vapour is drawn from the vapour to hermetic compressor through section pipe. It is compressed from low pressure to high pressure and supplied to the condenser.
- The liquid refrigerant is passed through the capillary into the evaporator. A motor driven fan draws air from room to evaporator surface through the air filter.
- In the evaporator the liquid refrigerant picks up heat from air in the evaporator surface and gets vaporized, hence the air is cooled and it is circulated back up into room.
- The vapour refrigerant from the evaporator goes to the compressor and the cycle is repeated. Thus the room is air conditioned.

4. With the help of line diagram, explain the working of a central air conditioning plant

The central air conditioning plant is mostly suitable for cinema theatre, restaurants, hospitals, etc.

The central systems are generally employed for the loads above 25TR and 2500m^3/min of conditioned air.

The layout of a central air conditioning plant is shown in figure. This plant serves for both summer and winter air conditioning.



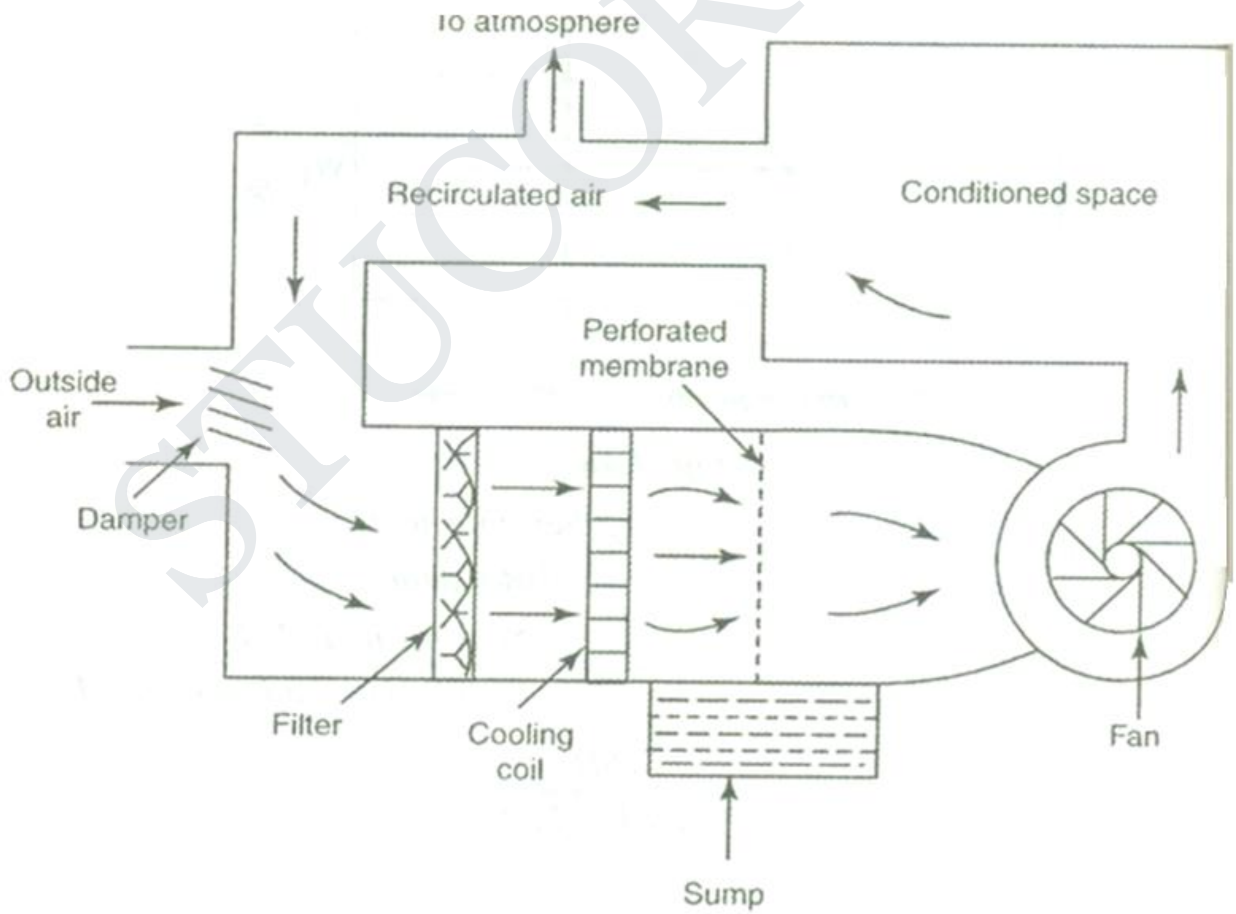
5. Explain with neat sketch the summer air conditioning suitable for Chennai weather conditioning (or) Explain summer air conditioning with a layout.(N/D-2012)

