ATME College of Engineering

9001:2015

APPLIED THERMODYNAMICS BME401

INTRODUCTION

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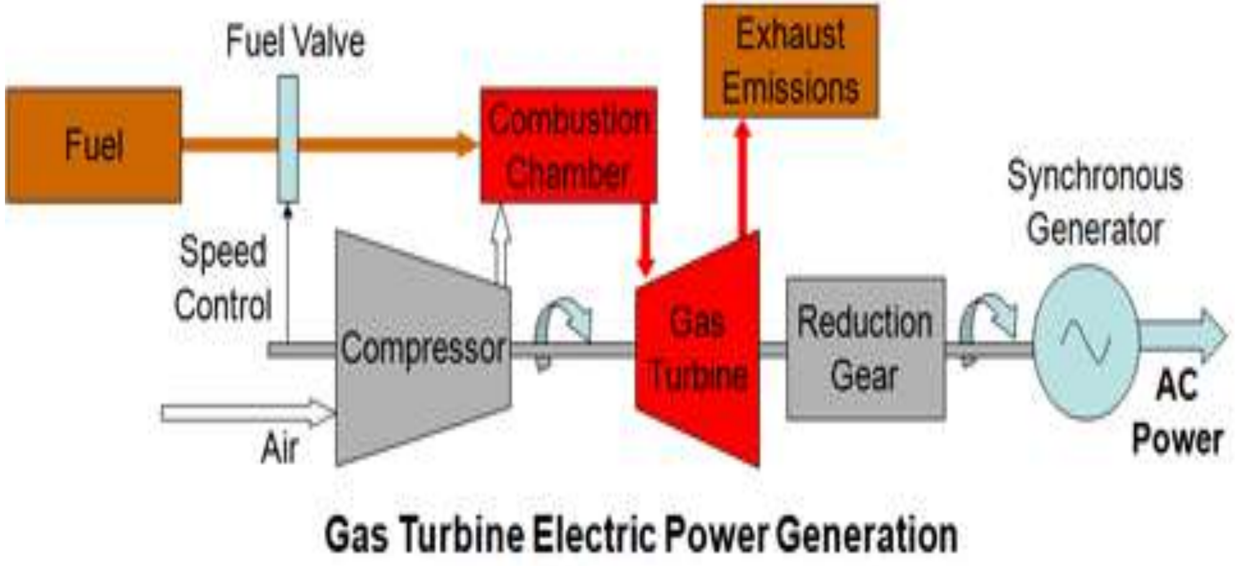
Syllabus

- **Module – 1: Air standard cycles, I.C. Engines**
- **Module – 2: Gas power Cycles**
- **Module – 3: Vapour Power Cycles**
- **Module – 4: Refrigeration Cycles, Psychometrics and Air-conditioning Systems**
- **Module – 5: Reciprocating Compressors, Steam nozzles**

Importance of studying the subject (Applications of Applied Thermodynamics)

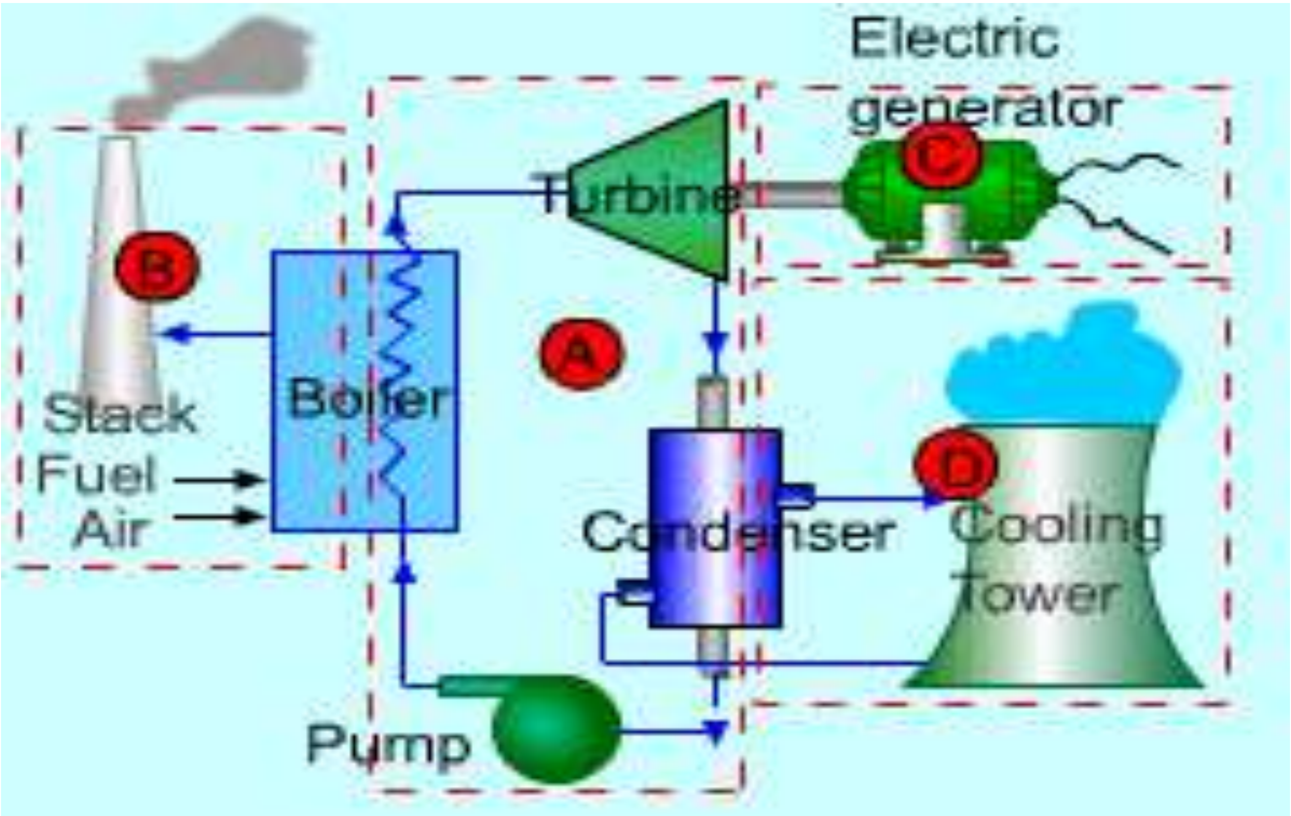


Gas turbine used in rocket

Importance of studying the subject (Applications of Applied Thermodynamics)

Coal: 204,724.5 MW (55.6%)
Large Hydro: 45,399.22 MW (12.3%)
Small Hydro: 4,671.56 MW (1.3%)
Wind Power: 37,505.18 MW (10.2%)
Solar Power: 33,730.56 MW (9.2%)
Biomass: 10,001.11 MW (2.7%)
Nuclear: 6,780 MW (1.8%)
Gas: 24,955.36 MW (6.8%)
Diesel: 509.71 MW (0.1%)

Vapour Power Cycle in Thermal power plant



Importance of studying the subject (Applications of Applied Thermodynamics)

Refrigeration Cycles, Psychometrics and Air-conditioning Systems

Importance of studying the subject (Applications of Applied Thermodynamics)

Reciprocating Compressors

References

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- Applications of Thermodynamics, V.Kadambi, T. R.Seetharam, K. B.Subramanya Kumar, Wiley Indian Private Ltd
- Thermodynamics, Yunus A, Cengel, Michael A Boles, Tata McGraw Hill, 7th Edition
- Thermodynamics for engineers, Kenneth A. Kroos and Merle C. Potter, Cengage Learning 2016
- Thermodynamics, Radhakrishnan, PHI 2nd revised Edition
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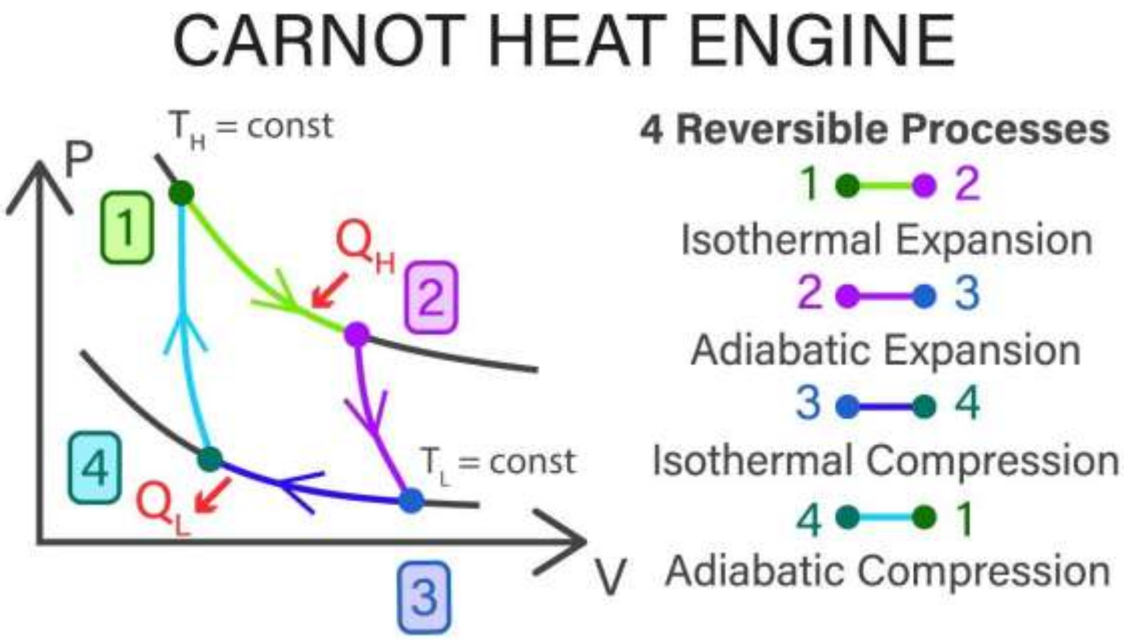
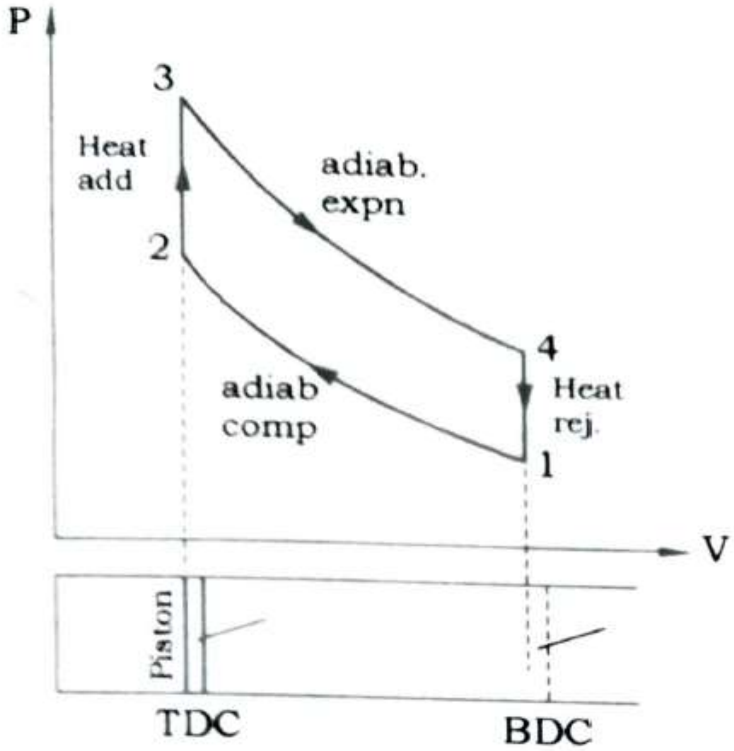
Module – 1: Air standard cycles

- **Air standard cycles:** Carnot, Otto, Diesel, Dual and Stirling cycles, p-v and T -S diagrams, description, efficiencies and mean effective pressures. Comparison of Otto and Diesel cycles.

- **I.C.Engines:** Classification of IC engines, Combustion of SI engine and CI engine, Detonation and factors affecting detonation, Performance analysis of I.C Engines, Heat balance, Morse test.

Air standard cycles





Carnot cycle

Expression for air standard efficiency in Carnot cycle

Process 1-2: Isothermal Expansion

$\therefore$ Heat absorbed or heat added or heat supplied = $Q_S = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$

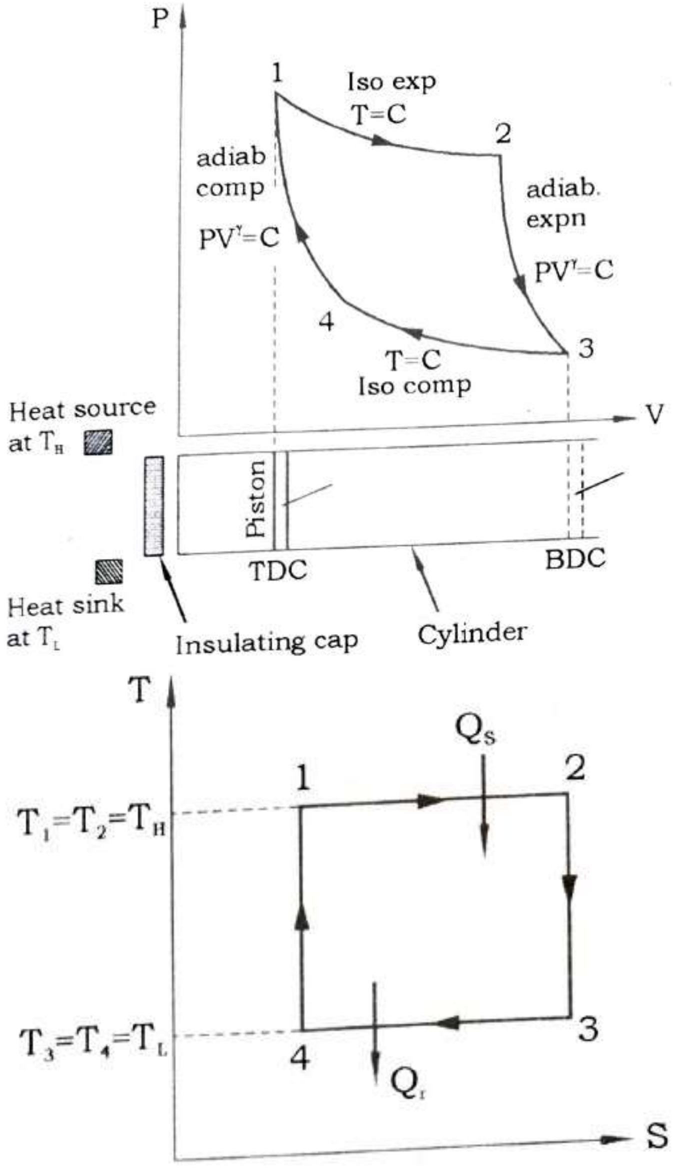
under ideal conditions, we have $PV = mRT$ i.e., $P_1 V_1 = mRT_1$

$$\therefore Q_S = mRT_1 \ln\left(\frac{V_2}{V_1}\right) \quad \text{-----(1)}$$

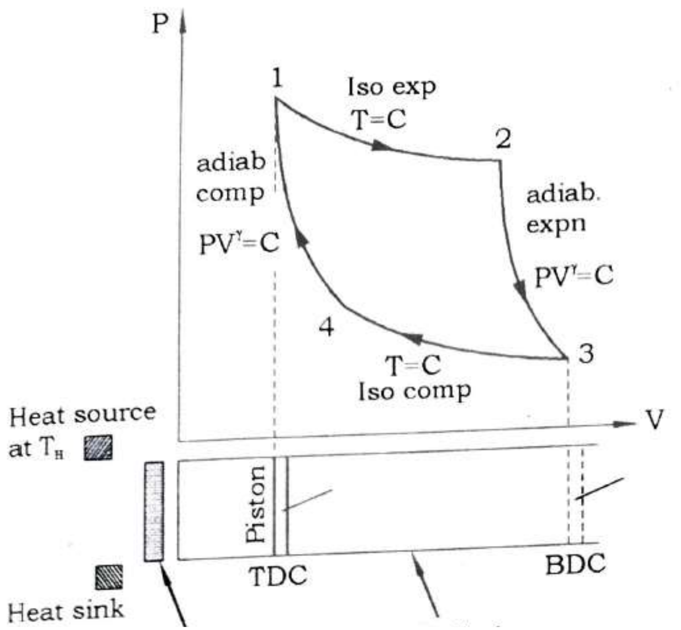
Process 2-3: Adiabatic Expansion

w.k.t. from adiabatic process, heat transfer $Q = 0$

$$\frac{T_2}{T_3} = \left(\frac{V_3}{V_2}\right)^{\gamma-1} \quad \text{-----(2)}$$



Carnot cycle



Process3-4: Isothermal compression

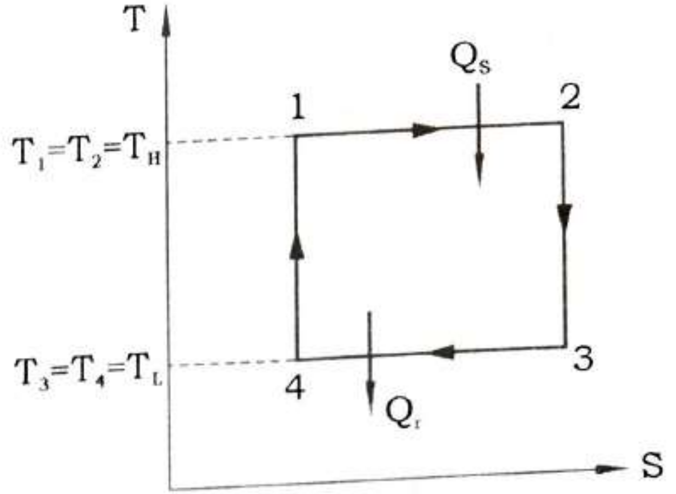
$$\text{Heat rejected} = Q_r = P_3V_3 \ln\left(\frac{V_3}{V_4}\right)$$

$$= mRT_3 \ln\left(\frac{V_3}{V_4}\right) \qquad \text{-----(3)}$$

Process 4-1: Adiabatic compression

w.k.t. for adiabatic process, heat transfer Q = 0

$$\frac{T_4}{T_1} = \left(\frac{V_1}{V_4}\right)^{\gamma-1} \qquad \text{-----(4)}$$



Carnot cycle

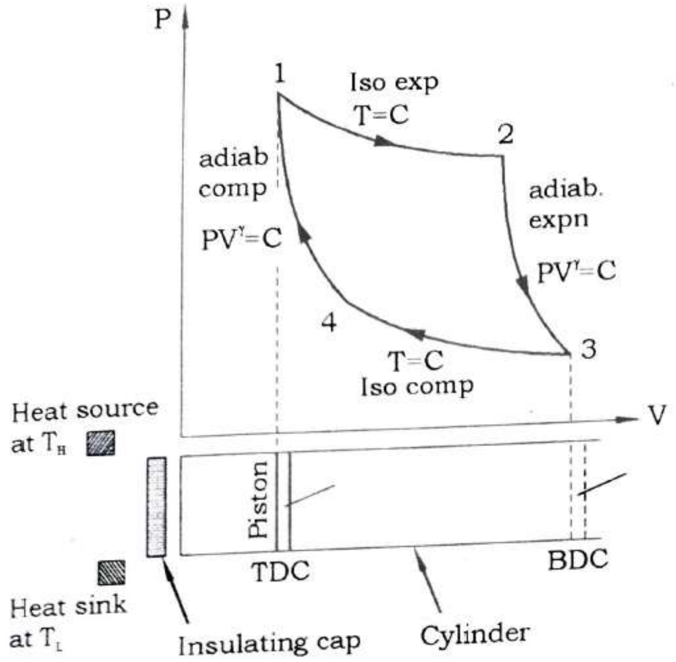
To find air standard efficiency:

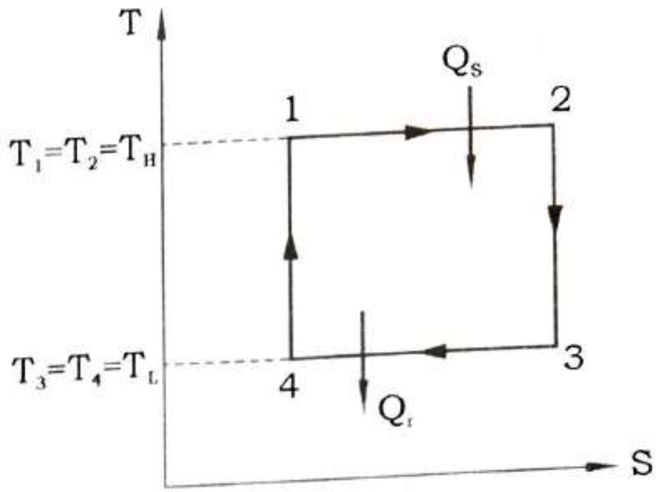
w.k.t. efficiency $\eta_{air} = \dfrac{\text{Work done (WD)}}{\text{Heat supplied } (Q_H)}$

