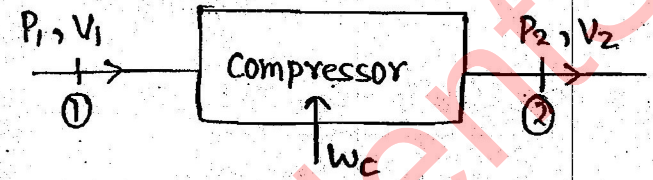
COMPRESSOR →

In compressor → T changes
In pump → T (No change)
(incompressible)
∴ water is used in pump.)

⇒ If water is supplied to the compressor then theoritically is possible but practically is not possible because compressor blade is light and easily breakable but pump blade is robust in design means hard.

$P_2 > P_1$, $V_2 \simeq V_1$



The Function of a compressor is to increase the pressure of gas and vapour from lower to higher pressure and for that work is done from outside.

Classification :-

Based upon working principle :-

i) +ve Displacement compressor :-

In these compressor the pressure of gas is increased by decreasing its volume in a confined cylinder i.e rise in pressure is obtained by positively displacement fluid to lower volume.

Ex → Reciprocating compressor.

ⓑ Dynamic compressor :-

In these compressor High kinetic energy is given to fluid by a rotating element called rotor and then this high kinetic energy is converted into pressure energy in the diffusor. That is rise in pressure is obtained due to dynamic action of gas.

Ex → Centrifugal and axial compressor.

② Based on pressure developed :-

(i) Low pressure → 10 bar

(ii) Medium pressure → 10 bar to 80 bar

(iii) High pressure → above 80 bar.

③ Based on pressure Ratio ($P_r = P_2/P_1$) :-

(i) Fan → $1.0 < P_r < 1.1$

(ii) Blower → $1.1 < P_r < 2.3$

(iii) compressor → $P_r > 2.3$

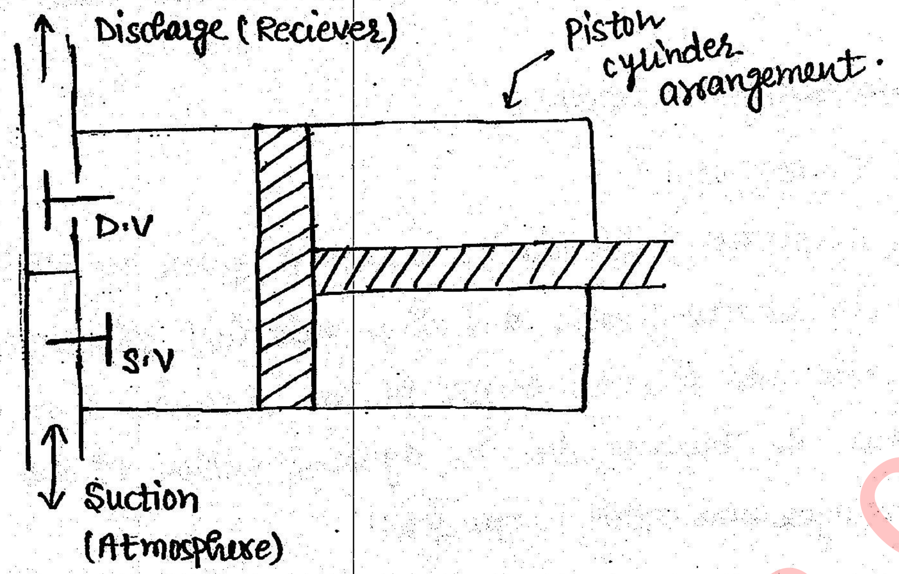
④ Based on Volume Handeling (m^3/sec) or (m^3/min) :-

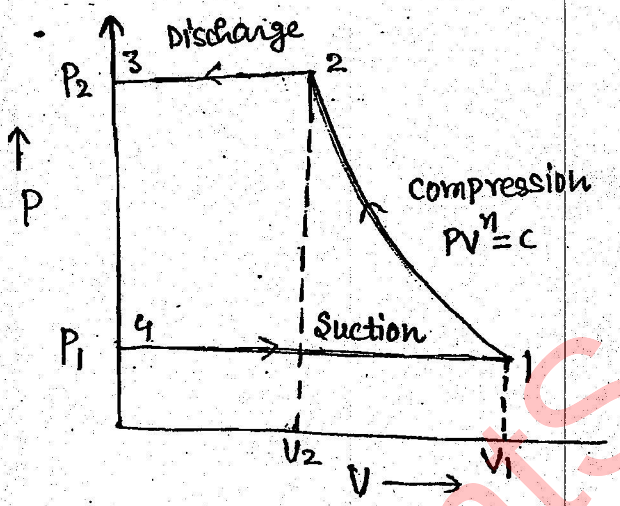
(i) Small → upto $9\ m^3/min$

(ii) Medium → 9 to $3000\ m^3/min$

(iii) large → above $3000\ m^3/min$

RECIPROCATING COMPRESSOR





* Reciprocating compressors are able to produce very high pressure but the volume delievered is very less and there is problem of intermittent supply and poor efficiency. In construction it consist of ~~two~~ piston cylinder arrangement with two valve one on the suction side and other on the discharge side. These are simple automatic valve which works due to pressure difference across the valve.