Summer air conditioning:

Heating coils is made inoperative during summer. The outside fresh air along with recirculated air enters the plant through an air filter. Filter removes dust particles and harmful bacteria's from the air and prevent going into the conditioned space.

Then air passes through the cooling coil. The cooling coil is kept at a temperature below the dew point temperature of air. Hence water vapour presents in the passing air condenser. Thus the air is dehumidified.

The fan draws the air conditioned air and sends through the duct. This air passes through the duct and enters the rooms to be air conditioning through the grilles opening provided in the duct way.



- Better accessibility for maintenance.
- The running cost is less per unit of refrigeration.

Disadvantages:

- Installation and labor charges are more.
- In requires larger size ducts which are costly and occupy large space.
- Even if one room requires air conditioning the whole plant is to be operated.
- Failure of central plant puts off air conditioning in all rooms.

7. What are the various loads for air conditioning?

The air conditioning systems carry two types of loads.

1. Room heat load
   a. Room sensible heat loads
   b. Room latent heat loads
2. Total heat load

1. A. Room sensible heat load:

- Solar and transmission heat gains through walls, roof, etc.
- Solar and transmission heat gain through glass.
- Supply duct heat gain, supply duct leakage.
- Internal heat gain from people, power lights, appliances', etc.
- Infiltration: It means air enters into the air conditioned space through crakes, doors, windows and ventilators and also through the door when opened.

B. Room latent heat load:

- Infiltration.
- Internal heat gain from people, steam appliances, etc.
- Vapour transmission.
- Supply ducts leakage loss.

2. Total heat load = Total sensible heat + Total latent heat

Total sensible heat load:

It is the summation of effective room sensible heat load and return ducts heat gain, return duct leakage gain, dehumidifier pump horse power and dehumidifier and piping losses.

Total latent heat load:

It is the summation of effective room detent and return duct leakage gain.

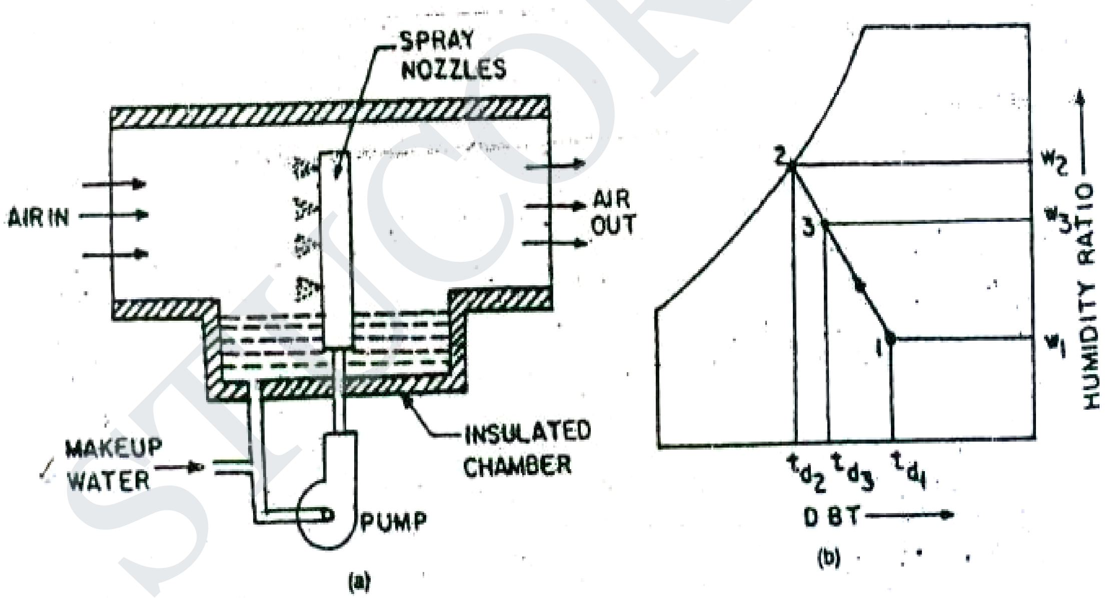
8. Sketch various processes of summer air conditioning in a psychometric chart.