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

$$= \frac{Q_S - Q_r}{Q_S}$$

$$\eta_{air} = 1 - \frac{Q_r}{Q_s} = 1 - \frac{m.RT_3 \ln\left(\frac{V_3}{V_4}\right)}{m.RT_1 \ln\left(\frac{V_2}{V_1}\right)}$$





Carnot cycle

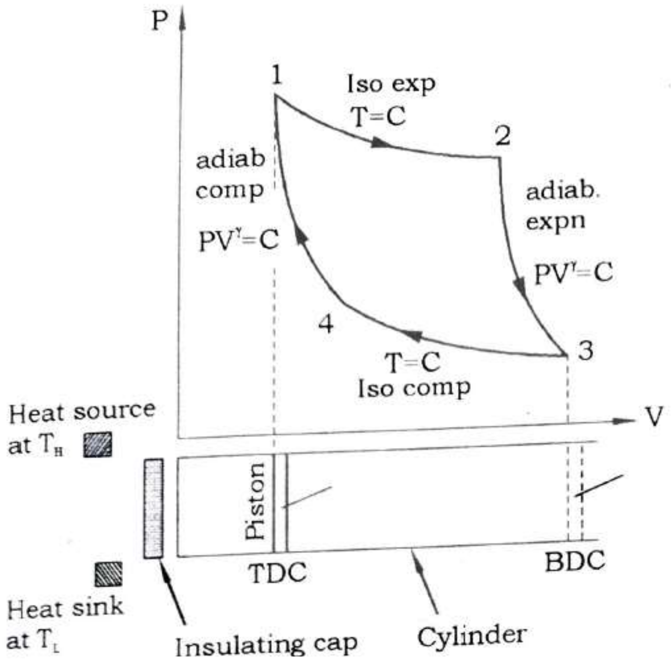
Consider equation (2) $\dfrac{T_2}{T_3} = \left(\dfrac{V_3}{V_2}\right)^{\gamma-1}$

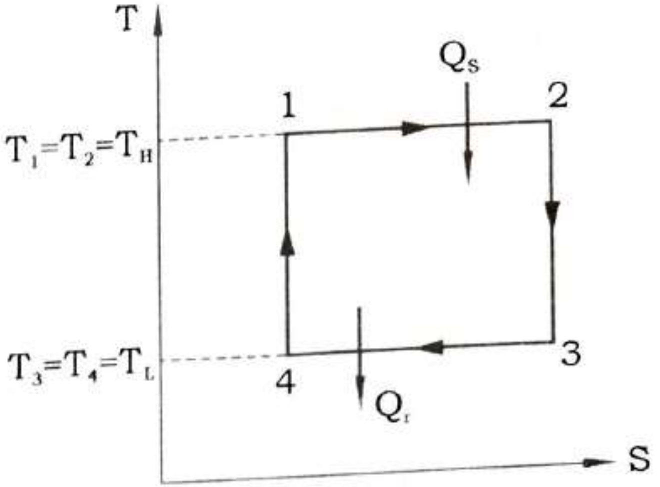
But, from t-s diagram, $T_2 = T_1$ and $T_3 = T_4$

$$\therefore \quad \frac{T_1}{T_4} = \left(\frac{V_3}{V_2}\right)^{\gamma-1}$$

we have $\left(\dfrac{V_1}{V_4}\right)^{\gamma-1} = \left(\dfrac{V_2}{V_3}\right)^{\gamma-1}$

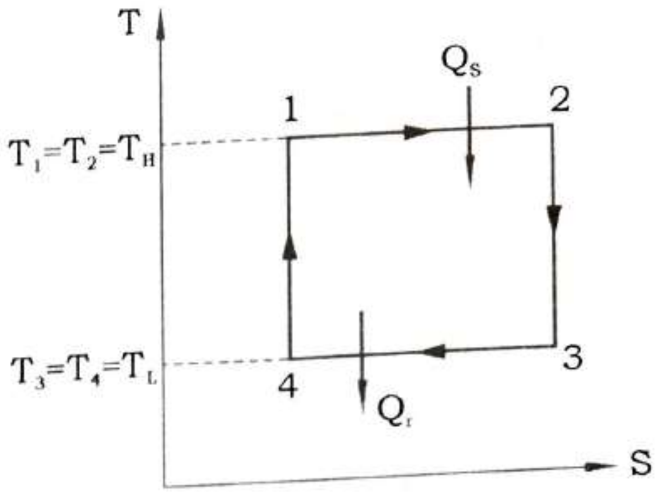
$$\frac{V_1}{V_4} = \frac{V_2}{V_3} \quad \text{or} \quad \frac{V_3}{V_4} = \frac{V_2}{V_1}$$





Carnot cycle

, we get $$\eta_{air} = 1 - \frac{m.RT_3 \ln\left(\frac{V_2}{V_1}\right)}{m.RT_1 \ln\left(\frac{V_2}{V_1}\right)} = 1 - \frac{T_3}{T_1}$$



$$\eta_{air} = 1 - \frac{T_L}{T_H} \quad \text{for Carnot cycle}$$

where $T_L = T_3 = T_4$ = Lowest temperature of the cycle, and
$T_H = T_1 = T_2$ = highest temperature of the cycle

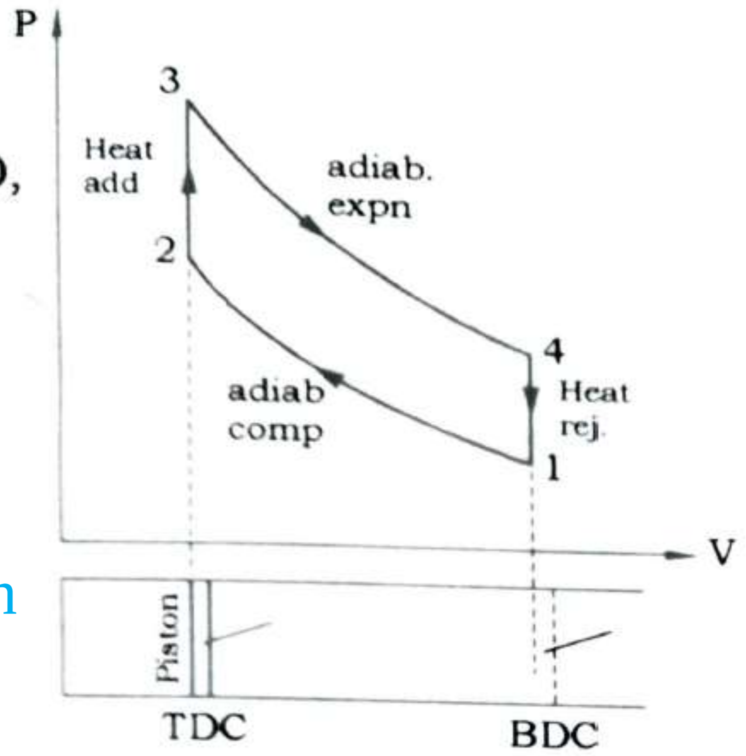
Otto cycle (constant volume cycle)

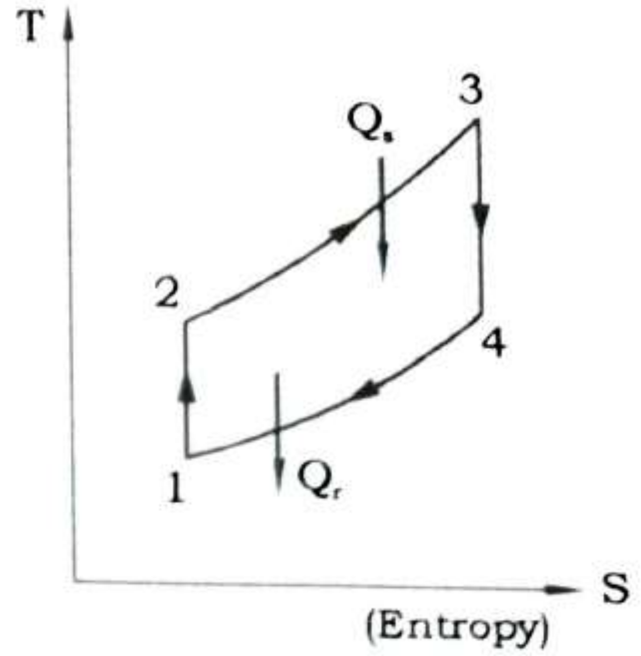
Expression for air standard efficiency in Otto cycle

Process 1-2: Adiabatic compression

w.k.t. for adiabatic process, heat transfer Q = 0,

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





Process 2-3: constant volume heat addition

$$\text{Heat supplied } Q_s = mC_v(T_3 - T_2) \quad \text{-----(2)}$$

Otto cycle (constant volume cycle)

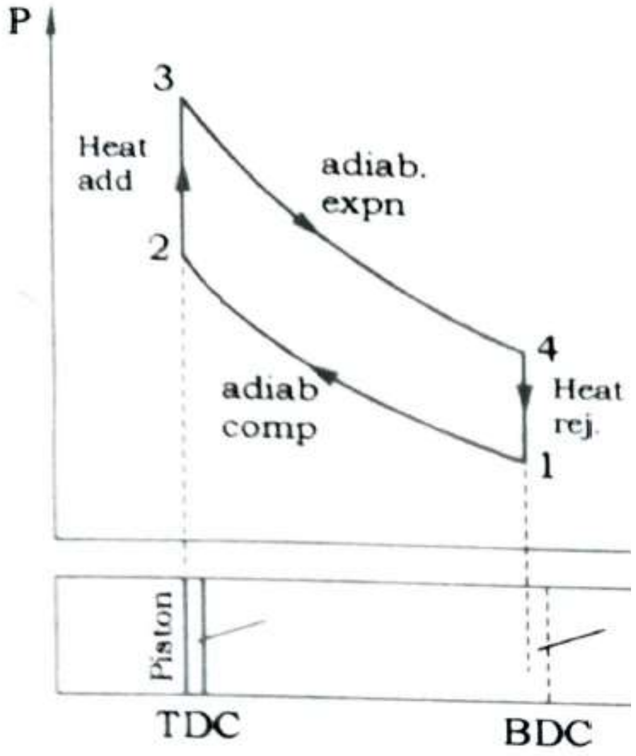
Process 3-4: Adiabatic Expansion

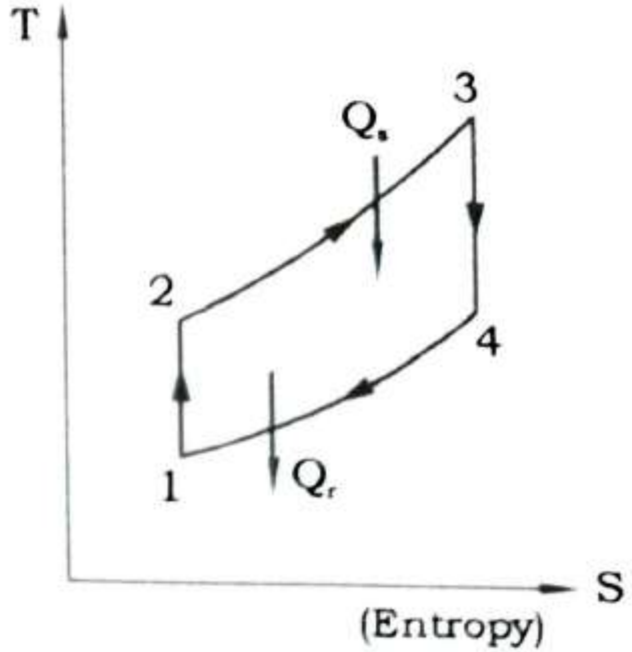
w.k.t. for adiabatic process, heat transfer Q = 0,

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} \qquad \text{-----(3)}$$

Process 4-1: constant volume heat rejection

$$\text{Heat rejected } Q_r = mC_v\,(T_4 - T_1) \qquad \text{-----(4)}$$





Otto cycle (constant volume cycle)

To find air standard efficiency:

w.k.t. efficiency $\eta_{air} = \dfrac{\text{Work done}}{\text{Heat supplied}}$

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

$$= \frac{Q_s - Q_r}{Q_s}$$

i.e., $\eta_{air} = 1 - \dfrac{Q_r}{Q_s} = 1 - \dfrac{mC_V(T_4 - T_1)}{mC_V(T_3 - T_2)}$

$$\eta_{air} = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)}$$

$$= 1 - \frac{\left(\frac{T_4}{T_1} - 1\right)T_1}{\left(\frac{T_3}{T_2} - 1\right)T_2}$$

From equation (1) we have $\dfrac{T_1}{T_2} = \left(\dfrac{V_2}{V_1}\right)^{\gamma-1}$

But $V_2 = V_3$ and $V_1 = V_4$

$\therefore \dfrac{T_1}{T_2} = \left(\dfrac{V_3}{V_4}\right)^{\gamma-1}$ or $\dfrac{T_2}{T_1} = \left(\dfrac{V_4}{V_3}\right)^{\gamma-1}$

Otto cycle (constant volume cycle)

we have $\frac{T_3}{T_4} = \frac{T_2}{T_1}$

$$\frac{T_4}{T_1} = \frac{T_3}{T_2}$$

$$\eta_{air} = 1 - \frac{\left(\frac{T_3}{T_2} - 1\right)T_1}{\left(\frac{T_3}{T_2} - 1\right)T_2}$$

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

Defining compression ratio $R_C = \frac{V_1}{V_2}$,

we have from equation (1),

$$\frac{T_1}{T_2} = \left(\frac{1}{R_C}\right)^{\gamma-1} \quad \text{or} \quad \frac{T_1}{T_2} = \frac{1}{(R_C)^{\gamma-1}}$$

we get $\eta_{air} = 1 - \frac{1}{(R_C)^{\gamma-1}}$ for Otto cycle

Mean Effective Pressure (MEP) for Otto cycle

Mathematically, $MEP = P_m = \dfrac{\text{Work done / cycle}}{\text{Swept volume}}$

$$= \frac{Q_s - Q_r}{V_1 - V_2}$$

$$= \frac{mC_v(T_3 - T_2) - mC_v(T_4 - T_1)}{V_1 - V_2}$$

$$MEP = \frac{mC_v\left[(T_3 - T_2) - (T_4 - T_1)\right]}{V_1 - V_2} \qquad \text{-----(1)}$$

Mean Effective Pressure (MEP) for Otto cycle

Express temperatures T_2 T_3 and T_4 in terms of T_1

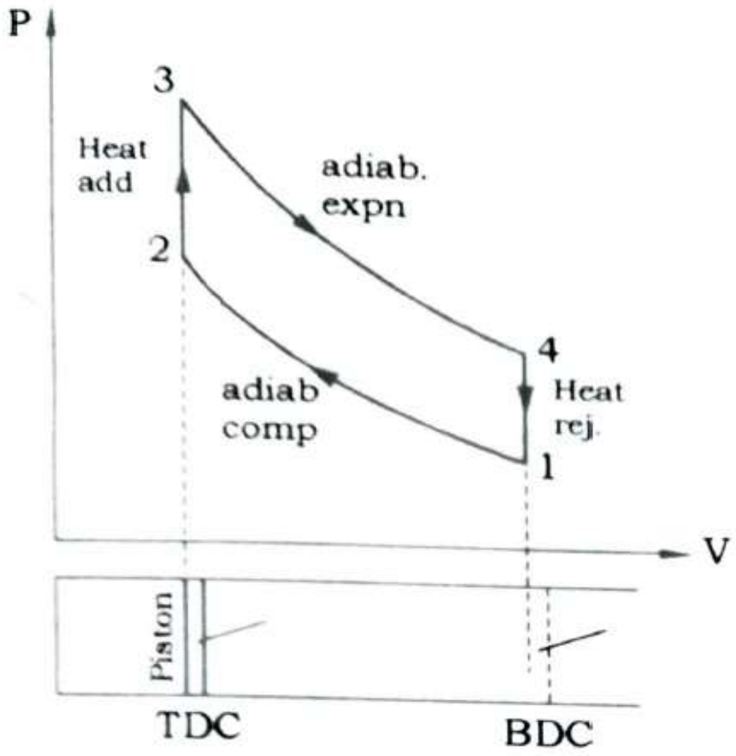
$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1} \quad \text{or} \quad \frac{T_1}{T_2} = \left(\frac{1}{R_C}\right)^{\gamma-1} \quad \left(\because R_C = \frac{V_1}{V_2}\right)$$

$$\therefore \; T_2 = T_1 . (R_C)^{\gamma-1} \quad \text{-----(2)}$$

For constant volume process 2-3,

we have $\dfrac{P}{T}$ = constant.

$$\frac{P_2}{T_2} = \frac{P_3}{T_3} \quad \text{or} \quad \frac{P_3}{P_2} = \frac{T_3}{T_2}$$



Mean Effective Pressure (MEP) for Otto cycle

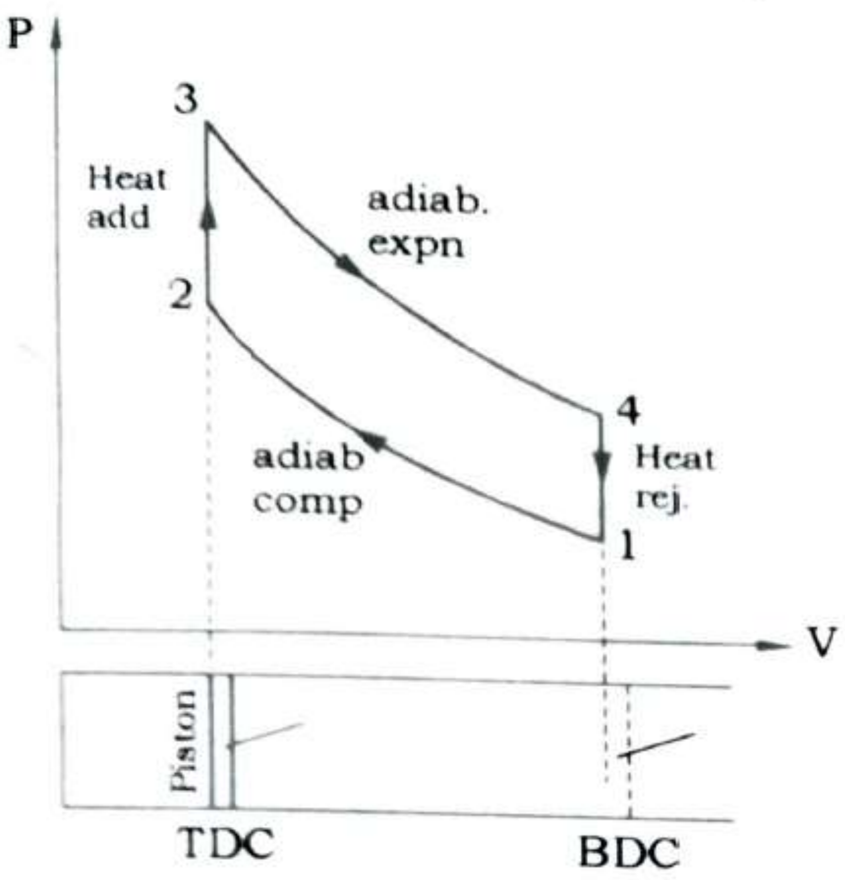
$$\therefore T_3 = T_2 \cdot \left(\frac{P_3}{P_2}\right) = T_2\ \alpha$$

where α = explosion ratio or pressure ratio = $\frac{P_3}{P_2}$

$T_3 = T_1\ (R_C)^{\gamma-1} \cdot \alpha$ from equation (2) -----(3)

For adiabatic process 3-4, we have, $\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1}$

But $V_4 = V_1$ & $V_3 = V_2$



Mean Effective Pressure (MEP) for Otto cycle

$$\therefore \frac{T_3}{T_4} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \quad \text{or} \quad \frac{T_3}{T_4} = (R_C)^{\gamma-1}$$

$$T_4 = \frac{T_3}{(R_C)^{\gamma-1}} = \frac{T_1.(R_C)^{\gamma-1}.\alpha}{(R_C)^{\gamma-1}} \quad \text{from equation (3)}$$

$$\therefore T_4 = T_1\,\alpha \qquad \text{-----(4)}$$

Substituting equations (2), (3) and (4) in (1), we have

$$\text{MEP} = \frac{mC_V\left\{\left[T_1(R_C)^{\gamma-1}.\alpha - T_1(R_C)^{\gamma-1}\right]\right\}}{(V_1 - V_2)}$$

$$= \frac{mC_V.T_1\left[\left(\alpha.R_C^{\gamma-1} - R_C^{\gamma-1}\right) - (\alpha - 1)\right]}{(V_1 - V_2)} \qquad \text{-----(5)}$$

Under ideal conditions, at point (1),

we have $P_1V_1 = mRT_1$, $\quad V_1 = \dfrac{mRT_1}{P_1}$ -----(6)

compression ratio $R_C = \dfrac{V_1}{V_2}$

$$\therefore V_2 = \frac{V_1}{R_C} = \frac{mRT_1}{P_1.R_C} \quad \text{from equation (6)} \qquad \text{-----(7)}$$