These compressors are used in Air conditioners, Refrigeration system, Minning work, air filling station, air motor, drilling, chemical factories etc.

Work input required without clearance volume :-

workdone per cycle is given by area 1-2-3-4-1.

workdone by air during suction (4-1), $W_S = P_1(V_1-0) = P_1V_1$

LECTURE-4
16/09/2016

Workdone on air during compression (1-2),

$$w_c = \frac{P_1V_1 - P_2V_2}{n-1} = \frac{-(P_2V_2 - P_1V_1)}{n-1}$$

Workdone on air during Discharge, (2,3), $w_d = P_2(0-V_2) = -P_2V_2$

$$w/\text{cycle} = -\left[P_2V_2 - P_1V_1 + \frac{P_2V_2 - P_1V_1}{n-1}\right] = -(P_2V_2 - P_1V_1)\frac{n}{n-1}$$

As compressor work is always -ve, so taking only the magnitude.

$$\boxed{w/\text{cycle} = \left(\frac{n}{n-1}\right)(P_2V_2 - P_1V_1)}$$

$$w/\text{cycle} = \left(\frac{n}{n-1}\right)P_1V_1\left[\frac{P_2}{P_1}\frac{V_2}{V_1} - 1\right]$$

process, 1-2 $\rightarrow$ $P_1V_1^n = P_2V_2^n \Rightarrow \frac{V_2}{V_1} = \left(\frac{P_1}{P_2}\right)^{\frac{1}{n}} = \left(\frac{P_2}{P_1}\right)^{-\frac{1}{n}}$

$\therefore$ $$w/\text{cycle} = \left(\frac{n}{n-1}\right)P_1V_1\left[\frac{P_2}{P_1}\left(\frac{P_2}{P_1}\right)^{-\frac{1}{n}} - 1\right]$$

$$\boxed{w/\text{cycle} = \left(\frac{n}{n-1}\right)P_1V_1\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]} \text{ kJ/cycle}$$

$V_1 \rightarrow m^3/\text{cycle}$

$P_1 \rightarrow$ kPa

If N is rpm $\boxed{\text{Power} = w/\text{cycle} \times \frac{N}{60}}$ (kW)

Que A single cylinder reciprocating compressor takes in air 10 m³/min at 1 bar and 20°C and compresses air to a discharge pressure of 8 bar. The possible compression process are –

(i) Polytropic compression (n = 1.3)

(ii) isentropic compression (n = 1.4)

(iii) isothermal compression (n = 1)

Neglecting clearance volume for each case determine –

(a) Temp at the end of compression.

(b) W_s

(c) W_c

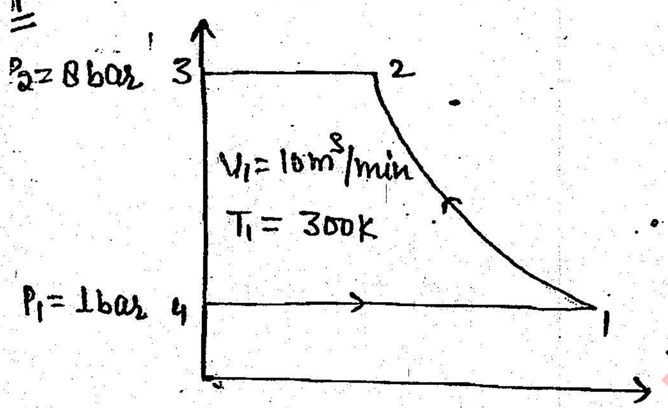
(d) W_d

(e) W_{net}

(f) Heat transfer to cylinder valve during compression.

(g) change in internal Energy during compression.

$\underline{\underline{1^n}}$



1) (a) $\frac{T_2}{T_1} = (r_p)^{\frac{n-1}{n}}$ $\boxed{T_2 = 484.75K}$

2) $W_s = P_1V_1 = 16.67$ kw.