Summer air conditioning involves the combination of the following processes.

1.Adiabatic humidification

2.Sensible cooling.

1. Adiabatic humidification:



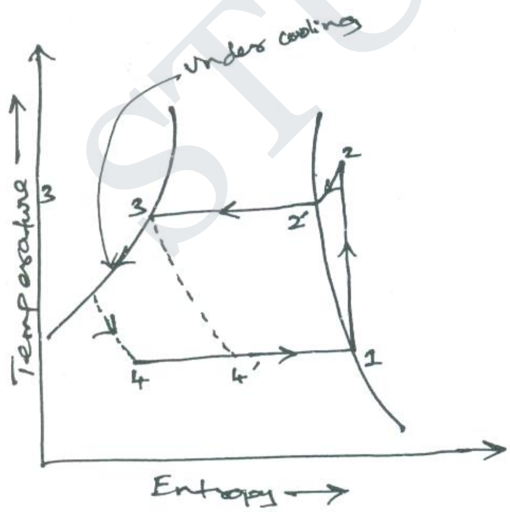
When the air is passed through at insulated chamber having sprays of water maintained at a temperature higher than the dew point temperature of entering air but lower than its dry bulb temperature, the air will be both cooled and humidified.

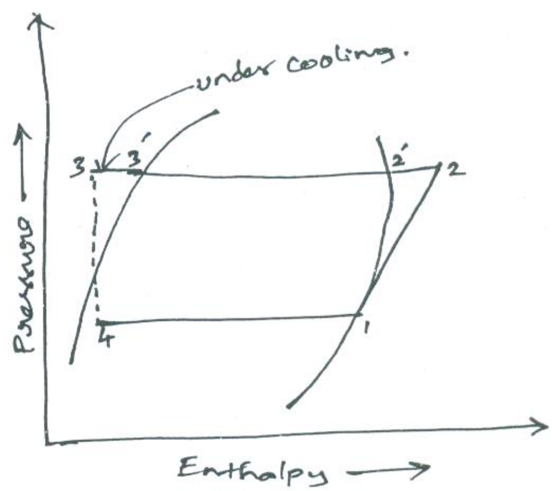
2. Sensible cooling:

9. A refrigerator works on vapour cycle between temperature limits of 253 K and 298 K. If the liquid refrigerant enters the throttle value at 293 K and the entry to the compressor is dry and saturated, find the tonnage of refrigeration, work required to drive the compressor and COP if the mass flow rate of refrigerant is 1 Kg/s. The properties of refrigerants are given in table.

Temperature	**Enthalpy**		**Entropy**		**Specific heat**	
	Liquid h_f **kJ/kgk**	**Vapour** h_g **kJ/kgk**	**Liquid** S_f **kJ/kgk**	**Vapour** S_g **kJ/kgk**	C_{pl}	C_{pv}
253	**327.4**	**1655.9**	**3.8416**	**9.09**	**-**	**-**
298	**536.3**	**1703.3**	**4.5956**	**8.50**	**1.15**	**0.8875**