Mean Effective Pressure (MEP) for Otto cycle

Substituting equations (6) and (7) in (5), we have

$$MEP = \frac{m.C_V T_1\left[\left(\alpha R_C^{\gamma-1} - R_C^{\gamma-1}\right) - (\alpha - 1)\right]}{\frac{mRT_1}{P_1} - \frac{mRT_1}{P_1 R_C}} = \frac{m.C_V T_1\left[R_C^{\gamma-1}(\alpha-1) - (\alpha-1)\right]}{\frac{mRT_1}{P_1}\left(1 - \frac{1}{R_C}\right)}$$

$$MEP = \frac{P_1 C_V (\alpha - 1)\left[R_C^{\gamma-1} - 1\right]}{R\left[\frac{R_C - 1}{R_C}\right]} \quad \text{-----(8)}$$

w.k.t. Gas constant $R = C_P - C_V$

$$\frac{R}{C_V} = \frac{C_P}{C_V} - 1$$

$$\frac{R}{C_V} = \gamma - 1 \qquad \therefore \frac{C_V}{R} = \frac{1}{\gamma - 1}$$

$$MEP = P_m = \frac{P_1 . R_C (\alpha - 1)\ R_C^{\gamma-1} - 1}{(\gamma - 1)(R_C - 1)}$$

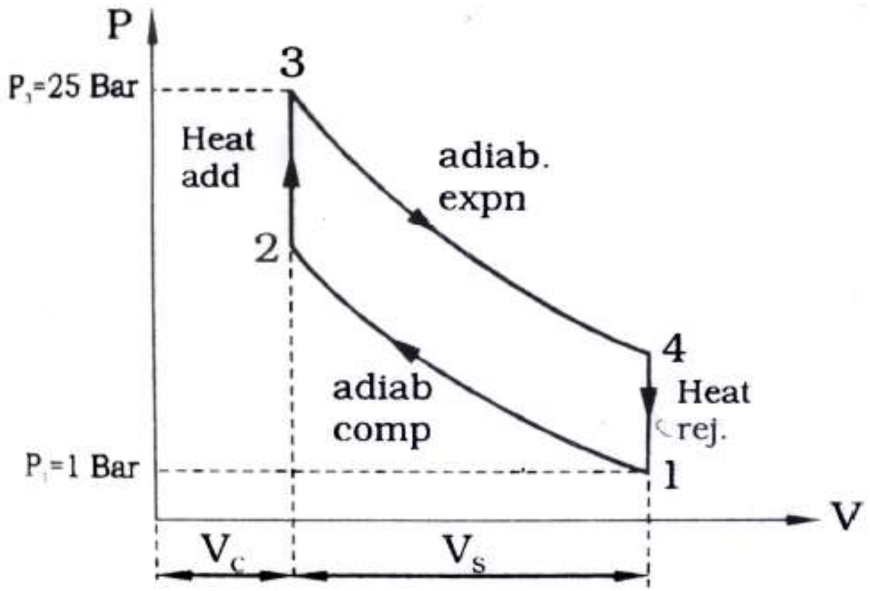
Problems on Otto Cycle

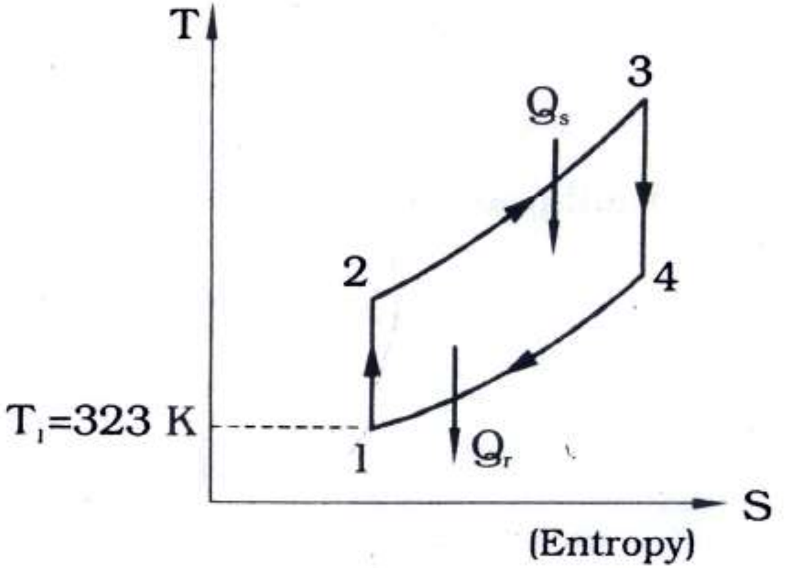
1. A engine of 250 mm bore ad 375 mm stroke works on constant volume cycle, the clearance volume is 0.00263 m3. The initial temperature and pressure are 1 bar and 50ºC. If maximum pressure is 25 bar. Find i) air standard efficiency ii) MEP

bore = d = 250 mm = 0.25 m; stroke = L = 375 mm = 0.375 m

$$\text{Clearance volume} = V_C = 0.00263\ \text{m}^3$$

$$P_1 = 1\ \text{Bar}\ T_1 = 50°\text{C} = 323\ \text{K};\ P_3 = 25\ \text{Bar}$$





Problem -1

w.k.t. for Otto cycle, efficiency $= \eta_{air} = 1 - \dfrac{1}{(R_C)^{\gamma-1}}$

w.k.t. $R_c = \dfrac{V_1}{V_2}$ or $\dfrac{V_S + V_C}{V_C}$

where V_s = Stroke volume $= \dfrac{\pi}{4} d^2 \times L = \dfrac{\pi}{4}(0.25)^2 \times (0.375)$

$= 0.0184\ m^3$

$R_C = \dfrac{0.0184 + 0.00263}{0.00263} \cong 8$

$\eta_{air} = 1 - \dfrac{1}{(8)^{1.4-1}}$

$= 0.564$

η_{air} = **56.4%**

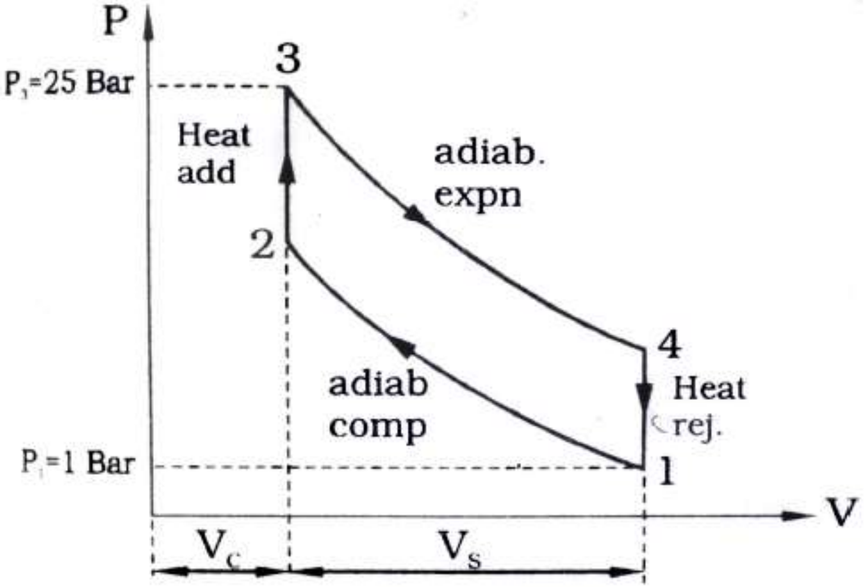
Problem -1

w.k.t. for Otto cycle, MEP = $P_m = \dfrac{P_1 R_C(\alpha-1)\left(R_C^{\gamma-1}-1\right)}{(\gamma-1)(R_C-1)}$

w.k.t. $\alpha = \dfrac{P_3}{P_2}$

w.k.t. for adiabatic process 1-2, $\dfrac{P_1}{P_2} = \left(\dfrac{V_2}{V_1}\right)^{\gamma}$

$P_1 = 1\,\text{Bar}$; $V_2 = V_C$ & $V_1 = V_C + V_S$



Problem -1

$$\therefore \left(\frac{1}{P_2}\right) = \left(\frac{0.00263}{0.00263+0.0184}\right)^{1.4}$$

$$P_2 = 18.36 \text{ Bar}$$

$$\text{MEP} = \frac{\text{W.D / Cycle}}{\text{Stroke Volume}} = \frac{Q_s - Q_r}{V_1 - V_2},$$

$$\alpha = \frac{2.5}{18.36} = 1.36$$

$$\text{MEP} = P_m = \frac{(1)(8)(1.36-1)\left(8^{1.4-1}-1\right)}{(1.4-1)(8-1)}$$

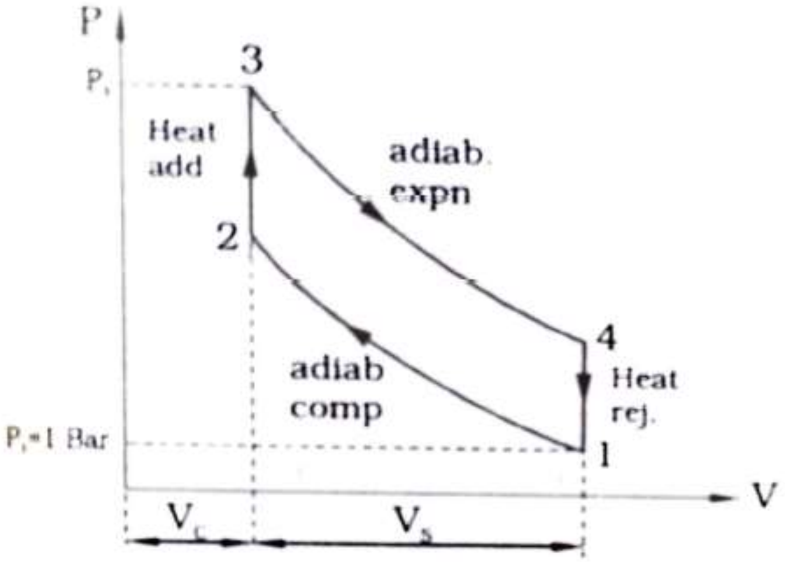
$$= \mathbf{1.33\ Bar}$$

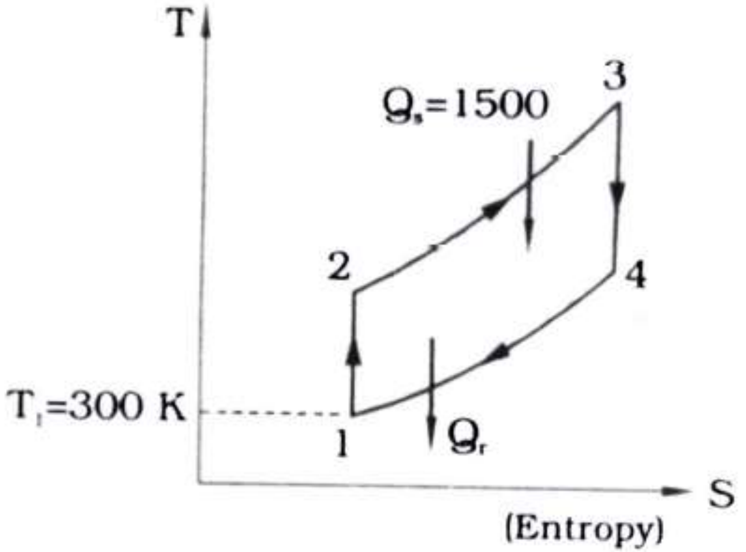
2. The minimum pressure and temperature in an Otto cycle are 100kPa and 27°C. The amount of heat added to the air per cycle is 1500 kJ/kg. Determine a) The pressure and temperature at all points of the air standard Otto cycle. b) The specific work and thermal efficiency of the cycle for a compression ratio of 8:1.

Data Given:

$P_1 = 100\ \text{kPa} = 1 \times 10^2 \times 10^3\ \text{N/m}^2 = 1\ \text{Bar}\ (\because 1\text{Bar} = 10^5\ \text{N/m}^2)\ ;\ T_1 = 27°\text{C} = 300\ \text{K}$

$$Q_s = 1500\ \text{kJ/kg};\quad R_c = \frac{V_1}{V_2} = 8;\quad C_v = 0.72\ \text{kJ/kg},\quad \gamma = 1.4$$





Problem -2

For adiabatic process 1-2, we have $\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^{\gamma}$

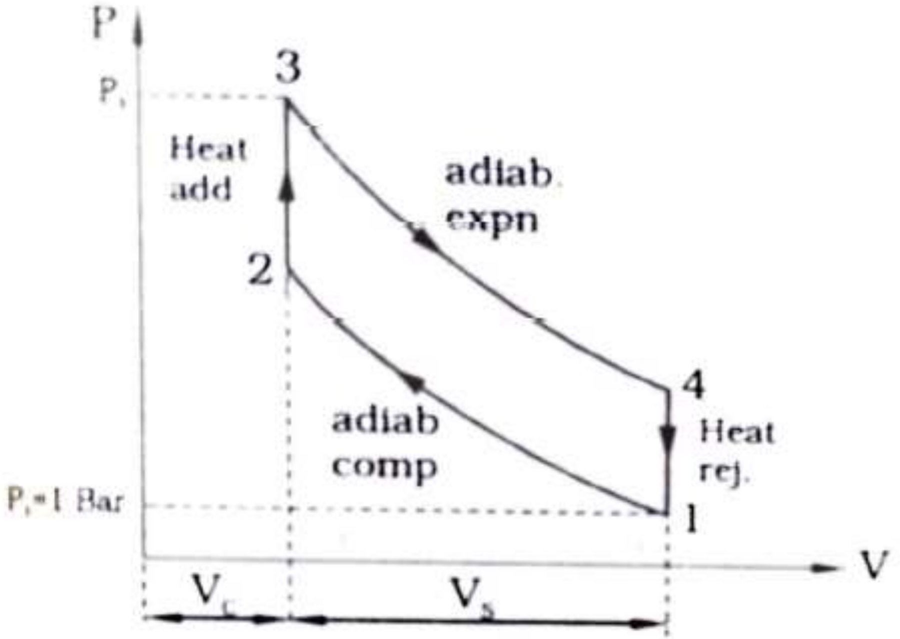
$$\left(\frac{1}{P_2}\right) = \left(\frac{1}{8}\right)^{1.4}$$

$$\mathbf{P_2 = 18.38\ Bar}$$

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

$$\frac{300}{T_2} = \left(\frac{1}{18.38}\right)^{\frac{1.4-1}{1.4}}$$

$$\mathbf{T_2 = 689.22\ K}$$



Problem -2

For process 2-3, we have, $Q_s = mC_v(T_3 - T_2)$

Note that $Q_s = 1500$ kJ/kg, hence mass of air = m = 1kg

$$1500 = 1(0.72)(T_3 - 689.22)$$

$$\therefore \mathbf{T_3 = 2772.5\ K}$$

w.k.t. for constant volume process, $\frac{P}{T} = \text{const}$

$\therefore$ for process 2-3, we have $\frac{P_2}{T_2} = \frac{P_3}{T_3}$

$$\frac{18.38}{689.22} = \frac{P_3}{2772.5}$$

$\mathbf{P_3 = 73.93\ Bar}$

For adiabatic process 3-4,

$$\left(\frac{P_3}{P_4}\right) = \left(\frac{V_4}{V_3}\right)^{\gamma}$$

But $V_4 = V_1$ & $V_3 = V_2$

i.e., $$\left(\frac{P_3}{P_4}\right) = \left(\frac{V_1}{V_2}\right)^{\gamma}$$

$$\left(\frac{73.93}{P_4}\right) = (8)^{1.4}$$

$\mathbf{P_4 = 4.02\ Bar}$

Problem -2

Also, $\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$

$$\frac{2772.5}{T_4} = \left(\frac{73.93}{4.02}\right)^{\frac{1.4-1}{1.4}}$$

$$T_4 = 1206.5\ K$$

P_1 = 1 Bar; P_2 = 18.38 Bar; P_3 = 73.93 Bar; P_4 = 4.02 Bar

T_1 = 300 K; T_2 = 689.22 K; T_3 = 2772.5 K; T_4 = 1206.5 K

w.k.t. Specific work $= Q_s - Q_r$

$$= [mC_v(T_3 - T_2)] - [mC_v(T_4 - T_1)]$$

$$= 1(0.72)\,[(2772.5 - 689.22) - (1206.5 - 300)]$$

Specific work = 847.2 kJ/kg of air

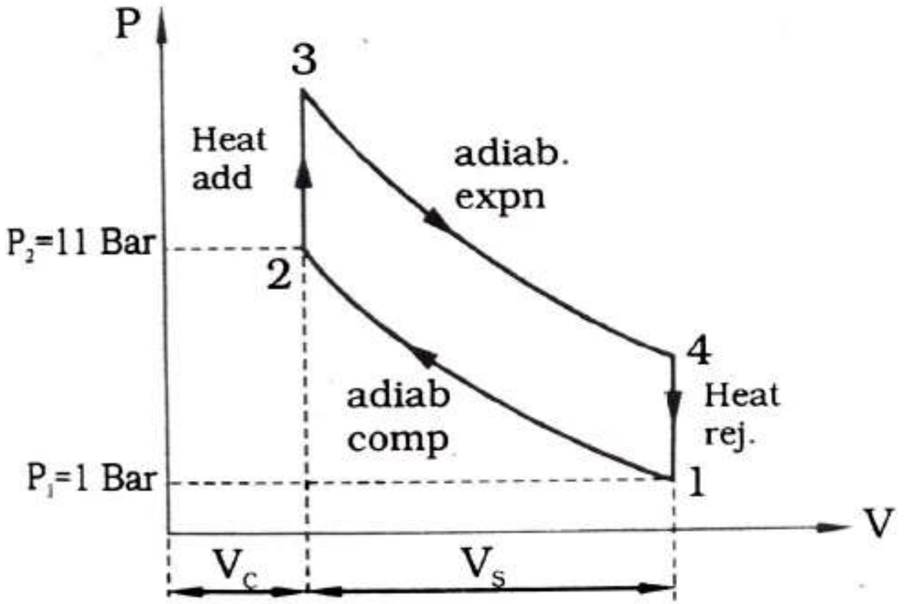
w.k.t. $\eta_{air} = 1 - \frac{1}{(R_C)^{\gamma-1}}$

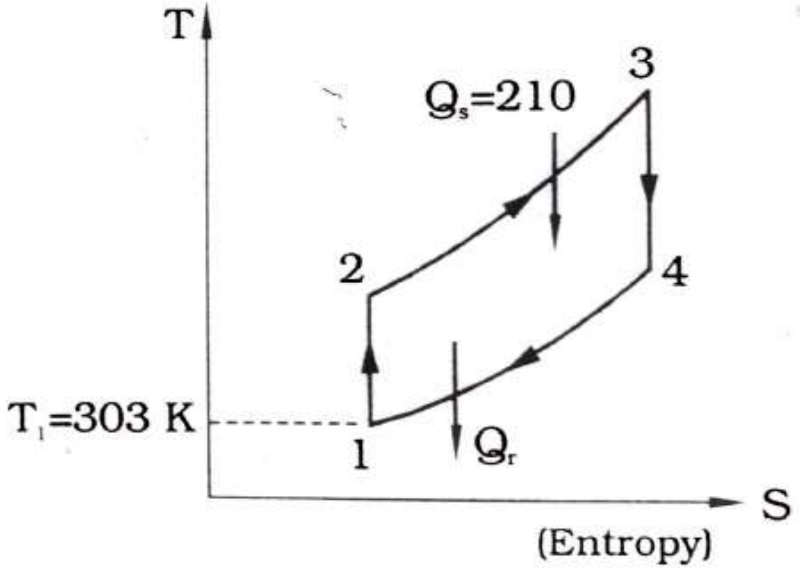
$$= 1 - \frac{1}{(8)^{1.4-1}} = 0.564$$

$$\eta_{air} = 56.4\%$$

3. The pressure, volume and temperature at the beginning of the compression stroke of an Otto cycle engine are respectively 1 bar, 0.45 m^3 & 30ºC. At the end of compression stroke, the pressure is 11 bar & 210kJ of heat is added at constant volume. For the give data, determine the following: a) Pressure, temperature & volume at all salient points of the cycle. b) Percentage clearance c) air standard efficiency d) MEP ideal power developed by the engine, if the number of working cycles/min is 210. Take Cv for air is 0.718 kJ/kg.