3) $W_c = \frac{P_2V_2 - P_1V_1}{n-1} = \frac{\dot{m}R(T_2-T_1)}{n-1}$

$\dot{m} = \frac{P_1V_1}{RT_1} = 0.1935$ kg/sec

$\boxed{W_c = 34.21 \text{ kw}}$

4) $W_d = P_2V_2 = \dot{m}RT_2$

$\boxed{W_d = 26.9 \text{ kw}}$

(e) $W_{net} = W_c + W_d - W_s$

$= 34.21 + 26.9 - 16.67$

$\boxed{W_{net} = 44.47 \text{ kw}}$

(e)

$W_{net} = \left(\frac{n}{n-1}\right) P_1V_1\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$

$= \frac{1.3}{0.3} \times 16.67\left[(8)^{\frac{0.3}{1.3}} - 1\right]$

$\boxed{W_{net} = 44.47 \text{ kw}}$

(f) $Q_{1-2} = \frac{\gamma - n}{\gamma - 1} \times W_c$ [Formula for closed system only]

$= \left(\frac{1.4-1.3}{1.4-1}\right) \times (-34.21)$

$\boxed{Q_{1-2} = -8.55 \text{ kw}}$

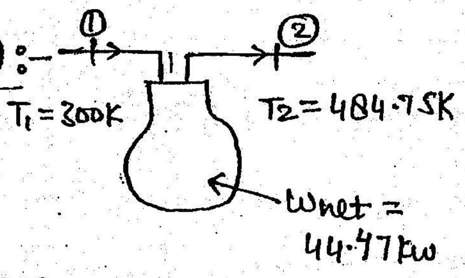
(g) $dQ = dW + \Delta U$

$-8.55 = -34.21 + \Delta U$

$\boxed{\Delta U = +25.6 \text{ kw}}$

OR $\Delta U = \dot{m}c_v(T_2 - T_1)$.

For (f):



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$h_1 + Q = h_2 + W_{net}$

$Q = \dot{m}c_p(T_2 - T_1) - 44.47$

$\boxed{Q = -8.55 \text{ kw}}$

(2) When $n = 1.4$:- (adiabatic)

ⓐ $T_2 = 543.43\,K$

ⓑ $W_s = 16.67\,kW$

ⓒ $W_c = 33.79\,kW$

ⓓ $W_d = 30.18\,kW$

ⓔ $W_{net} = 47.30\,kW$

ⓕ $Q_{1-2} = 0$

ⓖ $\Delta U = -W_c = +33.79\,kW$

(3) When $n = 1$:- (isothermal)

ⓐ $T_2 = T_1 = 300K$

ⓑ $W_s = 16.67\,kW$

ⓒ $W_c = P_1V_1 \ln(P_2/P_1)$

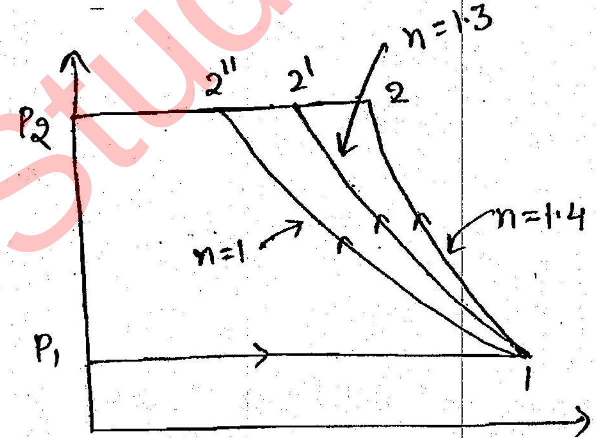
$= 34.68\,kW.$

ⓓ $W_d = P_1V_1 = P_2V_2 = 16.67\,kW.$

ⓔ $W_{net} = W_c = 34.68\,kW.$

ⓕ $Q_{1-2} = W_c = -34.68\,kW.$

ⓖ $\Delta U = 0$



Practically $n \simeq 1.25$ to 1.35

Isothermal efficiency

$$\boxed{\eta_{iso} = \frac{\text{Isothermal work}}{\text{Actual work}} = \frac{W_{iso}}{W_{act}}}$$