Solution:





h_1 = 1655.9 KJ/kgK

$h_3 = h'_3 - C_{pl}[T_3' - T_3]$

$= 536.3 - 1.15[298 - 293]$

$= 530.55$ KJ/kg

$S_1 = S_2$

$9.09 = 8.5 + 0.8875 \ln [T_2 / 298]$

$T_2 = 579.34$ K

$h_2 = h_2' + C_{pv}[T_2' - T_2]$

$= 1703.3 + 0.8875 [579.34 - 298]$

$= 1953$ KJ/Kg

COP $= (h_1 - h_3) / (h_3 - h_1)$

$= (1655.9 - 530.55) / (1953 - 1655.9)$

$= 3.79$

Work required $= m_r [h_2 - h_1]$

$= 1 [1655.9 - 530.55]$

$= 1125.33$ kw

$= 321.5$ tonnes

10. A cold storage room requires a refrigeration system of 20 tonnes capacity. The evaporator temperature is 265 K and condenser temperature is 303 K. The refrigerant is sub cooled by 5°C and the vapour is super heated by 6°C. Calculate mass flow rate of refrigerant and coefficient of performance. The properties of the refrigerant R-12 are given in the table.

Temperature	**Enthalpy**		**Entropy**		**Specific heat**	
	Liquid	**Vapour**	**Liquid**	**Vapour**	C_{pl}	C_{pv}
265	**28.72**	**184.07**	**0.1149**	**0.7007**	**-**	**0.733**
303	**64.59**	**199.62**	**0.2400**	**0.6853**	**1.235**	**0.733**

$h_1 = h_1' + C_{pv}[T_1 - T_1']$

$= 184.07 + 0.733\ [271 - 265]$

$= 188.468$ KJ/Kg

$h_3 = h'_3 - C_{pl}\ [T_3 - T_3']$

$= 64.59 - 1.235\ [303 - 298]$

$= 58.415$ KJ/Kg

$h_2 = h_2' + C_{pv}[T_2 - T_2']$

but,

$S_1 = S_1' + C_{pv} \ln[T_1 / T_1']$

$= 0.7007 + 0.73 \ln [271/265]$

= 0.7170

$S_1 = S_2$

$S_2 = S_2' + C_{pv} \ln[T_2 / T_2']$

$0.7170 = 0.6853 + 0.733 \ln [T_2 / 303]$

$T_2 = 316.38$ K

$h_2 = h_2' + C_{pv}[T_2 - T_2']$

= 199.62 + 0.733 [316.38 - 303]

=209.43 KJ/Kg

$(h_1 - h_3) / (h_2 - h_1) = (188.468 - 58.415)/(209.43 - 188.468)$

= 6.2

Refrigeration effect = $m_r [h_1 - h_4]$

$20 (3.5) = m_r [188.468 - 58.415]$

$m_r = 0.54$ Kg/s

11. An air conditioning plant is to be designed for the following conditions.

Outdoor conditions	**= 9°C DBT and 8°C WBT**
Required indoor conditions	**= 21°C and 59% R.H**
Amount of free air circulation	**= 0.5m^3/min/person**

Seating capacity of the orifice = 100

The required condition is achieved first by heating and then by adiabatic humidifying. Find the heating capacity of the coil and the surface temperature required if the bypass factor of the coil is 0.32 and also the capacity of the humidifier. **(May-14)**

Solution:

From psychometric chart,

$h_1 = 25$ KJ/Kg

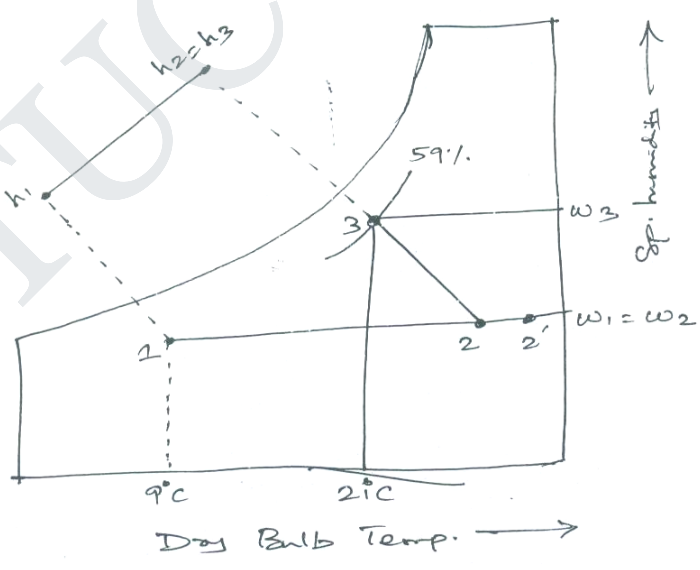
$h_2 = h_3 = 42$ KJ/Kg

$w_1 = w_2 = 0.0058$ KJ/Kg

$w_3 = 0.0085$ KJ/Kg

$T_2 = 27$ °C

$Vs_1 = 0.80$ m^3/kg



The mass flow of air circulated = (0.5× 100) / (60 × 0.80)