Data Given: $P_1 = 1$ Bar, $V_1 = 0.45\ m^3$; $T_1 = 30^3\ C = 303\ K$; $P_2 = 11$ Bar; $Q_s = 210\ kJ$





Problem -3

For adiabatic process 1-2,

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

$$\left(\frac{1}{11}\right) = \left(\frac{V_2}{0.45}\right)^{1.4}$$

$$\mathbf{V_2 = 0.0811\ m^3 = V_3}$$

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

$$\frac{303}{T_2} = \left(\frac{1}{11}\right)^{\frac{1.4-1}{1.4}}$$

$$\mathbf{T_2 = 601.15\ K}$$

For process 2-3, we have, $Q_s = mC_v(T_3 - T_2)$

w.k.t. $PV = mRT$, where $R = 0.287$ kJ/kg K

$P_1V_1 = mRT_1$, $m = 0.517$ kg

$210 = 0.517 \times (0.718)(T_3 - 601.15)$ $T_3 = 1166.8$ K

Problem -3

w.k.t. for constant volume process, $\frac{P}{T}$ = constant

for process 2-3, we have $\frac{P_2}{T_2} = \frac{P_3}{T_3}$

$$P_3 = \frac{P_2 . T_3}{T_2} = \frac{11(1166.8)}{601.15}$$

P_3 **= 21.35 Bar**

w.k.t. for adiabatic process 3-4, $\frac{P_3}{P_4} = \left(\frac{V_4}{V_3}\right)^{\gamma}$

But $V_4 = V_1$ & $V_3 = V_2$

$$\frac{21.35}{P_4} = \left(\frac{0.45}{0.0811}\right)^{1.4}$$

P_4 **= 1.93 Bar**

For constant volume process 4-1, we have $\frac{P_4}{T_4} = \frac{P_1}{T_1}$

$$\frac{1.93}{T_4} = \frac{1}{303}$$

Problem -3

$P_1 = 1$ Bar $\quad T_1 = 303$ K $\quad V_1 = V_4 = 0.45\ m^3$

$P_2 = 11$ Bar $\quad T_2 = 601.15$ K $\quad V_2 = V_3 = 0.0811\ m^3$

$P_3 = 21.35$ Bar $\quad T_3 = 1166.8$ K

$P_4 = 1.93$ Bar $\quad T_4 = 584.8$ K

$$\text{Percentage clearance} = \frac{V_C}{V_S} \times 100$$

$$= \frac{V_2}{V_1 - V_2} \times 100$$

$$= \frac{0.0811}{0.45 - 0.0811} \times 100$$

Percentage clearance = 21.98%

w.k.t. for Otto cycle, efficiency $\eta_{air} = 1 - \dfrac{1}{(R_C)^{\gamma-1}}$

$$R_c = \frac{V_1}{V_2} = \frac{0.45}{0.0811} = 5.54$$

$$\eta_{air} = 1 - \frac{1}{(5.54)^{1.4-1}}$$

$$\eta_{air} = 49.5\%$$

Problem -3

w.k.t. $MEP = P_m = \dfrac{P_1 R_C (\alpha - 1)(R_C^{\gamma-1} - 1)}{(\gamma - 1)(R_C - 1)}$

α = explosion ratio = $\dfrac{P_3}{P_2} = \dfrac{21.35}{11} = 1.94$

$$MEP = \frac{1(5.54)(1.94 - 1)(5.54^{1.4-1} - 1)}{(1.4 - 1)(5.54 - 1)}$$

MEP = 2.82 Bar

Ideal power for 210 working cycles/min

w.k.t. Power = (W.D/cycle) (No. of cycles/sec)

$$= (Q_s - Q_r)\frac{210}{60}$$

$$Q_r = mC_v(T_4 - T_1)\text{ kJ}$$

$$= (0.517)(0.718)(584.8 - 303)$$

$$= 104.6\text{ kJ}$$

$$\text{Power} = (210 - 104.6) \times \frac{210}{60}$$

Power = 368.9 kW

4. From the P-V diagram of a engine working on Otto cycle, it is found that the pressure in the cylinder after 1/8th of the compression stroke is executed is 1.4 bar. After 5/8th of the compression stroke the pressure is 3.5 bar. Compute the compression ratio and the air standard efficiency. Also if the maximum cycle temperature is limited to 1000ºC , find the net work output.

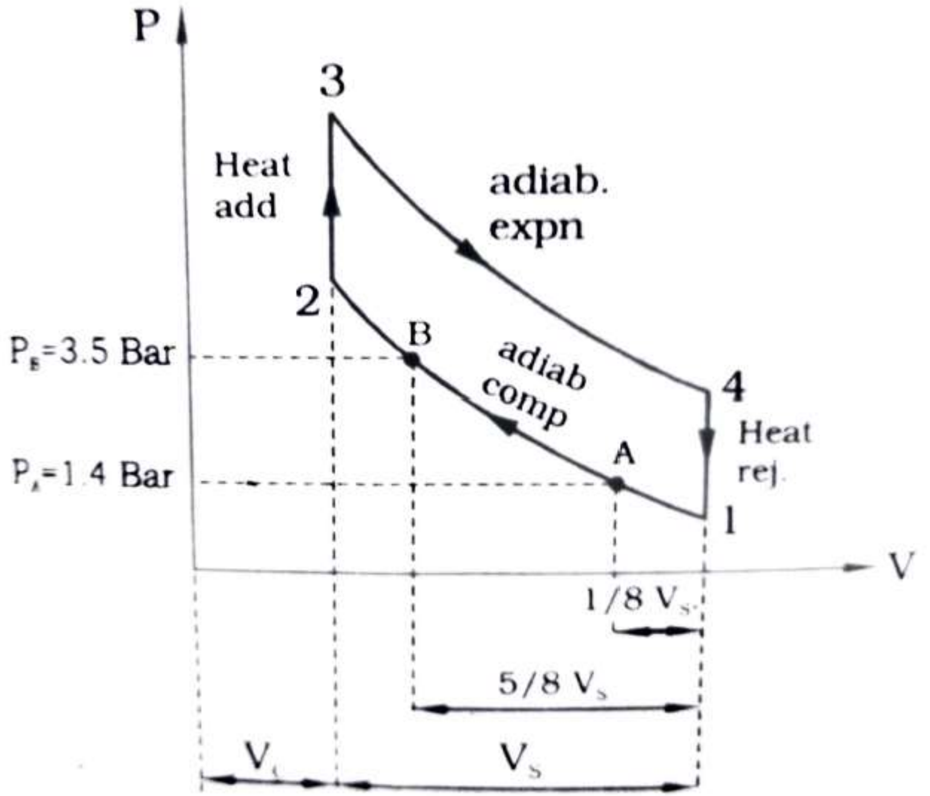
Data Given: $T_3 = 1000°C = 1273\ K$

$$R_C = \frac{V_1}{V_2} = \frac{V_C + V_S}{V_C}$$

$$V_A = V_C + \left(V_S - \frac{1}{8}V_S\right) \qquad V_B = V_C + \left(V_S - \frac{5}{8}V_S\right)$$

For adiabatic process from point *A* to point *B*.

we have $\dfrac{P_A}{P_B} = \left(\dfrac{V_B}{V_A}\right)^{\gamma}$



Problem -4

$$\frac{1.4}{3.5} = \left(\frac{V_C + V_S - \frac{5}{8}V_S}{V_C + V_S - \frac{1}{8}V_S}\right)^{1.4}$$

$$\left(\frac{1.4}{3.5}\right)^{1/1.4} = \left(\frac{V_C + \frac{3}{8}V_S}{V_C + \frac{7}{8}V_S}\right)$$

$$0.519 = \frac{8V_C + 3V_S}{8V_C + 7V_S}$$

$$4.152\,V_c + 3.633\,V_s = 8\,V_c + 3\,V_s$$

$$\frac{V_S}{V_C} = 6.07$$

we have, $R_c = \frac{V_C + V_S}{V_C} = 1 + \frac{V_S}{V_c}$

Compression ratio = R_c = 7.07

w.k.t. $\eta_{air} = 1 - \frac{1}{(R_C)^{\gamma-1}}$

$$= 1 - \frac{1}{(7.07)^{1.4-1}}$$

$$\eta_{air} = 54.2\%$$

Problem -4

w.k.t. net work output = work done = $Q_s - Q_r$

$$= [mC_v(T_3 - T_2)] - [mC_v(T_4 - T_1)]$$

$$W.D = mC_v[(T_3 - T_2) - (T_4 - T_1)]$$

Assume $m = 1$ kg & $C_v = 0.718$ kJ/kg K.

$$T_1 = 27 + 273 = 300 \text{ K}$$

we have $\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$ $\qquad \frac{300}{T_2} = \left(\frac{1}{R_C}\right)^{1.4-1}$

$$\frac{300}{T_2} = \left(\frac{1}{7.07}\right)^{0.4}$$

$$T_2 = 655.97 \text{ K}$$

for adiabatic process 3-4, we have, $\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1}$

But $V_3 = V_2$ & $V_4 = V_1$

$$\therefore \quad \frac{T_3}{T_4} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \qquad \frac{1273}{T_4} = (7.07)^{1.4-1}$$

$$T_4 = 582.18 \text{ K}$$

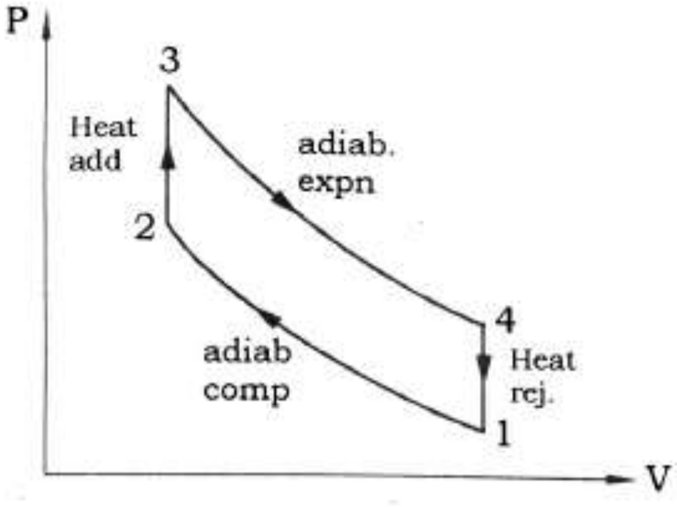
Problem -4

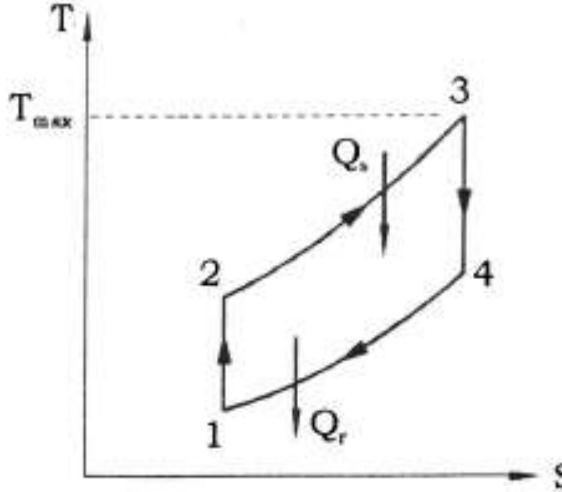
$$\text{Net work output} = 1(0.718)\,[(1273 - 655.97) - (582.18 - 300)]$$

$$\textbf{Net work output} = \mathbf{240.42\ kJ/kg\ of\ air}$$

5. Show that the optimum compression ratio for maximum network output in an Otto cycle is given by Rc= $(\frac{T_3}{T_1})^{1.25}$ and the intermediate temperatures for maximum work is given by $T_2 = T_4 = \sqrt{T_3 T_1}$

w.k.t. compression ratio $R_c = \frac{V_1}{V_2}$





W = net work done = Heat supplied (Q_s) – Heat rejected (Q_r)

$$= mC_v(T_3 - T_2) - mC_v(T_4 - T_1)$$

For maximum work output, $\frac{dW}{dR_C} = 0$

Problem -5

For adiabatic process 1-2, we have, $\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$

$$T_2 = T_1 . (R_C)^{\gamma-1}$$

Similarly, for adiabatic process 3-4, we have $\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1}$

$$\therefore \frac{T_3}{T_4} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \quad \text{or} \quad T_4 = \frac{T_3}{(R_C)^{\gamma-1}}$$

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

Problem -5

network done $W = mC_V\left[T_3 - T_1(R_C)^{\gamma-1}\right] - mC_V\left[T_3(R_C)^{1-\gamma} - T_1\right]$

For maximum work output, $\frac{dW}{dR_C} = 0$

Differentiating with respect to R_C and equating to zero we have,

$$\frac{dW}{dR_C} = mC_V\left[-T_1.(\gamma-1)\,R_C^{\gamma-1-1}\right] - mC_V\left[T_3(1-\gamma)\,R_C^{1-\gamma-1}\right] = 0$$

$$mC_V\left[-T_1.(\gamma-1)\,R_C^{\gamma-2}\right] = mC_V\left[T_3(1-\gamma)\,.R_C^{-\gamma}\right]$$

$$-T_1(\gamma-1)R_C^{\gamma-2} = -T_3(\gamma-1)R_C^{-\gamma}$$

$$T_1\ R_C^{\gamma-2} = T_3\ R_C^{-\gamma}$$

Problem -5

$$\therefore \frac{T_3}{T_1} = \frac{R_C^{\gamma-2}}{R_C^{-\gamma}}$$

$$= R_C^{\gamma-2+\gamma}$$

$$= R_C^{2\gamma-2} = R_C^{2(\gamma-1)}$$

$$\text{i.e., } \frac{T_3}{T_1} = R_C^{2(\gamma-1)} \qquad \therefore R_C = \left(\frac{T_3}{T_1}\right)^{\frac{1}{2(\gamma-1)}}$$

γ for air = 1.4, $\qquad R_C = \left(\frac{T_3}{T_1}\right)^{1.25}$

Problem -5

we have $\frac{T_2}{T_1} = \frac{T_3}{T_4}$ $\quad \therefore T_4 = \frac{T_1 T_3}{T_2}$ $\quad T_2 = \frac{T_1 T_3}{T_4}$

W = net work done = Heat supplied (Q_s) – Heat rejected (Q_r)

$$= mC_V(T_3 - T_2) - mC_V(T_4 - T_1)$$

$$W = mC_V(T_3 - T_2) - mC_V\left(\frac{T_1 T_3}{T_2} - T_1\right)$$

$$W = mC_V\left[(T_3 - T_2) - \left(\frac{T_1 T_3}{T_2} - T_1\right)\right]$$

The intermediate temperature T_2 for maximum work output can be obtained using the condition $\frac{dW}{dT_2} = 0$

Problem -5

$$\therefore \frac{dW}{dT_2} = mC_v \cdot \frac{d}{dT_2}\left[(T_3 - T_2) - \left(\frac{T_1T_3}{T_2} - 1\right)\right] = 0$$

$$mC_v \quad -1 - T_1 T_3 \quad \frac{-1}{T_2^2} \quad = 0$$

$$-1 + \frac{T_1 T_3}{T_2^2} = 0$$

$$\frac{T_1 T_3}{T_2^2} = 1$$

$$\therefore T_2 = \sqrt{T_1 T_3}$$

$$\frac{dW}{dT_4} = m.C_v \frac{d}{dT_4} \quad T_3 - \frac{T_1T_3}{T_4} \quad -(T_4 - T_1) = 0$$

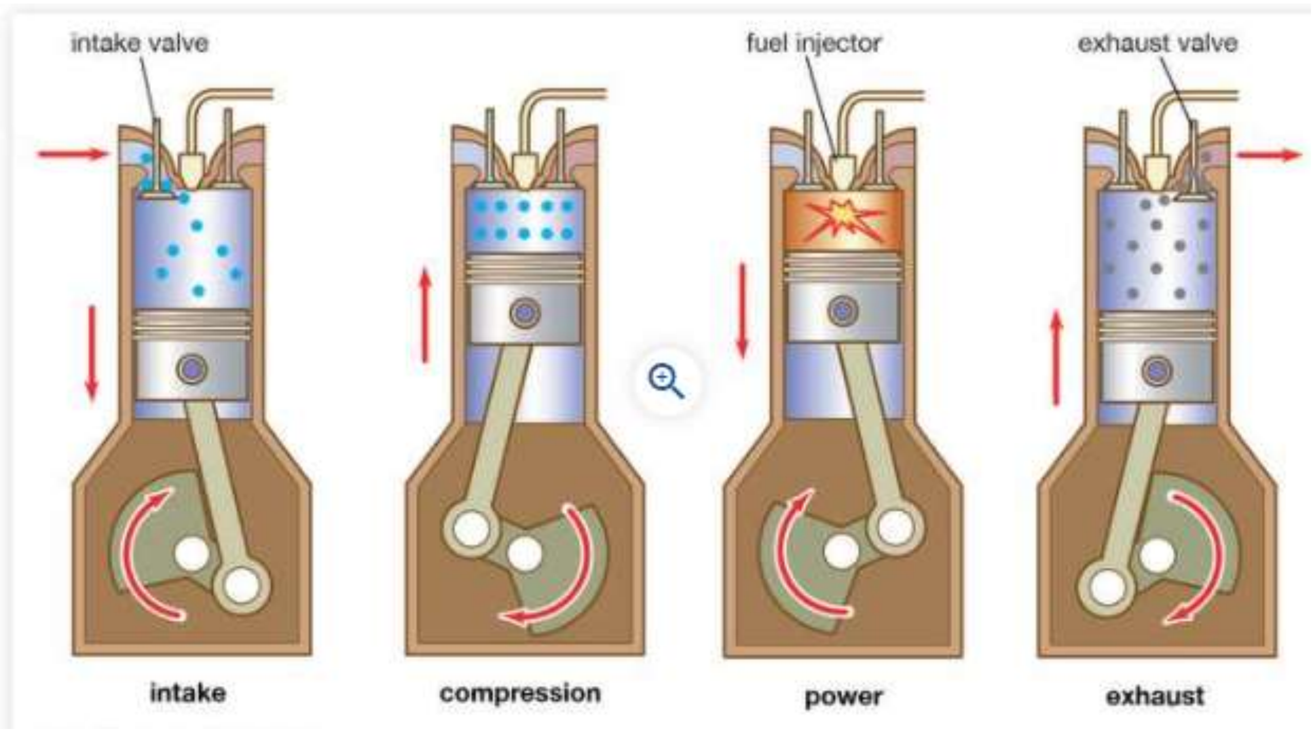
$$mC_v \quad -T_1 T_3 \quad \frac{-1}{T_4^2} \quad -1 \quad = 0$$

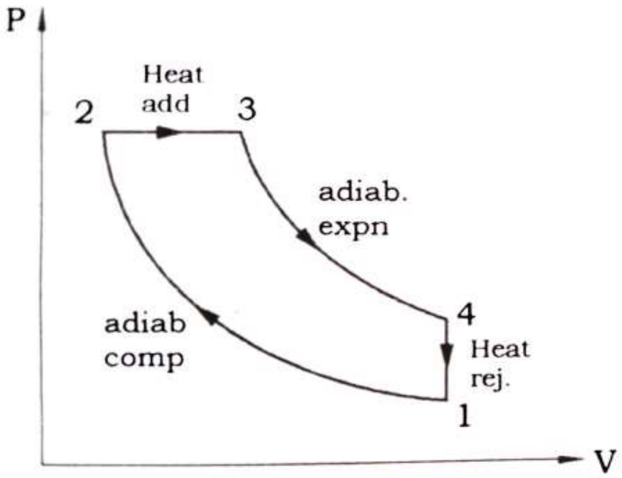
$$\frac{T_1 T_3}{T_4^2} = 1$$

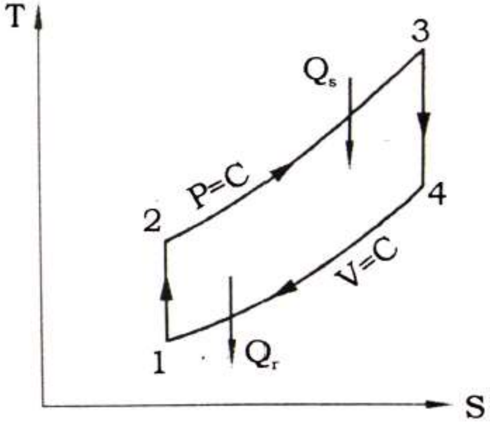
$$\therefore T_4 = \sqrt{T_1 T_3}$$

Diesel cycle (Constant Pressure cycle)

Expression for air standard efficiency in Diesel cycle



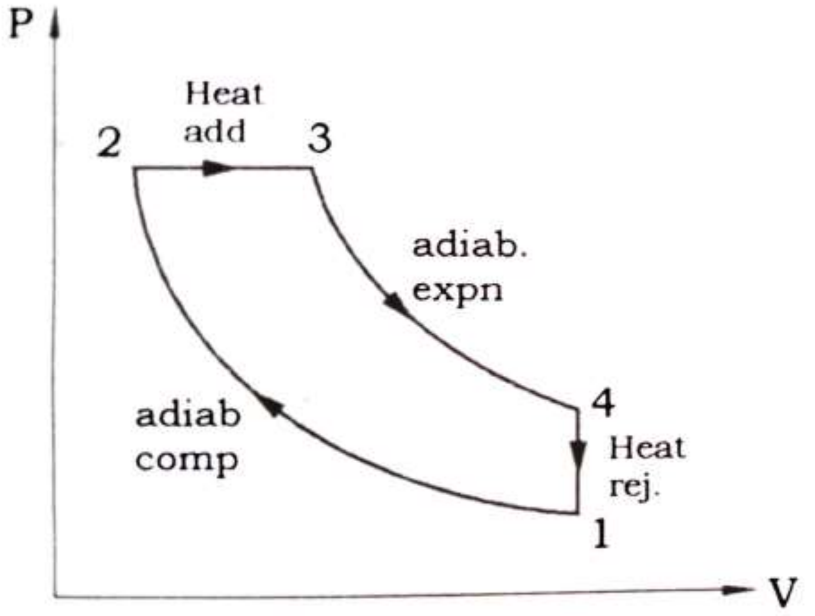




Diesel cycle (constant Pressure cycle)