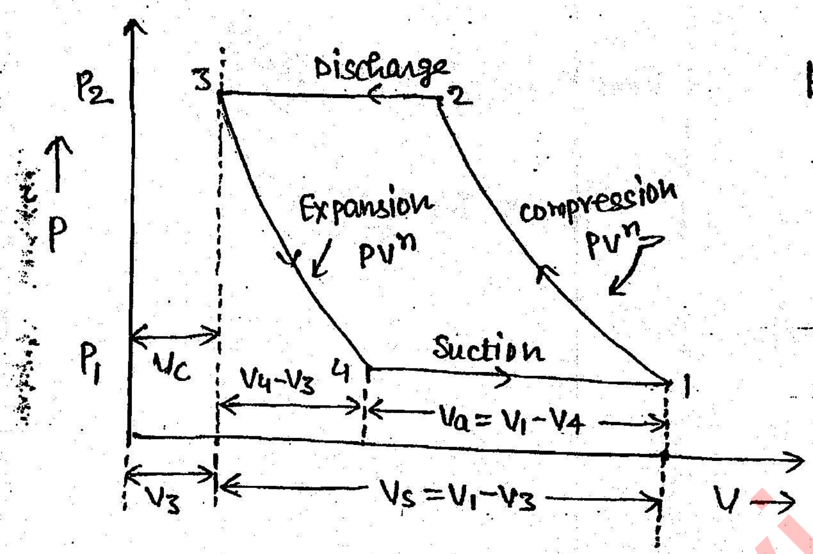
$$W_{iso} = P_1V_1 \ln(P_2/P_1)$$

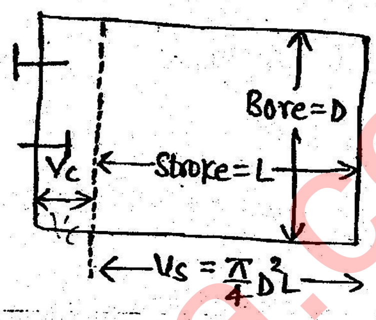
$$W_{act} = \left(\frac{n}{n-1}\right) P_1V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$\eta_{iso} \simeq 80$ to 85%

Work input with clearance volume :-

In actual working always left a minimum volume b/w the piston and cylinder head known as clearance volume. It is provided for thermal expansion, valve tolerance and to avoide piston striking the cylinder head.





Clearance Ratio (C)

$$\boxed{C = \frac{V_c}{V_s}}$$

$C\% \simeq 5\%$

workdone/cycle is given by area 1-2-3-4-1.

$$W/cycle = W_{c,1-2} - W_{c,4-3}$$

$$= \left(\frac{n}{n-1}\right) P_1V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right] - \left(\frac{n}{n-1}\right)\left[\left(\frac{P_3}{P_4}\right)^{\frac{n-1}{n}} - 1\right] P_4V_4$$

But $P_2 = P_3$ & $P_4 = P_1$

$$W/cycle = \left(\frac{n}{n-1}\right) P_1V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right] - \left(\frac{n}{n-1}\right)\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right] P_1V_4$$

$$\boxed{W/cycle = \left(\frac{n}{n-1}\right) P_1 (V_1 - V_4) \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]} \quad KJ/cycle.$$

NOTE :- Due to clearance volume there is no change in work input required by the compressor. The only difference the actual volume of air delievered per cycle is decreased. Thus for the same volume to be delievered no. of cycles required increases.

$V_a \rightarrow$ Actual volume $= V_1 - V_4$

$P_1 V_a = m_a R T_1$

m_a = actual mass.

Volumetric efficiency :-

It indicates the volume that is delievered during the total displacement of piston. It is ratio of actual volume of air entering the cylinder to the piston swept volume.

$$\eta_v = \frac{\text{Actual Volume}}{\text{Swept Volume}}$$

$$\boxed{\eta_v = \frac{V_a}{V_s}}$$

$$V_a = V_s - (V_4 - V_3)$$

$$\eta_v = 1 - \frac{V_3}{V_s}\left(\frac{V_4}{V_3} - 1\right)$$

For expansion process 3-4

$$P_3 V_3^n = P_4 V_4^n$$

$$\frac{V_4}{V_3} = \left(\frac{P_3}{P_4}\right)^{\frac{1}{n}} = \left(\frac{P_2}{P_1}\right)^{\frac{1}{n}}$$

$$\eta_v = 1 - \frac{V_3}{V_s}\left[\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right]$$

as $V_3 = V_c$ and $\frac{V_c}{V_s} = C$

$$\boxed{\eta_v = 1 - C\left[\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right]}$$

Condition for $\eta_v = 0$:-

$$0 = 1 - C\left[\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right]$$

$$\boxed{\frac{P_2}{P_1} = \left[\frac{1}{C} + 1\right]^n}$$

Conclusions :-

(i) When $P_2 = P_1$ there is no compression but η_v becomes 100%

(2) With increase in P_2 η_v decreases.

(3) η_v decreases with increase in clearance ratio.

(4) η_v increases with increase in expansion coefficient (n).

(5) If $T_1 \uparrow \rightarrow \eta_v \uparrow$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$$

$$\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} = \left(\frac{T_2}{T_1}\right)^{\frac{1}{n-1}}$$