= 1.04 kg/s

Heating capacity of the cooling coil = $m_a (h_2 - h_1)$

$= 1.04 (42 - 25)$

$= 17.7kw$

The bypass factor of the heating coil = $[T_2' - T_2] / [T_2' - T_1]$

$0.32 = [T_2' - 27] / [T_2' - 9]$

$= 35.5°C$

The capacity of the humidifier = $m_a (w_3 - w_2)$

$= 1.04 [0.0085 - 0.0058]$

$= 2.8$ gm/s

12. An office is to be air conditioned for staff of when the outdoor conditions are 29°C DBT and 73% RH. If the quantity of outdoor air supplied is 0.5 m^3/min/person, find the capacity of the cooling coil and capacity of the heating coil. Also find the amount of water removed if the required comfort condition are 21°C and 59% RH. Air is conditioned first by cooling and dehumidifying and then heating.

Solution:

$h_1 = 82$ kJ/kg

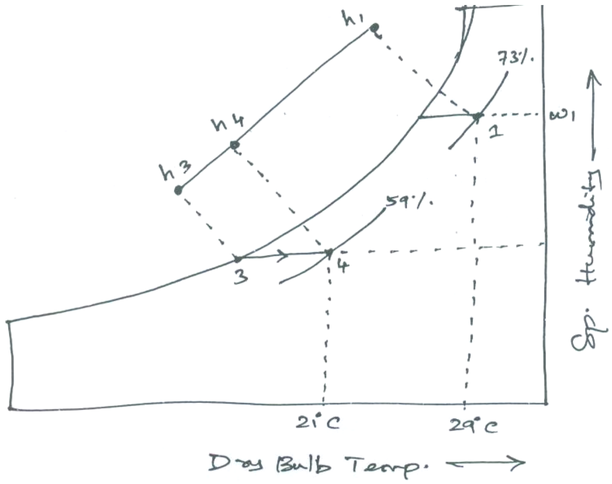
$h_3 = 34$ kJ/kg

$h_4 = 43$ kJ/kg

$w_1 = 0.02$ kg/kg

$w_2 = 0.0085$ kg/kg

$Vs_1 \quad = 0.89\ m^3/kg$



The mass flow of air supplied = $0.5 \times 25 / Vs_1$

$= 0.5 \times 25 / 0.89 \times 60$

$= 0.24$ kg/s

The capacity of the cooling coil = $m_a (h_1 - h_3)$

$= 0.234\ [82 - 34]$

$= 11.23$ KW

The capacity of heating coil = $m_a (h_4 - h_3)$

$= 0.234\ [43 - 34]$

$= 2.1$ KW

Amount of water vapour removed = $m_a (w_1 - w_3)$

$= 0.234\ [0.002 - 0.0085]$

$= 9.72$ kg/hr

13. Explain the working of Lithium Bromide-Water vapour absorption refrigeration system with neat sketch.

This refrigeration system is used for large tonnage capacity. In this system, lithium-bromide is acting as the absorbent and water is acting as refrigerant. Thus in the absorber the lithium bromide absorbent absorbs the water refrigerant and solution of water and lithium bromide is formed. This solution is pumped by the pump to the generator where the solution is heated. The water refrigerant gets vaporized and moves to the condenser where it is heated while lithium bromide flows back to the absorber where it further absorbs water coming from the evaporator.

The water-lithium bromide vapor absorption system is used in a number of air conditioning applications. This system is useful for the applications where the temperature required is more than 32 degree F.