Process 1-2: Adiabatic compression

heat transfer Q = 0, and $\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$ -----(1)



Process 2-3: constant Pressure heat addition

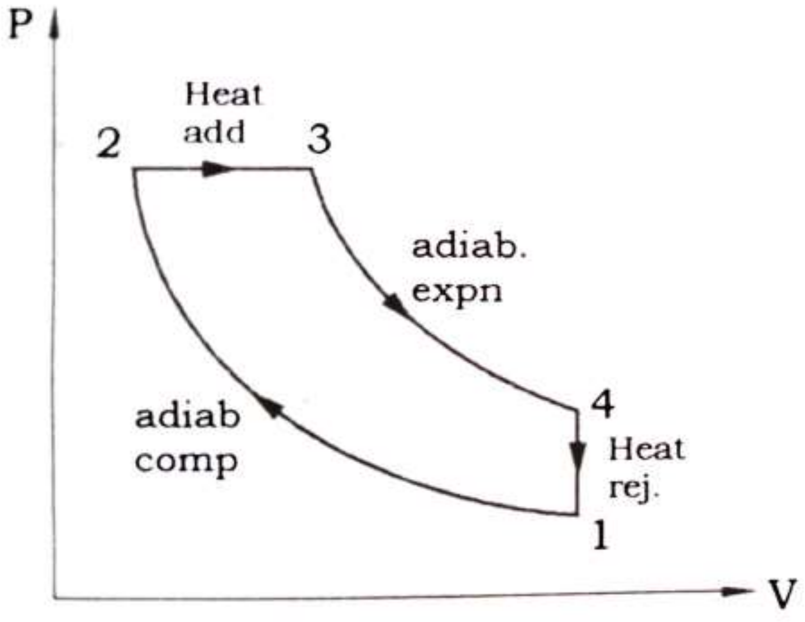
Heat supplied at constant pressure = $Q_s = mC_P(T_3 - T_2)$ -----(2)

Diesel cycle (constant Pressure cycle)

Process 3-4: Adiabatic Expansion

w.k.t. for adiabatic process, heat transfer Q = 0,

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} \qquad \text{-----(3)}$$



Process 4-1: constant volume heat rejection

$$\text{Heat rejected } Q_r = mC_V (T_4 - T_1) \qquad \text{-----(4)}$$

Diesel cycle (constant Pressure cycle)

w.k.t. $\eta_{air} = \frac{\text{Work done}}{\text{Heat supplied}}$

$$= \frac{Q_s - Q_r}{Q_s} = 1 - \frac{Q_r}{Q_s}$$

$$\eta_{air} = 1 - \frac{mC_V(T_4 - T_1)}{m.C_P(T_3 - T_2)}$$

$$\frac{C_P}{C_V} = \gamma$$

$$\therefore \eta_{air} = 1 - \frac{1(T_4 - T_1)}{\gamma(T_3 - T_2)}$$

Express temperatures T_2 T_3 and T_4 in terms of T_1

From equation (1), $\frac{T_1}{T_2} = \left(\frac{1}{R_C}\right)^{\gamma-1}$

$\because R_C = \frac{V_1}{V_2}$ = compression ratio

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

For constant pressure process 2-3, $\frac{V}{T}$ = constant

$$\frac{V_2}{T_2} = \frac{V_3}{T_3} \quad \text{or} \quad \frac{T_3}{T_2} = \frac{V_3}{V_2}$$

Diesel cycle (constant Pressure cycle)

Defining cut-off ratio $\rho = \frac{V_3}{V_2}$,

$$T_3 = T_2\left(\frac{V_3}{V_2}\right) = T_2\,\rho$$

$$T_3 = T_1\,(R_C)^{\gamma-1}.\rho$$

From equation (3), $\frac{T_3}{T_4} = \left(\frac{V_1}{V_3}\right)^{\gamma-1}$

or $\frac{T_3}{T_4} = \left(\frac{V_1}{V_2}.\frac{V_2}{V_3}\right)^{\gamma-1}$

$$\frac{T_3}{T_4} = R_C^{\gamma-1}.\frac{1}{\rho^{\gamma-1}} \qquad T_4 = T_3.\frac{\rho^{\gamma-1}}{(R_C)^{\gamma-1}}$$

we have $T_4 = T_1.(R_C)^{\gamma-1}\rho\,\frac{\rho^{\gamma-1}}{(R_C)^{\gamma-1}}$

$$\therefore T_4 = T_1\,\rho^{\gamma}$$

$$\therefore \eta_{air} = 1 - \frac{1(T_4 - T_1)}{\gamma\,(T_3 - T_2)}$$

$$\eta_{air} = 1 - \frac{1}{\gamma}\,\frac{(T_1\,\rho^{\gamma} - T_1)}{(T_1\,R_C^{\gamma-1}\rho - T_1\,R_C^{\gamma-1})}$$

$$= 1 - \frac{1}{\gamma}\,\frac{T_1\,(\rho^{\gamma} - 1)}{T_1\,R_C^{\gamma-1}(\rho - 1)}$$

$$.\ \eta_{air} = 1 - \frac{1}{\gamma.(R_C)^{\gamma-1}}.\frac{(\rho^{\gamma} - 1)}{(\rho - 1)}$$

Mean Effective Pressure (MEP) for Diesel cycle

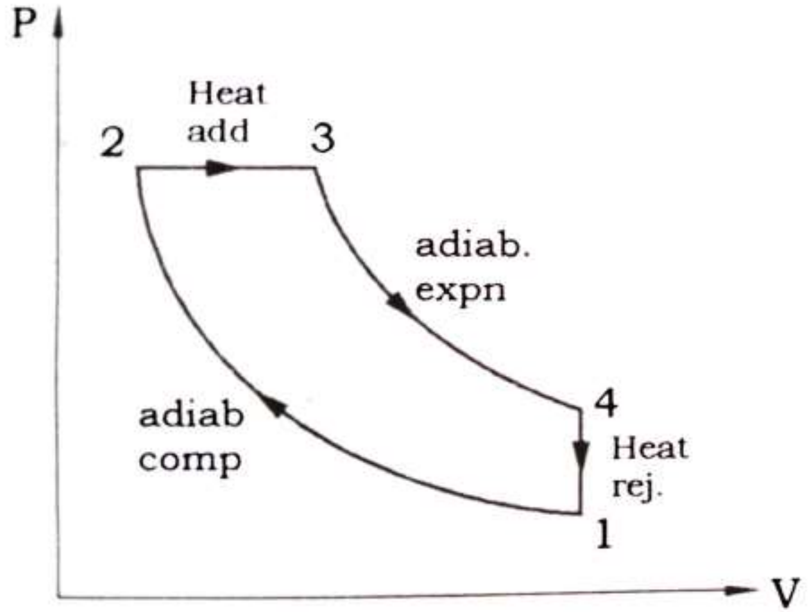
$$P_m = \frac{\text{Work done / cycle}}{\text{swept volume}}$$

$$= \frac{Q_s - Q_r}{V_1 - V_2}$$

$$= \frac{mC_p(T_3 - T_2) - mC_v(T_4 - T_1)}{V_1 - V_2}$$

Express all temperature in terms of T_1

$$MEP = \frac{P_1 R_C \left\{ \gamma R_C^{\gamma-1}(\rho - 1) - \rho^\gamma - 1 \right\}}{(\gamma - 1)(R_C - 1)}$$

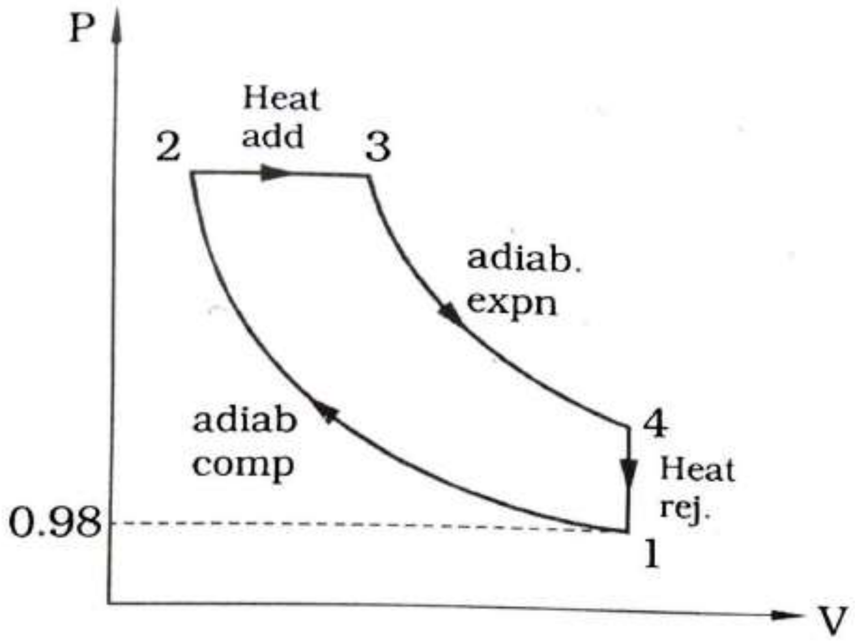


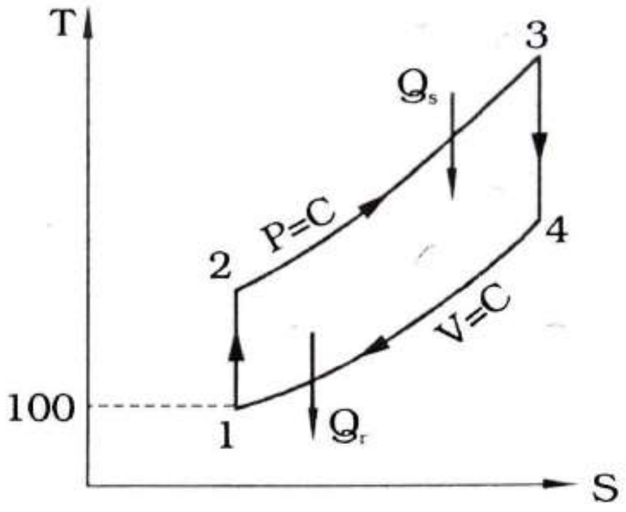
Problems on Diesel Cycle

1. The compression ratio of a diesel cycle is 14 and cut-off ratio is 2.2. At the beginning of the cycle, air is at 0.98 bar and 100ºC. Find (a)Temperature and Pressure at salient points (b) Air standard efficiency.

Data Given:

Compression ratio $R_C = \frac{V_1}{V_2} = 14$; Cut-off ratio $= \rho = \frac{V_3}{V_2} = 2.2$ $P_1 = 0.98$ Bar, $T_1 = 100°C = 373$ K





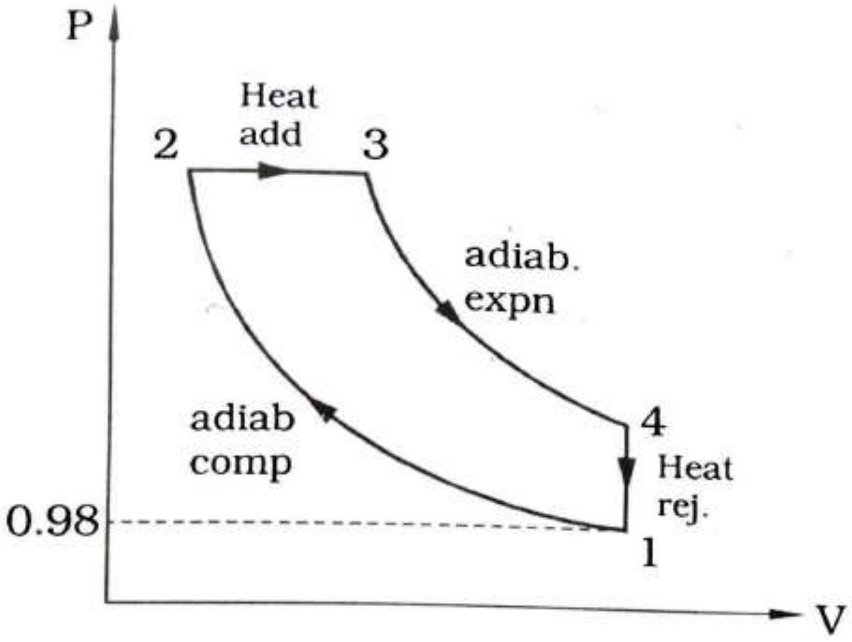
Problem -1

To find temperature and pressure at all points

For adiabatic process 1–2, we have $\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$

$$\frac{373}{T_2} = \left(\frac{1}{14}\right)^{1.4-1}$$

$\mathbf{T_2 = 1071.9\ K}$



Also, for process 1-2, we have, $\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^{\gamma}$

$$\frac{0.98}{P_2} = \left(\frac{1}{14}\right)^{1.4}$$

$\mathbf{P_2 = 39.4\ Bar = P_3}$ **(Constant pressure)**

Problem -1

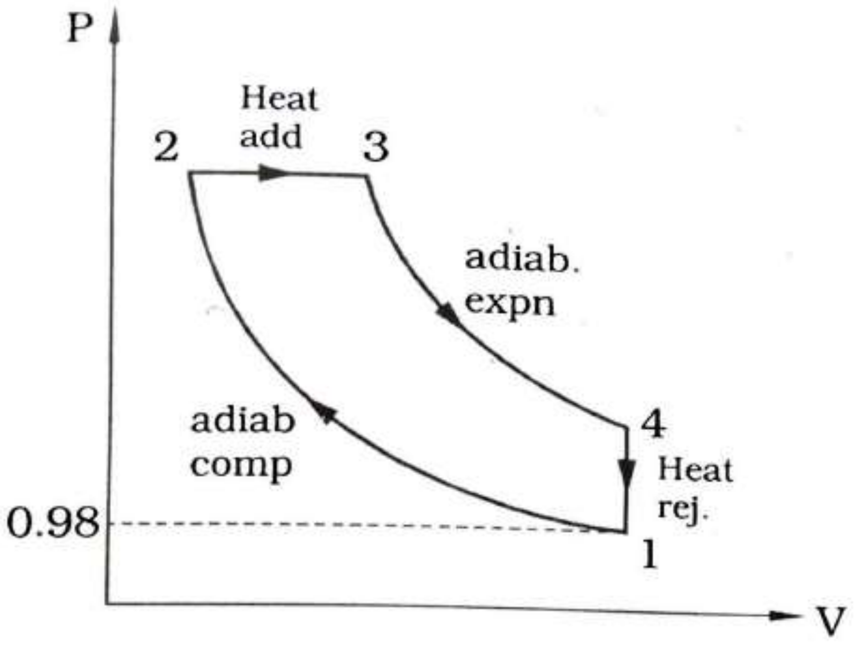
w.k.t. for constant pressure process $\frac{V}{T} = \text{Const}$

$\therefore$ For process 2-3, we have $\frac{V_2}{T_2} = \frac{V_3}{T_3}$

$$\therefore \; T_3 = T_2\left(\frac{V_3}{V_2}\right)$$

$$= 1071.9\,(2.2)$$

$$\mathbf{T_3 = 2358.2\ K}$$



Problem -1

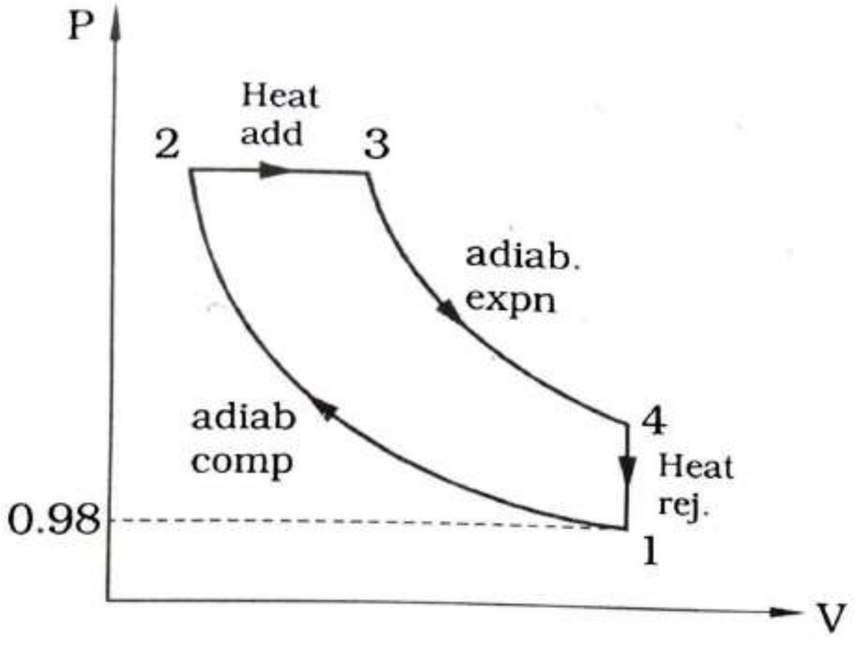
w.k.t. for adiabatic process 3-4, $\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1}$

$$\frac{23582}{T_4} = \left(\frac{V_4}{V_2} \cdot \frac{V_2}{V_3}\right)^{\gamma-1}$$

But $V_4 = V_1$

$$\frac{23582}{T_4} = \left(\frac{V_1}{V_2} \cdot \frac{V_2}{V_3}\right)^{1.4-1}$$

$$\frac{23582}{T_4} = \left(R_C \cdot \frac{1}{\rho}\right)^{0.4}$$



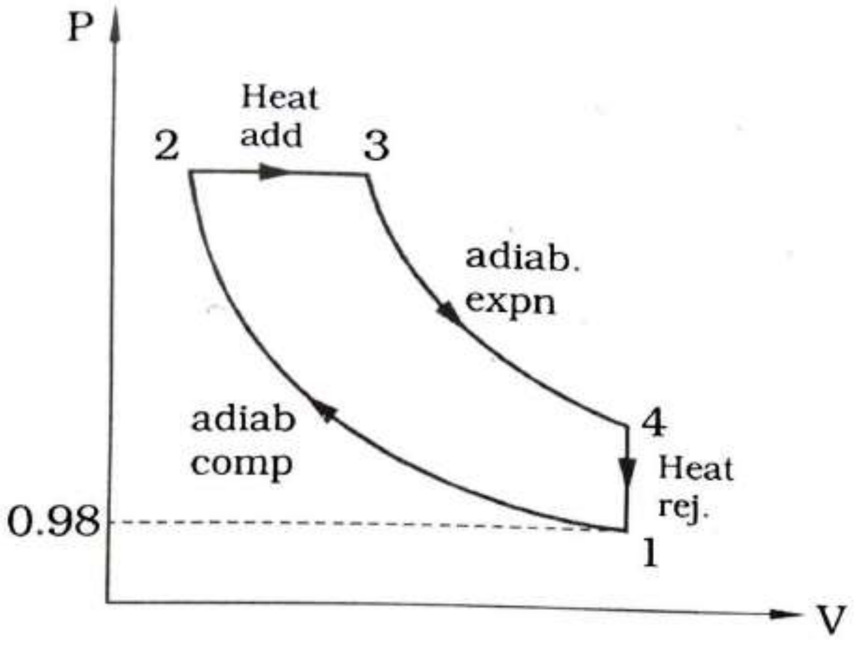
$$\therefore \; T_4 = 1124.8 \text{ K}$$

Problem -1

Also, for process 3-4, we have $\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$

$$\frac{2358.2}{1124.8} = \left(\frac{39.4}{P_4}\right)^{\frac{1.4-1}{1.4}}$$

$P_4 = 2.95$ **Bar**



Thus, $P_1 = 0.98$ **Bar** $T_1 = 373$ **K**

$P_2 = P_3 = 39.4$ **Bar** $T_2 = 1071.9$ **K**

$P_4 = 2.95$ **Bar** $T_3 = 2358.2$ **K** and $T_4 = 1124.8$ **K**

Problem -1

To find air standard efficiency

w.k.t. for Diesel cycle, $\eta = 1 - \frac{1}{\gamma (R_C)^{\gamma-1}} \left[\frac{\rho^{\gamma} - 1}{\rho - 1}\right]$

$$= 1 - \frac{1}{1.4(14)^{1.4-1}} \left[\frac{2.2^{1.4} - 1}{2.2 - 1}\right] = 0.582$$

$$\eta = \frac{\text{Work done}}{\text{Heat Suppleid}} = \frac{Q_s - Q_r}{Q_s}$$

where $Q_s = mC_p(T_3 - T_2) = 1(1.005)\ (2358.2 - 1071.9) = 1292.73$ kJ

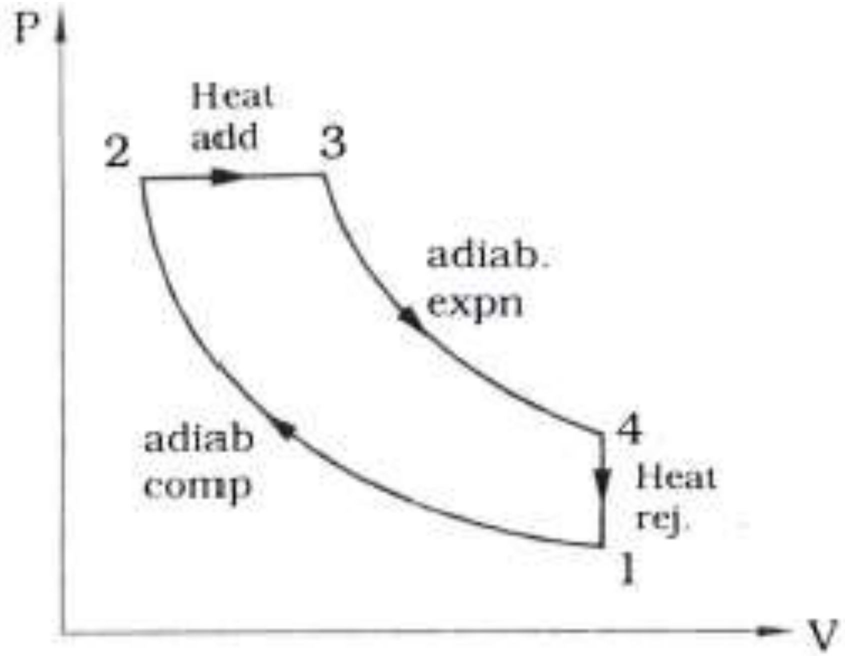
and $Q_r = mC_v(T_4 - T_1) = 1(0.718)(1124.8 - 373) = 539.79$ kJ

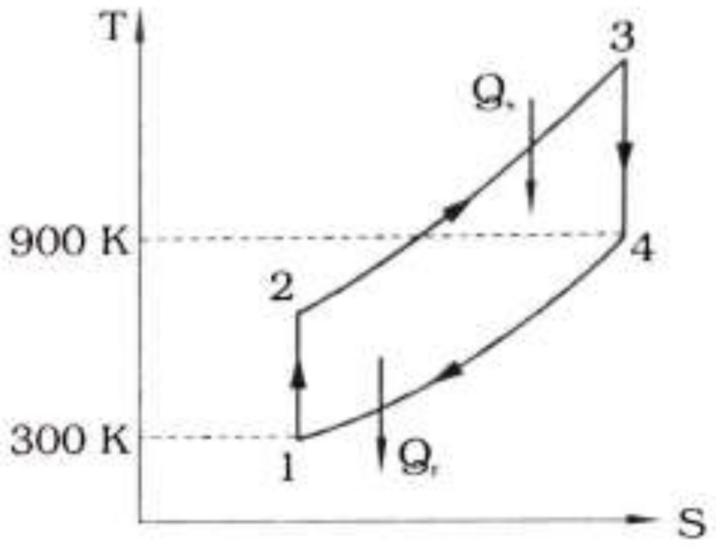
$$\therefore \quad \eta = \frac{1292.73 - 539.79}{1292.73} - 0.582$$

$$\eta = 58.2\%$$

2. The compression ratio of a compression ignition engine working on the ideal diesel cycle is 16. The temperature of air at the beginning of engine compression is 300K and the temperature of air at the end of expansion is 900K. Determine (a)cut-off ratio (b) expansion ratio and (c) the cycle efficiency.

Data Given: $R_c = \frac{V_1}{V_2} = 16;$ $T_1 = 300\ K;$ $T_4 = 900\ K$

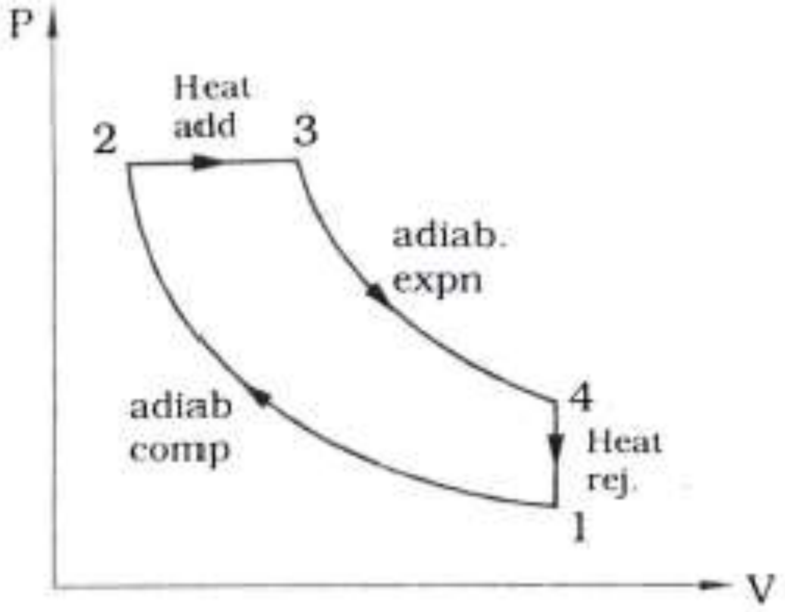




Problem -2

To find cut-off ratio (ρ)

w.k.t. Cut-off ratio $= \rho = \dfrac{V_3}{V_2}$ -----(1)



For constant pressure process 2-3, $\dfrac{V_2}{T_2} = \dfrac{V_3}{T_3}$ or $\dfrac{V_3}{V_2} = \dfrac{T_3}{T_2}$

∴ Cut-off ratio can also be written as $= \rho = \dfrac{T_3}{T_2}$

To find T_3 & T_2 For adiabatic process 1-2, we have $\dfrac{T_1}{T_2} = \left(\dfrac{V_2}{V_1}\right)^{\gamma-1}$

Problem -2

$$\frac{300}{T_2} = \left(\frac{1}{16}\right)^{1.4-1} \qquad T_2 = 909.4\ K$$

Also, for process 3-4, we have $\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1}$

$$\frac{T_3}{900} = \left(\frac{V_1}{V_3}\right)^{\gamma-1} \qquad (\because\ V_4 = V_1)$$

$$\text{or} \quad \frac{T_3}{900} = \left(\frac{V_1}{V_2}\cdot\frac{V_2}{V_3}\right)^{\gamma-1}$$

$$\frac{T_3}{900} = \left(R_C \times \frac{1}{\rho}\right)^{1.4-1}$$

But $T_3 = \rho . T_2$ from equation (2)

$$\therefore \frac{T_2 . \rho}{900} = \left(R_C \times \frac{1}{\rho}\right)^{0.4}$$

$$\text{or} \quad \frac{909.4 \times \rho}{900} = (16)^{0.4} \times \frac{1}{(\rho)^{0.4}}$$

$$909.4 \times \rho . \rho^{0.4} = (16)^{0.4} \times 900$$

$$\rho^{(1+0.4)} = \frac{(16)^{0.4} \times 900}{909.4}$$

$$\rho^{1.4} = 3 \quad \text{or} \quad \rho = (3)^{1/1.4}$$

Cut-off ratio = ρ = 2.19

Problem -2

To find expansion ratio

w.k.t. expansion ratio $= \frac{V_4}{V_3}$ But $V_4 = V_1$

$\therefore$ Expansion ratio $= \frac{V_1}{V_3} = \frac{V_1}{V_2} \cdot \frac{V_2}{V_3} = R_c \times \frac{1}{\rho}$

$= 16 \times \frac{1}{2.19} = 7.3$

expansion ratio = 7.3

To find efficiency

w.k.t. for Diesel cycle, $\eta = 1 - \frac{1}{\gamma(R_C)^{\gamma-1}}\left[\frac{\rho^\gamma - 1}{\rho - 1}\right]$

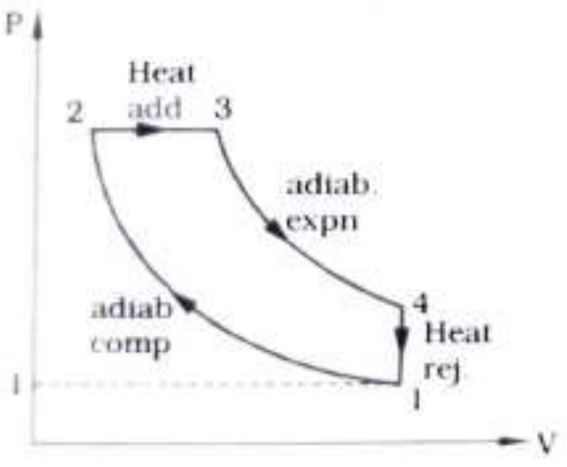
$= 1 - \frac{1}{1.4(16)^{1.4-1}}\left[\frac{2.19^{1.4} - 1}{2.19 - 1}\right] = 0.604$

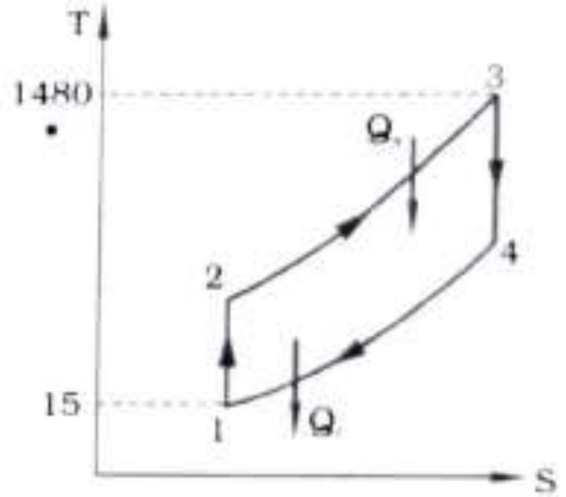
η = 60.4%

3. In air standard Diesel cycle, the compression ratio is 16. At the beginning of isentropic compression, the temperature is 15ºC and pressure is 0.1MPa. Heat is added until the temperature at the end of the constant pressure process is 1480ºC. Calculate (i) cut-off ratio (ii) heat supplied per kg of air (iii) cycle efficiency and (iv) mean effective pressure.

Data Given: Compression ratio $= R_c = \frac{V_1}{V_2} = 16$, $T_1 = 15°C = 288\ K$ $T_3 = 1480°C = 1753\ K$

$P_1 = 0.1\ MPa = 0.1 \times 10^6\ N/m^2 = 0.1 \times 10 \times 10^5\ N/m^2 = 1\,Bar$

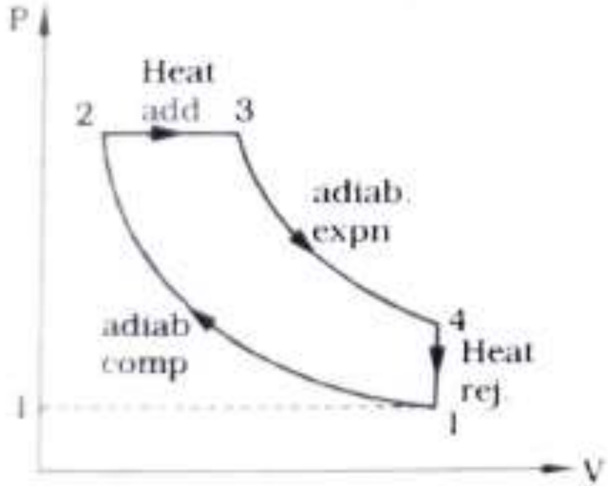




Problem -3

To find cut-off ratio

w.k.t. Cut-off ratio $= \rho = \frac{V_3}{V_2}$ or $\rho = \frac{T_3}{T_2}$



To find T_2 For adiabatic process 1–2, we have $\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$

$$\frac{288}{T_2} = \left(\frac{1}{16}\right)^{1.4-1} \qquad T_2 = 873\text{ K}$$

Now, Equation (1) becomes, $\rho = \frac{1753}{873} = 2$

Problem -3

To find heat supplied/kg of air

w.k.t. Heat supplied $= Q_s = mC_p(T_3 - T_2)$

$$= 1\,(1.005)\,(1753 - 873) = 884.4 \text{ kJ/kg of air}$$

$\therefore$ **Q_s = 884.4 kJ/kg of air**

To find cycle efficiency.

w.k.t. for Diesel cycle, $\eta = 1 - \dfrac{1}{\gamma (R_C)^{\gamma-1}}\left[\dfrac{\rho^{\gamma}-1}{\rho-1}\right]$

$$= 1 - \frac{1}{1.4(6)^{1.6-1}}\left[\frac{2^{1.4}-1}{2-1}\right] = 0.6138$$

η = 61.38%

To find mean effective pressure (MEP)

$$\text{MEP} = \frac{P_1 R_C^{\gamma}}{(R_c - 1)(\gamma - 1)}\left[\gamma(\rho - 1) - (R_C)^{1-\gamma}(\rho^{\gamma} - 1)\right]$$

$$= \frac{1(16)^{1.4}}{(16-1)(1.4-1)}\left[1.4\,(2 - 1) - (16)^{1-1.4}(2^{1.4} - 1)\right]$$

MEP = 6.94 Bar

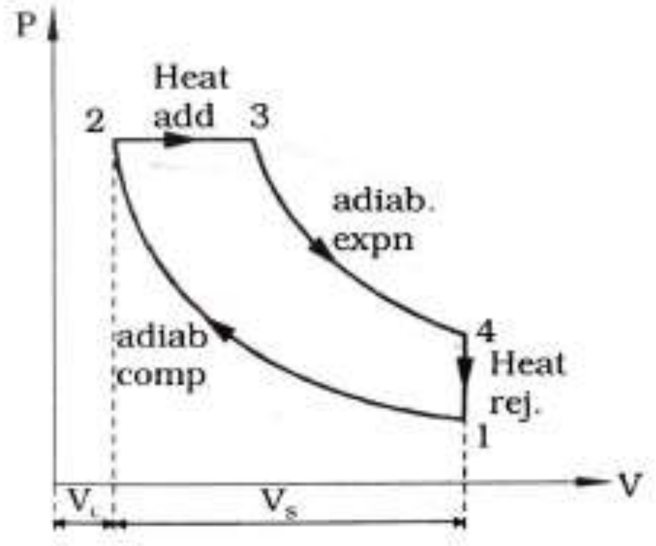
4. The stroke and cylinder diameter of a compression ignition engine working on theoretical Diesel Cycle are 250mm and 150mm respectively. The clearance volume is $0.0004m^3$. The fuel injection at constant pressure takes places for 5% of the stroke. Calculate the efficiency of the engine.

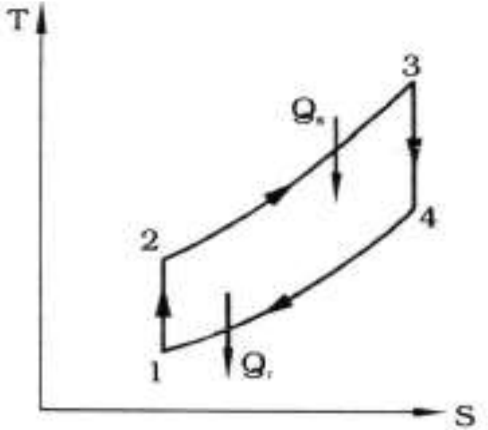
Data Given:

Stroke $L = 250$ mm $= 0.25$ m; Cylinder diameter $= d = 150$ mm $= 0.15$ m

Clearance volume $= V_C = 0.0004\ m^3 = V_2$

Fuel injection cut-off = 5% of stroke, i.e., Volume at cut-off $= V_3 = V_C + 5\%.V_S$





Problem -4

where V_s = stroke volume = $\frac{\pi}{4} d^2 L = \frac{\pi}{4} \times 0.15^2 \times 0.25 = 4.4178 \times 10^{-3}$

$$\therefore \quad V_3 = 0.0004 + \frac{5}{100}(4.4178 \times 10^{-3}) = 0.0006208 \text{ m}^3$$

To find efficiency (η)

$$\text{w.k.t. for Diesel cycle} = \eta = 1 - \frac{1}{\gamma (R_C)^{\gamma-1}} \left[\frac{\rho^\gamma - 1}{\rho - 1} \right] \quad \text{-----(1)}$$

To find cut-off ratio (ρ) and R_c

$$\text{w.k.t. } \rho = \frac{V_3}{V_2} = \frac{0.0006209}{0.0004} = 1.552$$

$$\text{Cut-off ratio} = \rho = 1.552$$

Problem -4

Also, compression ratio $= R_c = \frac{V_1}{V_2} = \frac{V_C + V_S}{V_C}$

$$\therefore \quad R_c = \frac{0.0004 + (4.417 \times 10^{-3})}{0.0004} = 12.04$$

Alternate method to calculate cut-off ratio (ρ)

Cut-off ratio is also given by $\rho = 1 + k\,(R_c - 1)$ where $k = 5\% = 0.05$

$$\rho = 1 + 0.05\,(12.04 - 1) = 1.552$$

w.k.t. for Diesel cycle $= \eta = 1 - \frac{1}{\gamma (R_C)^{\gamma-1}}\left[\frac{\rho^{\gamma} - 1}{\rho - 1}\right]$ -----(1)

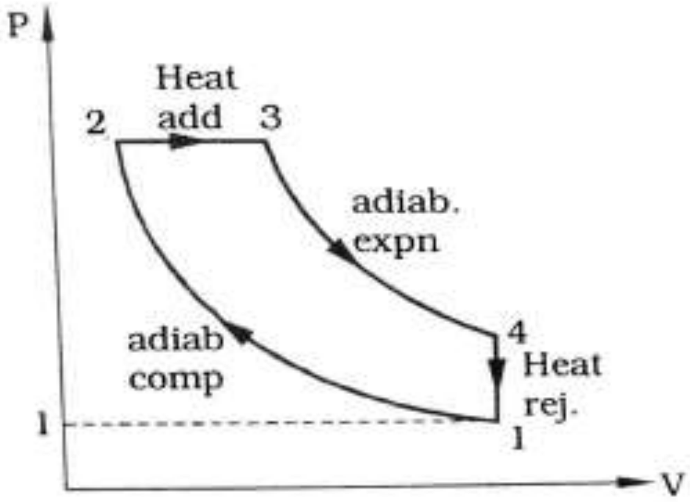
$$\eta = 1 - \frac{1}{1.4(12.04)^{1.4-1}}\left[\frac{1.552^{1.4} - 1}{1.552 - 1}\right] = 0.5933$$

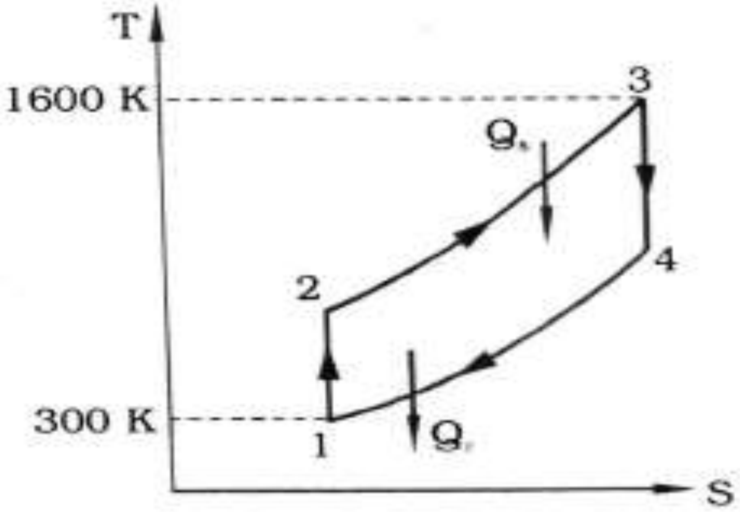
$$\eta = \mathbf{59.33\%}$$

5. In an air standard Diesel cycle, the compression ratio is 15 and the fluid properties at the beginning of compression are 100kPa and 300K. For a peak temperature of 1600K, calculate the percentage of stroke at which the cut-off takes place, the cycle efficiency and the work done/kg of air.