Special Features of Water-Lithium Bromide Solution

Here are some special features of the water and lithium bromide in absorption refrigeration system:

1) As such lithium bromide has great affinity for water vapor, however, when the water-lithium bromide solution is formed, they are not completely soluble with each other under all the operating conditions of the absorption refrigeration system. Hence, when the water-lithium bromide absorption refrigeration system is being designed, the designer must take care that such conditions would not be created where the crystallization and precipitation of lithium bromide would occur.

2) The water used as the refrigerant in the absorption refrigeration system means the operating pressures in the condenser and the evaporator would be very low. Even the difference of pressure between the condenser and the evaporator are very low, and this can be achieved even without installing the expansion valve in the system, since the drop in pressure occurs due to friction in the refrigeration piping and also in the spray nozzles.

3) The capacity of any absorption refrigeration system depends on the ability of the absorbent to absorb the refrigerant, which in turn depends on the concentration of the absorbent. To increase the capacity of the system, the concentration of absorbent should be increased, which would enable absorption of more refrigerant. Some of the most common methods used to change the concentration of the absorbent are: controlling the flow of the steam or hot water to the generator, controlling the flow of water used for condensing in the condenser, and re-concentrating the absorbent leaving the generator and entering the absorber.

Parts of the Water-Lithium Bromide Absorption Refrigeration and their Working

Let us see various parts of the water-lithium bromide absorption refrigeration and their working

1) Evaporator:

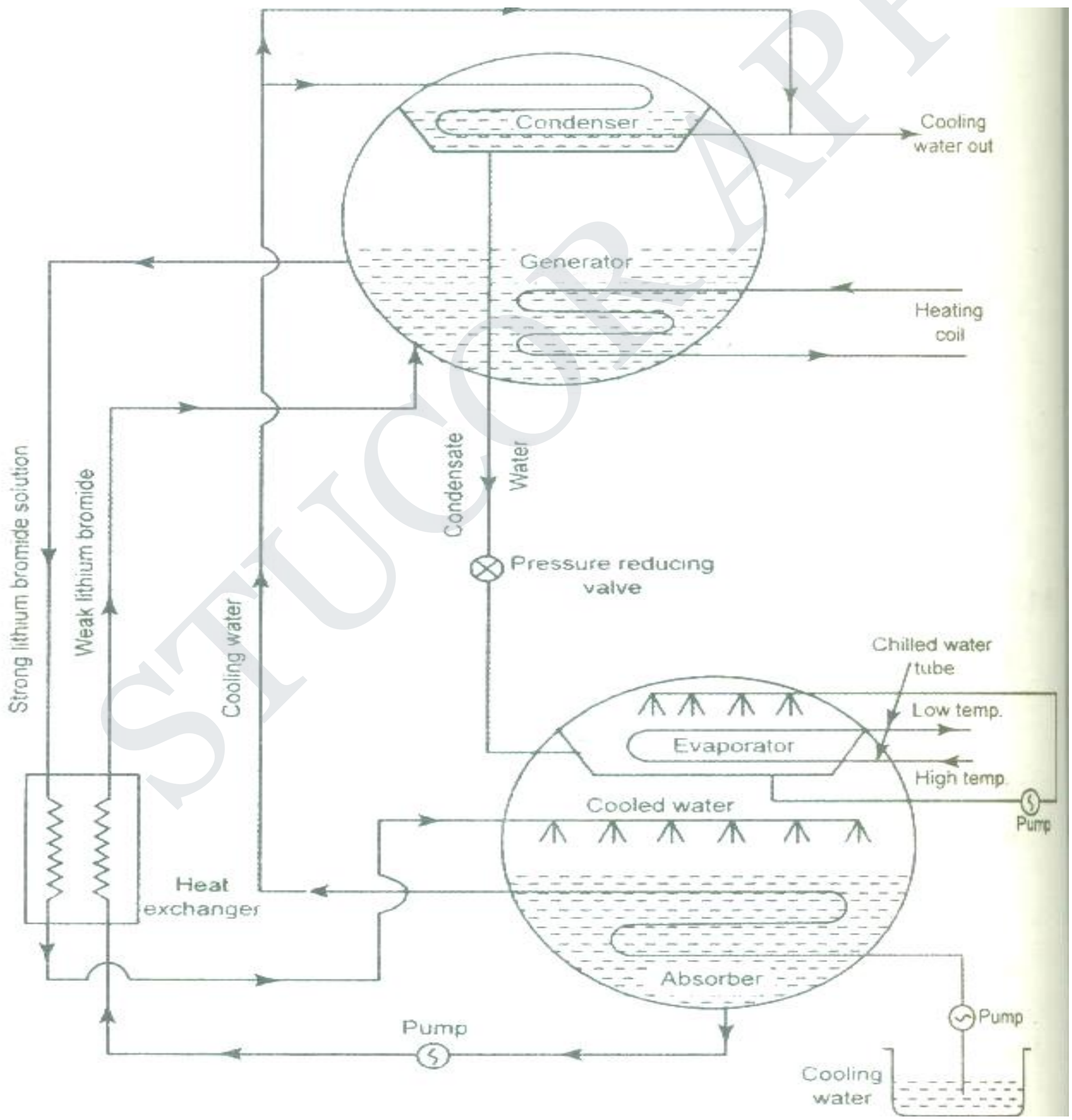
Water as the refrigerant enters the evaporator at very low pressure and temperature. Since very low pressure is maintained inside the evaporator the water exists in the partial liquid state and partial vapor state. This water refrigerant absorbs the heat from the substance to be chilled and gets fully evaporated. It then enters the absorber.