Data Given:

$$\text{Copression ratio} = R_C = \frac{V_1}{V_2} = 15\ ;\ P_1 = 100\ \text{kPa} = 1\ \text{Bar}\ ;\ T_1 = 300\ \text{K} \qquad \text{Maximum temperature} = T_3 = 1600\ \text{K}$$





Problem -5

To calculate % stroke (k) at which cut-off takes place

w.k.t. Cut-off ratio $= \rho = 1 + k(R_c - 1)$ -----(1)

w.k.t. cut-off ratio $= \rho = \frac{V_3}{V_2} = \frac{T_3}{T_2}$ -----(2)

To find T_2 For adiabatic process 1-2, we have $\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$

$$\frac{300}{T_2} = \left(\frac{1}{15}\right)^{1.4-1} \qquad T_2 = 886.25\ K$$

$\therefore$ equation (2) becomes, $\frac{1600}{886.25} = \rho$ Cut-off ratio $= \rho = 1.805$

Problem -5

Now equation (1) reduces to, $1.805 = 1 + k(15 - 1)$

$$k(14) = 1.805 - 1$$

$$\therefore \quad k = 0.0575$$

% stroke at which cut-off takes

$$k = 0.0575 \times 100 = \mathbf{5.75\ \%}$$

w.k.t. For Diesel cycle

$$\eta = 1 - \frac{1}{\gamma (R_C)^{\gamma-1}}\left[\frac{\rho^{\gamma} - 1}{\rho - 1}\right]$$

$$1 - \frac{1}{1.4(15)^{1.4-1}}\left[\frac{1.805^{1.4} - 1}{1.805 - 1}\right]$$

$$\eta = 61.37\%$$

Problem -5

w.k.t. Work done $= Q_s - Q_r$

$$= [mC_p(T_3 - T_2)] - [mC_v(T_4 - T_1)] \quad \text{-----(3)}$$

For adiabatic process 3-4, we have $\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1}$

But $V_4 = V_1$

$$\therefore \quad \frac{T_3}{T_4} = \left(\frac{V_1}{V_3}\right)^{\gamma-1}$$

$$\frac{T_3}{T_4} = \left(\frac{V_1}{V_2} \cdot \frac{V_2}{V_3}\right)^{\gamma-1}$$

$$\frac{1600}{T_4} = \left(R_C \cdot \frac{1}{\rho}\right)^{1.4-1}$$

$$(\because \quad \rho = \frac{V_3}{V_2} \; \& \; R_c = \frac{V_1}{V_2})$$

$$\frac{1600}{T_4} = \left(15 \times \frac{1}{1.805}\right)^{0.4}$$

$$T_4 = 685.92 \text{ K}$$

Problem -5

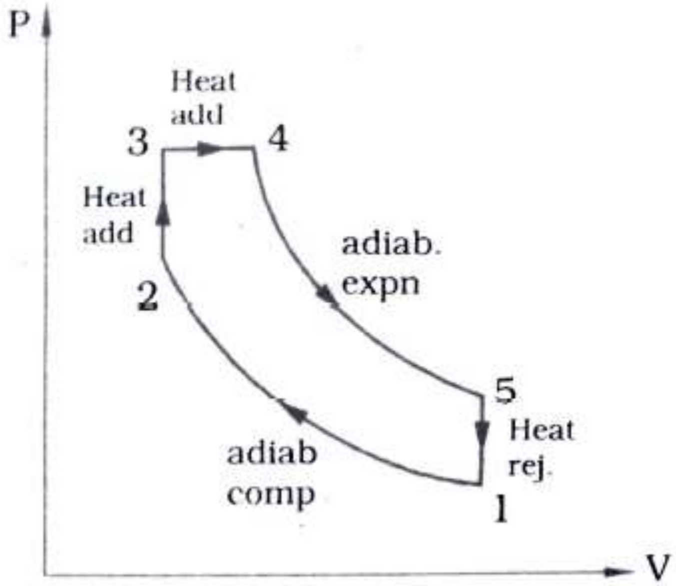
Take $C_p = 1.005$ kJ/kg K & $C_v = 0.718$ kJ/kg for air

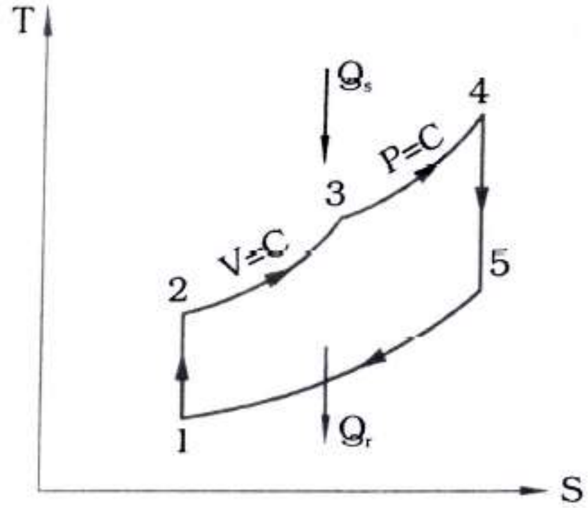
Equation (3) becomes W.D = [1.005 (1600 – 886.25)] – [0.718 (685.92 – 300)]

Work done (W.D) = 440.22 kJ/kg of air

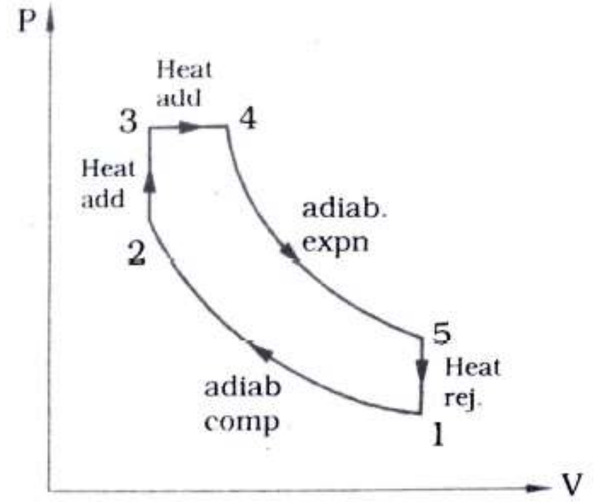
Dual Combustion Cycle (Semi- Diesel/Limited Pressure cycle)

Expression for air standard efficiency:





Dual Combustion Cycle (Semi- Diesel/Limited Pressure cycle)

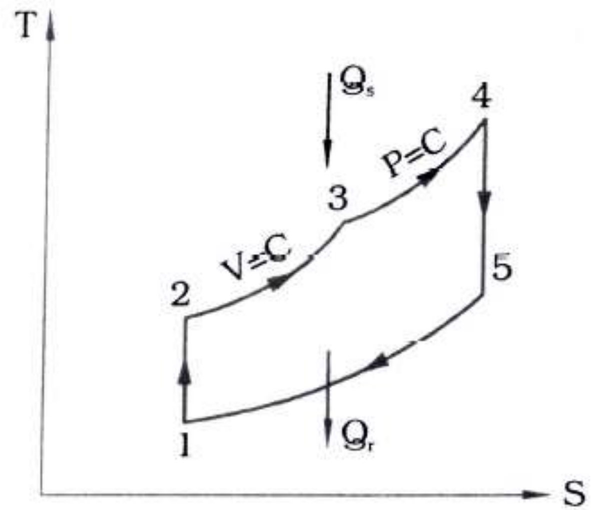


Process 1-2: Adiabatic compression

heat transfer Q = 0, and $\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$ -----(1)

Process 2-3: constant volume heat addition

Heat supplied $(Q_s)_{2-3} = mC_v (T_3 - T_2)$



Process 3-4: constant Pressure heat addition

Heat supplied $(Q_s)_{3-4} = mC_P (T_4 - T_3)$

Dual Combustion Cycle (Semi- Diesel/Limited Pressure cycle)

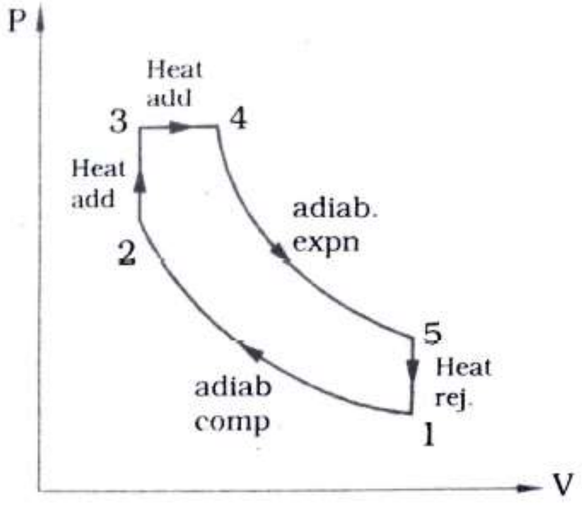
Process 4-5: Adiabatic Expansion

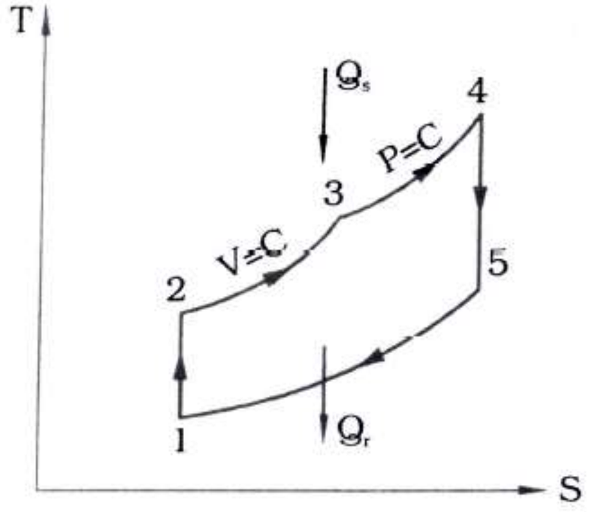
w.k.t. for adiabatic process, heat transfer, Q = 0,

$$\frac{T_4}{T_5} = \left(\frac{V_5}{V_4}\right)^{\gamma-1}$$

Process 5-1: constant volume heat rejection

$$\therefore \text{ Heat rejected } Q_r = mC_V (T_5 - T_1)$$





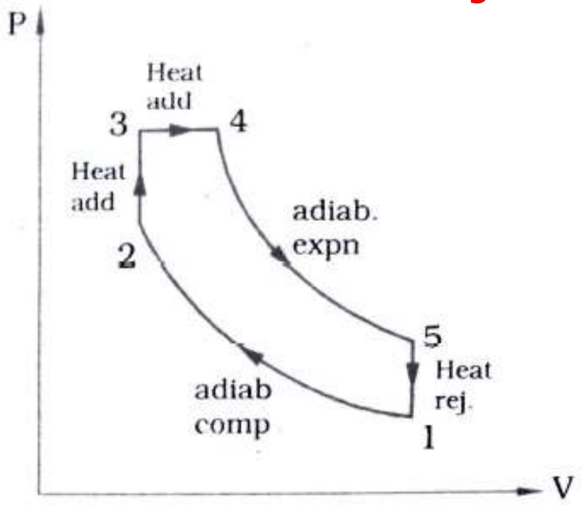
Dual Combustion Cycle (Semi- Diesel/Limited Pressure cycle)

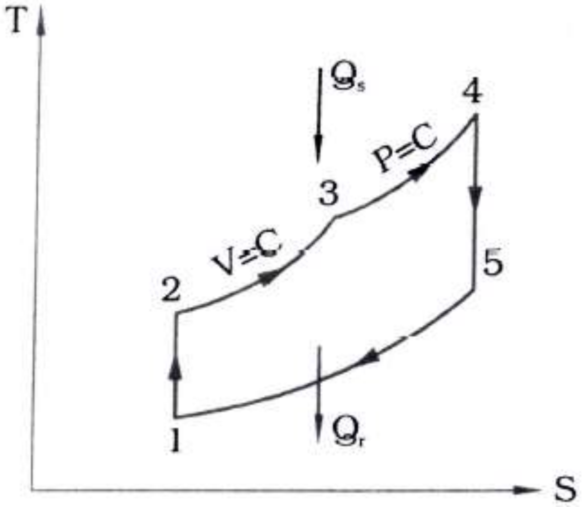
$$\text{w.k.t. } \eta_{air} = \frac{\text{Work done}}{\text{Heat supplied}}$$

$$= \frac{Q_s - Q_r}{Q_s} = 1 - \frac{Q_r}{Q_s} = 1 - \frac{Q_r}{(Q_s)_{2-3} + (Q_s)_{3-4}}$$

$$, \eta_{air} = 1 - \frac{mC_V(T_5 - T_1)}{mC_V(T_3 - T_2) + mC_P(T_4 - T_3)}$$

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





Dual Combustion Cycle (Semi- Diesel/Limited Pressure cycle)

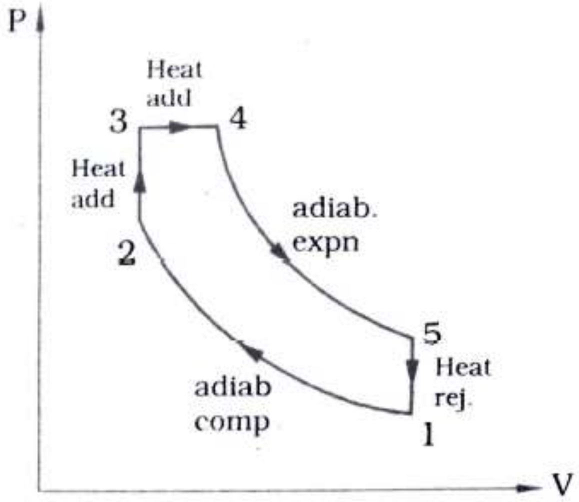
Express all temperatures in terms of T_1

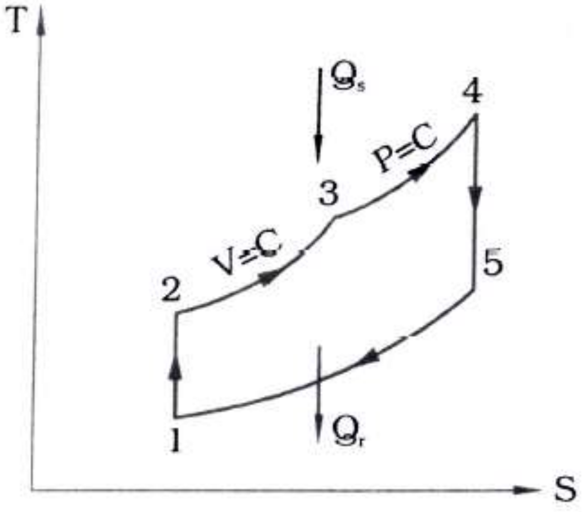
we have $\frac{T_1}{T_2} = \left(\frac{1}{R_C}\right)^{\gamma-1}$ where $R_C = \frac{V_1}{V_2}$ = compression ratio

we have $\frac{T_4}{T_5} = \left(\frac{V_1}{V_4}\right)^{\gamma-1}$ $\because V_5 = V_1$

$$\frac{T_4}{T_5} = \left(\frac{V_1}{V_2} \times \frac{V_2}{V_4}\right)^{\gamma-1}$$

$$\frac{T_4}{T_5} = \left(\frac{V_1}{V_2} \times \frac{V_3}{V_4}\right)^{\gamma-1} \quad \because V_2 = V_3$$





Dual Combustion Cycle (Semi- Diesel/Limited Pressure cycle)

$$\frac{T_4}{T_5} = \left(R_C \times \frac{1}{\rho}\right)^{\gamma-1}$$

$$\because \frac{V_4}{V_3} = \rho \text{ cut-off ratio}$$

$$T_4 = T_5\left[R_C^{\gamma-1} . \rho^{1-\gamma}\right]$$

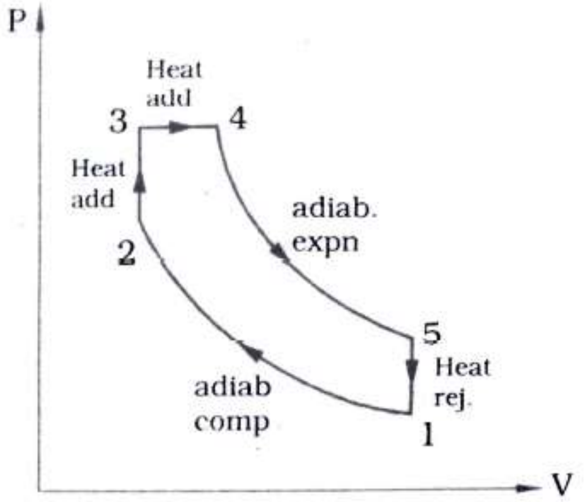
For constant volume process 2-3,

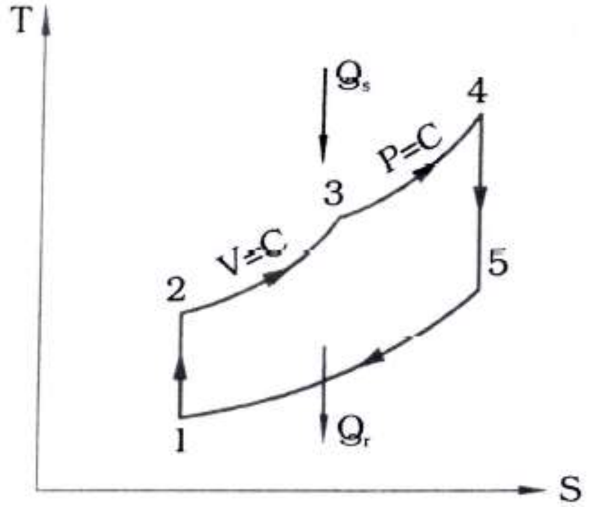
we have $\frac{P}{T} = \text{constant}$

$$\frac{P_2}{T_2} = \frac{P_3}{T_3} \quad \text{or} \quad T_3 = T_2\left(\frac{P_3}{P_2}\right)$$

$$= T_2\,(\alpha)$$

where α = explosion ratio = $\frac{P_3}{P_2}$





Dual Combustion Cycle (Semi- Diesel/Limited Pressure cycle)

we have, $T_3 = T_1 \cdot (R_C)^{\gamma-1} . \alpha$

For constant pressure process 3-4,

we have $\frac{V}{T}$ = constant.

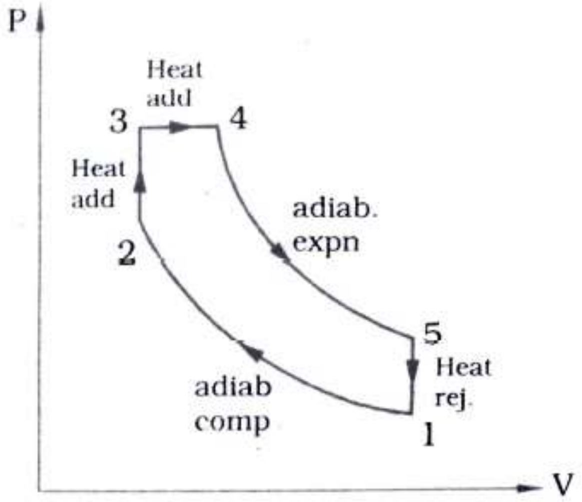
$$T_4 = T_3 \left(\frac{V_4}{V_3} \right) = T_3 (\rho)$$

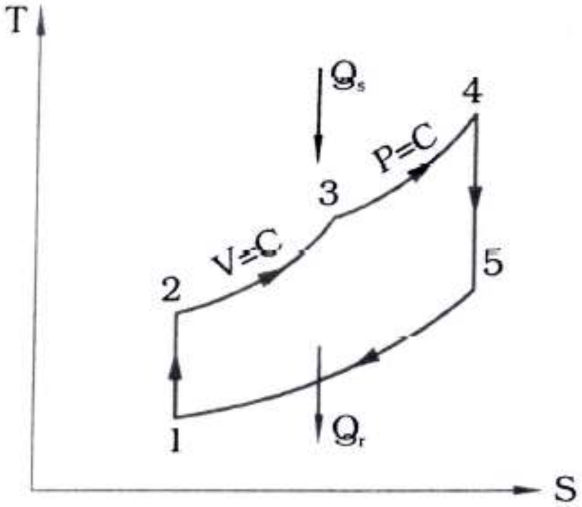
we have $T_4 = T_1 \cdot (R_C)^{\gamma-1} . \alpha . \rho$

we have $T_1 \cdot (R_C)^{\gamma-1} . \alpha . \rho = T_5 . (R_C)^{\gamma-1} . \rho^{1-\gamma}$

$$T_5 = \frac{T_1 \alpha \rho}{\rho^{1-\gamma}}$$

$$= T_1 \alpha \rho^{\gamma}$$





Dual Combustion Cycle (Semi- Diesel/Limited Pressure cycle)

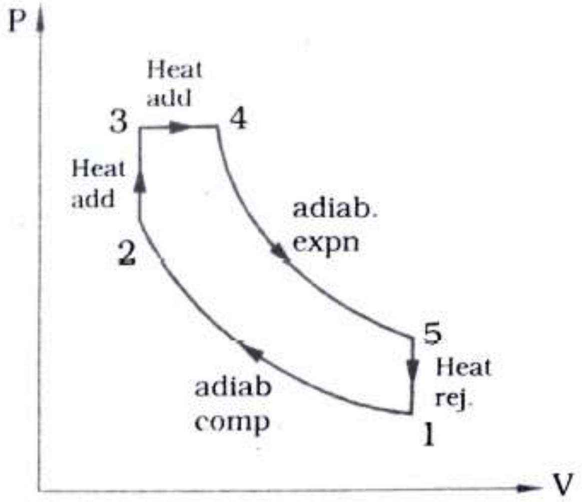
Substituting T_2, T_3, T_4 and T_5 in equation (6), we have