2) Absorber:

In the absorber concentrated solution of lithium bromide is already available. Since water is highly soluble in lithium bromide, solution of water-lithium bromide is formed. This solution is pumped by the pump to the generator.

3) Generator:

The heat is supplied to the refrigerant water and absorbent lithium bromide solution in the generator from the steam or hot water. Due to heating water gets vaporized and it moves to the condenser, where it gets cooled. As water refrigerant moves further in the refrigeration piping and though nozzles, it pressure reduces and so also the temperature. This water refrigerant then enters the evaporator where it produces the cooling effect. This cycle is repeated continuously. Lithium bromide on the other hand, leaves the generator and reenters the absorber for absorbing water refrigerant. As seen in the image above, the condenser water is used to cool the water refrigerant in the condenser and the water-Li Br solution in the absorber. Steam is used for heating water-Li Br solution in the generator. To change the capacity of this water-Li Br absorption refrigeration system the concentration of Li Br can be changed.



a) Ozone Depletion Potential (ODP):

According to the Montreal protocol, the ODP of refrigerants should be zero,i.e., they should be non-ozone depleting substances. Refrigerants having non-zero ODP have either already been phased-out (e.g. R 11, R 12) or will be phased-out in near-future(e.g. R22). Since ODP depends mainly on the presence of chlorine or bromine in the molecules, refrigerants having either chlorine (i.e.,CFCs and HCFCs) or bromine cannot be used under the new regulations

b) Global Warming Potential (GWP):

Refrigerants should have as low a GWP value as possible to minimize the problem of global warming. Refrigerants with zero ODP but a high value of GWP (e.g. R134a) are likely to be regulated in future.

c) Total Equivalent Warming Index (TEWI):

The factor TEWI considers both direct (due to release into atmosphere) and indirect (through energy consumption) contributions of refrigerants to global warming. Naturally, refrigerants with as a low a value of TEWI are preferable from global warming point of view.

d) Toxicity:

Ideally, refrigerants used in a refrigeration system should be non-toxic. However, all fluids other than air can be called as toxic as they will cause suffocation when their concentration is large enough. Thus toxicity is a relative term, which becomes meaningful only when the degree of concentration and time of exposure required to produce harmful effects are specified. Some fluids are toxic even in small concentrations. Some fluids are mildly toxic, i.e., they are dangerous only when the concentration is large and duration of exposure is long.

Some refrigerants such as CFCs and HCFCs are non-toxic when mixed with air in normal condition. However, when they come in contact with an open flame or an electrical heating element, they decompose forming highly toxic elements (e.g. phosgene-$COCl_2$).

In general the degree of hazard depends on:

- Amount of refrigerantused vs total space -Type of occupancy -Presence of open flames
- Odor of refrigerant, and