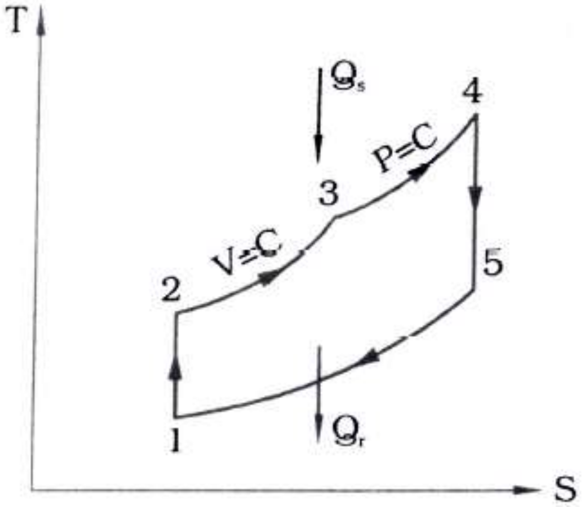
$$\eta_{air} = 1 - \frac{C_V \ T_1 \alpha \rho^{\gamma} - T_1}{C_V \ T_1 R_C^{\gamma-1}.\alpha - T_1 R_C^{\gamma-1} \ + C_P \ T_1 R_C^{\gamma-1}.\alpha \rho - T_1 R_C^{\gamma-1}.\alpha}$$

$$= 1 - \frac{T_1 \ \alpha \rho^{\gamma} - 1}{T_1 \ R_C^{\gamma-1}.\alpha - R_C^{\gamma-1} \ + \frac{C_P}{C_V}.T_1 \ R_C^{\gamma-1}.\alpha \rho - R_C^{\gamma-1}.\alpha}$$

$$= 1 - \frac{\alpha \rho^{\gamma} - 1}{R_C^{\gamma-1}(\alpha - 1) + \gamma \, . \, R_C^{\gamma-1} \, . \, \alpha(\rho - 1)}$$

$$\eta_{air} = 1 - \frac{1}{R_C^{\gamma-1}} \ \frac{\alpha . \rho^{\gamma} - 1}{(\alpha - 1) + \alpha \gamma (\rho - 1)}$$





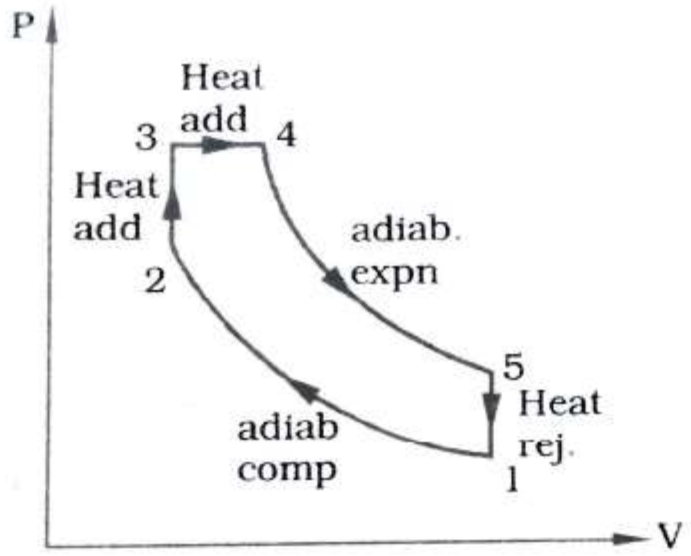
Dual Combustion Cycle (Semi- Diesel/Limited Pressure cycle)

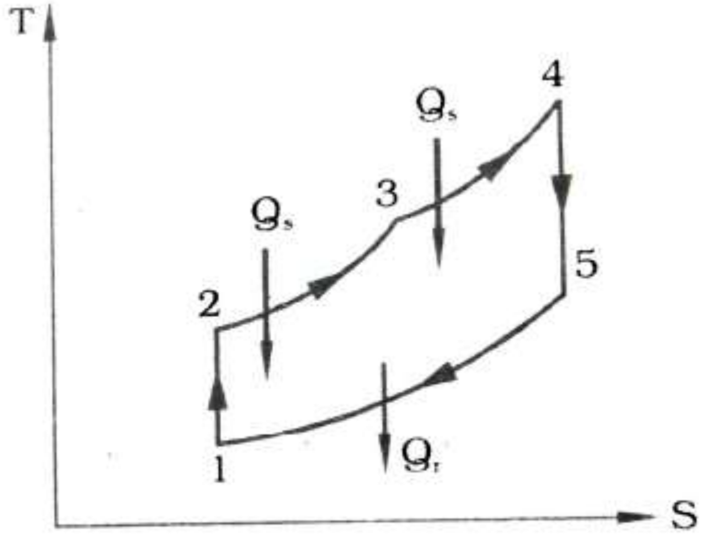
$$MEP = \frac{P_1 R_C}{(R_C - 1)((\gamma - 1))} \; R_C^{\gamma-1}(\alpha - 1) + \alpha.\gamma \; R_C^{\gamma-1}(\rho - 1) - (\alpha.\rho^{\gamma} - 1)$$

1. A engine working on dual combustion cycle draws air at 1 bar & 27ºC. Maximum pressure is limited to 55 bar, the compression ratio is 15. if the heat transfer at constant volume is twice that at constant pressure , determine (a) cut off ratio (b) explosion ratio & temperatures at all salient points of the cycle (c) air standard cycle

Data Given:

$P_1 = 1$ Bar, $T_1 = 27°C = 300$ K, $P_3 = P_4 = 55$ Bar ; $R_C = \frac{V_1}{V_2} = 15$; $(Q_s)_{2-3} = 2(Q_s)_{3-4}$





Problem -1

To find cut-off ratio (ρ)

w.k.t. cut-off ratio $= \rho = \dfrac{T_4}{T_3}$ or $\dfrac{V_4}{V_3}$

To find T_3 and T_4 Given $(Q_s)_{2\text{-}3} = 2.(Q_s)_{3\text{-}4}$

$$mC_V\,(T_3 - T_2) = 2\,[mC_P\,(T_4 - T_3)]$$

where $m = 1$ kg; $C_P = 1.005$ kJ/kg K & $C_V = 0.718$ kJ/kg K

But $T_2 = ?$

Problem -1

For adiabatic process 1-2, we have $\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$

$$\frac{300}{T_2} = \left(\frac{1}{15}\right)^{1.4-1}$$

$$T_2 = 886.25 \text{ K}$$

For constant volume process 2-3, we have $\frac{P}{T} = \text{Constant}$

$$\text{i.e.,} \quad \frac{P_2}{T_2} = \frac{P_3}{T_3}$$

$$\therefore \quad T_3 = \frac{T_2 . P_3}{P_2} = \frac{(886.25)(55)}{P_2}$$

Problem -1

But $P_2 = ?$

For process 1–2, we have $\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma}$

$$\therefore \quad P_2 = P_1(R_C)^{\gamma} = 1(15)^{1.4} = 44.31 \text{ Bar}$$

Now, equation (4) becomes, $T_3 = \frac{(886.25)(55)}{44.31}$

$$\therefore \quad T_3 = 1100 \text{ K}$$

Substituting T_2 & T_3 in equation (3), we have

$$1\,(0.718)\,(1100 - 886.25) = 2\,[1\,(1.005)\,(T_4 - 1100)] \qquad \therefore \quad T_4 = 1176.35 \text{ K}$$

Problem -1

Now equation (3) becomes, $\rho = \dfrac{1176.35}{1100} = 1.07$

$\therefore$ Cut-off ratio $= \rho = \mathbf{1.07}$

To find explosion ratio (α) & temperatures at all points

w.k.t. $\alpha = \dfrac{P_3}{P_2}$

$$\alpha = \frac{55}{44.31} = 1.241$$

$\therefore$ explosion ratio $= \boldsymbol{\alpha} = \mathbf{1.241}$

Problem -1

As calculated in previous steps, we have

$$T_1 = 300\text{ K},\ T_2 = 886.25\text{ K},\ T_3 = 1100\text{ K},\ T_4 = 1176.35\text{ K}$$

To find T_5 for adiabatic process 4-5, $\dfrac{T_4}{T_5} = \left(\dfrac{V_5}{V_4}\right)^{\gamma-1}$

$$\frac{1176.35}{T_5} = \left(\frac{V_1}{V_4}\right)^{1.4-1}$$

$$\frac{1176.35}{T_5} = \left(\frac{V_1}{V_3}\cdot\frac{V_3}{V_4}\right)^{0.4}$$

But $V_3 = V_2$

i.e., $$\frac{1176.35}{T_5} = \left(\frac{V_1}{V_2}\cdot\frac{V_3}{V_4}\right)^{0.4}$$

Problem -1

$$= \left(R_C \times \frac{1}{\rho}\right)^{0.4}$$

$$\frac{1176.35}{T_5} = \left(15 \times \frac{1}{1.07}\right)^{0.4} \qquad \mathbf{T_5 = 409.12\ K}$$

Thus, $\mathbf{T_1 = 300\ K}$, $\mathbf{T_2 = 886.25\ K}$, $\mathbf{T_3 = 1100\ K}$, $\mathbf{T_4 = 1176.35\ K}$, $\mathbf{T_5 = 409.12\ K}$

To find air standard efficiency (η)

for dual cycle, use $$\eta = \frac{\text{Work done}}{\text{Heat supplied}} = \frac{Q_s - Q_r}{Q_s} \qquad \text{-----(5)}$$

where $Q_s = (Q_s)_{2-3} + (Q_s)_{3-4}$

Problem -1

i.e., $Q_s = mC_V(T_3 - T_2) + mC_P(T_4 - T_3)$ -----(6)

& $Q_r = mC_V(T_5 - T_1)$ -----(7)

$\therefore$ $Q_s = 0.718(1100 - 886.25) + 1.005(1176.35 - 1100)$

$= 230.20$ kJ/kg of air

$Q_r = 0.718(409.12 - 300)$

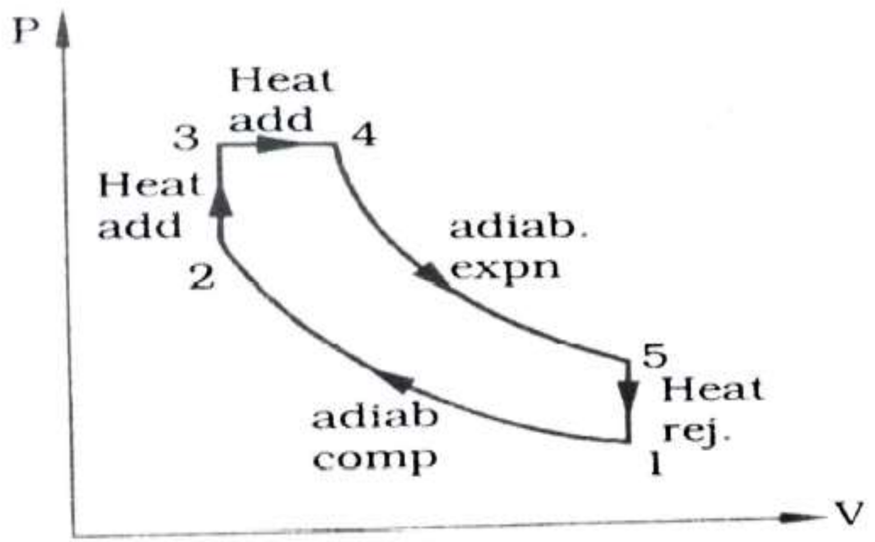
$= 78.34$ kJ/kg of air

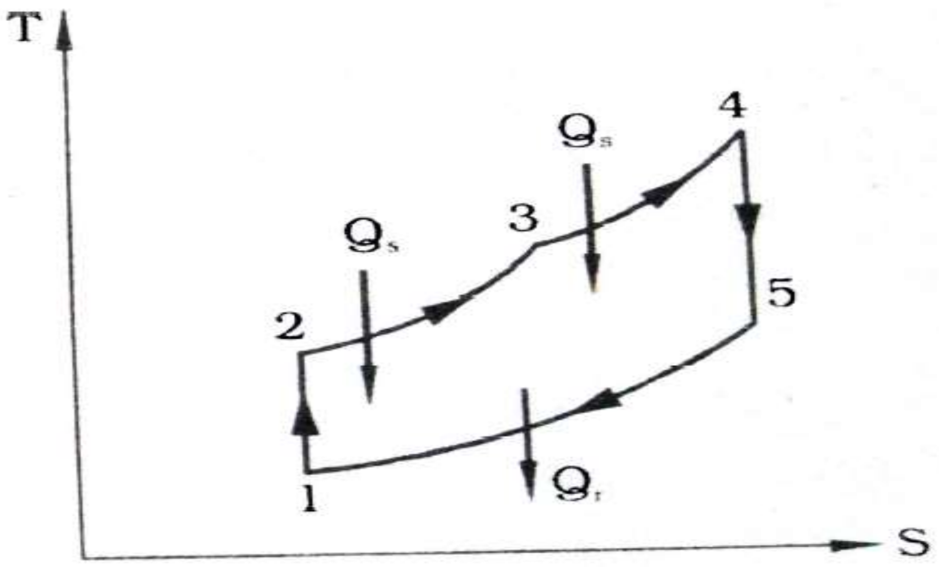
$\therefore$ Equation (5) reduces to, $\eta = \dfrac{(230.2 - 78.34)}{230.2}$

$\eta = 65.9\%$

2. An air standard limited pressure cycle has a compression ratio of 15 and compression begins at 0.1MPa, 40ºC. The maximum pressure is limited to 6MPa and heat added is 1.675MJ/kg. Compute (i) The heat supplied at constant volume per kg of air. (ii) The heat supplied at constant pressure per kg of air (iii) The work done per kg of air (iv) The cycle efficiency (v) The cut-off ratio (vi) The M.E.P of the cycle.

Data Given:





Problem -2

Compression ratio $= R_c = \dfrac{V_1}{V_2} = 15$

$P_1 = 0.1\text{MPa} = 0.1 \times 10^6 \text{N/m}^2$; $= 0.1 \times 10 \times 10^5 \text{ N/m}^2 = 1 \text{ Bar}$

$Q_s = 1.675 \text{ MJ/kg} \quad = 1.675 \times 10^3 \text{ kJ/kg} \quad = 1675 \text{ kJ/kg}$

$T_1 = 40°C = 313 \text{ K}$;

$T_1 = 40°C = 313 \text{ K}$; $P_3 = P_4 = 6\text{MPa} = 60 \text{ Bar} \quad Q_s = 1.675 \text{ MJ/kg}$

Note that $Q_s = 1675 \text{ kJ/kg} = (Q_s)_{2\text{-}3} + (Q_s)_{3\text{-}4}$

To find Heat supplied at constant volume $(Q_s)_{2\text{-}3}$

w.k.t. $(Q_s)_{2\text{-}3} = mC_V(T_3 - T_2)$

Problem -2

To find T_2 & T_3 For adiabatic process 1-2, we have $\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$

$$\frac{313}{T_2} = \left(\frac{1}{15}\right)^{1.4-1} \qquad T_2 = 924.65\ \text{K}$$

Also, for process 1-2, $\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^{\gamma}$

$$\frac{1}{P_2} = \left(\frac{1}{15}\right)^{1.4} \qquad P_2 = 44.31\ \text{Bar}$$

Problem -2

For constant volume process 2-3, we have $\frac{P}{T} = \text{Const}$

i.e., $$\frac{P_2}{T_2} = \frac{P_3}{T_3}$$

$$\therefore \quad T_3 = \frac{T_2 . P_3}{P_2} = \frac{(924.65)60}{44.31} = 1252 \text{ K}$$

$\therefore$ Equation (1) becomes $(Q_s)_{2-3} = 1 \times 0.718\,(1252 - 924.65)$

$$\therefore \quad (Q_s)_{2-3} = \mathbf{235\ kJ/kg\ of\ air}$$

Problem -2

To find heat supplied at constant pressure $(Q_s)_{3.4}$

By data $Q_s = 1675 = (Q_s)_{2\text{-}3} + (Q_s)_{3\text{-}4}$

$\therefore (Q_s)_{3\text{-}4} = 1675 - (Q_s)_{2\text{-}3} = 1675 - 235 = 1440$

To find work done

Work done $= Q_s - Q_r$

where $Q_s = 1675$ kJ/kg of air

$Q_r = mC_V (T_5 - T_1)$

Problem -2

To find T_5 Initially find T_4 & then proceed to find T_5

$$\text{w.k.t. } (Q_s)_{3\text{-}4} = mC_p (T_4 - T_3)$$

$$1440 = 1\,(1.005)\,(T_4 - 1252)$$

$$\therefore \quad T_4 = 2684.8 \text{ K}$$

For adiabatic process 4-5, we have $\dfrac{T_4}{T_5} = \left(\dfrac{V_5}{V_4}\right)^{\gamma-1}$

$$\frac{2684.8}{T_5} = \left(\frac{V_1}{V_4}\right)^{1.4-1} \qquad (\because V_5 = V_1)$$

Problem -2

$$\frac{2684.8}{T_5} = \left(\frac{V_1}{V_3}\cdot\frac{V_3}{V_4}\right)^{0.4}$$

w.k.t. cut-off ratio $= \rho = \dfrac{V_4}{V_3}$

$$\therefore \quad \frac{2684.8}{T_5} = \left(\frac{V_1}{V_3}\cdot\frac{1}{\rho}\right)^{0.4}$$

But $V_3 = V_2$

$$\frac{2684.8}{T_5} = \left(R_C\cdot\frac{1}{\rho}\right)^{0.4} \qquad \text{-----(4}$$

But $\rho = ?$

w.k.t. cut-off ratio is also given by $\rho = \dfrac{T_4}{T_3} = \dfrac{2684.8}{1252} = 2.144$

Problem -2

$$\therefore \quad \rho = 2.144$$

$\therefore$ Equation (4) becomes, $\dfrac{2684.8}{T_5} = \left(\dfrac{15}{2.144}\right)^{0.4}$

$$T_5 = 1233 \text{ K}$$

$$Q_r = 1\ (0.718)\ (1233 - 313)$$

$$= 660.56 \text{ kJ/kg of air}$$

$$\text{Work done} = 1675 - 660.56$$

Work done = 1014.4 kJ/kg of air

Problem -2

$$\text{we have } \eta = \frac{\text{Work done}}{\text{Heat supplied}}$$

$$= \frac{Q_s - Q_r}{Q_s} = \frac{1014.4}{1675} = 0.605$$

To find mean effective pressure (MEP)

$$\text{w.k.t. MEP} = \frac{P_1 (R_C)^{\gamma}}{(\gamma - 1)(R_C - 1)} [(\alpha - 1) + \gamma \alpha (\rho - 1) (R_c)^{1-\gamma} (\alpha \rho^{\gamma} - 1)]$$

$$\text{w.k.t. } \alpha = \text{explosion ratio} = \frac{P_3}{P_2} = \frac{60}{44.31} = 1.35$$

Problem -2

$$MEP = \frac{1(15)^{1.4}}{(1.4-1)(15-1)}[(1.35-1)+(1.4)(1.35)(2.144-1)-15^{1-1.4}(1.35\times 2.144^{1.4}-1)]$$

MEP = 12 Bar

Alternate method

$$MEP = \frac{W.D/Cycle}{Swept\ volume} = \frac{Q_s - Q_r}{V_1 - V_2}$$

$P_1V_1 = mRT_1$ where m = 1kg

$$V_1 = \frac{RT_1}{P_1} = \frac{(0.287)(313)}{1\times 10^2 kPa} = 0.898\ m^3/kg$$

w.k.t. $R_C = \frac{V_1}{V_2} = 15$

$$V_2 = \frac{V_1}{15} = \frac{0.898}{15} = 0.0598 m^3/kg$$

$$MEP = \frac{1675-660.56}{0.898-0.0598}$$

MEP = 12.10 Bar

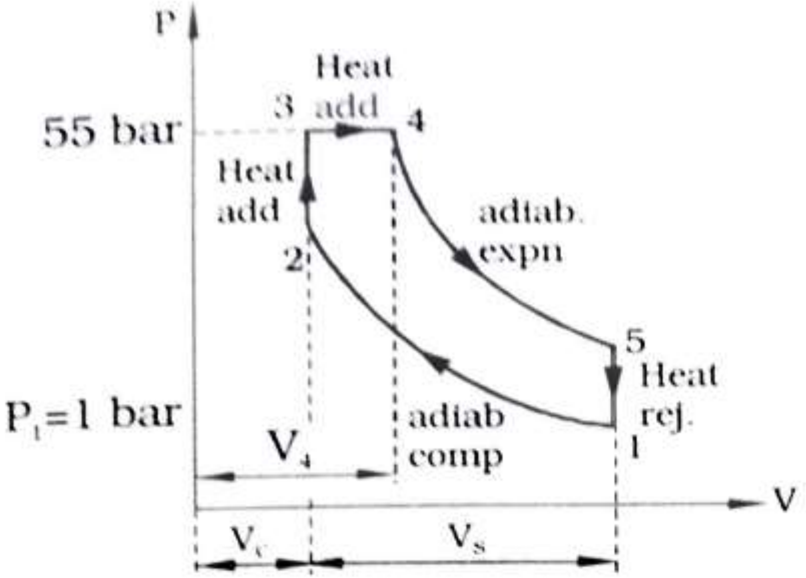
3. The compression ratio for a single cylinder engine operating on dual cycle is 8. The maximum pressure in the cycle is limited to 55 bar. The pressure and temperature of air at the beginning of the cycle are 1 bar and 27ºC. Heat is added during constant pressure process upto 3% of the stroke. Assuming the diameter as 25 cm and stroke as 30 cm, find the following. (a) The workdone per cycle (b) The air standard efficiency of the cycle (c) The power developed if number of working cycles are 200/min

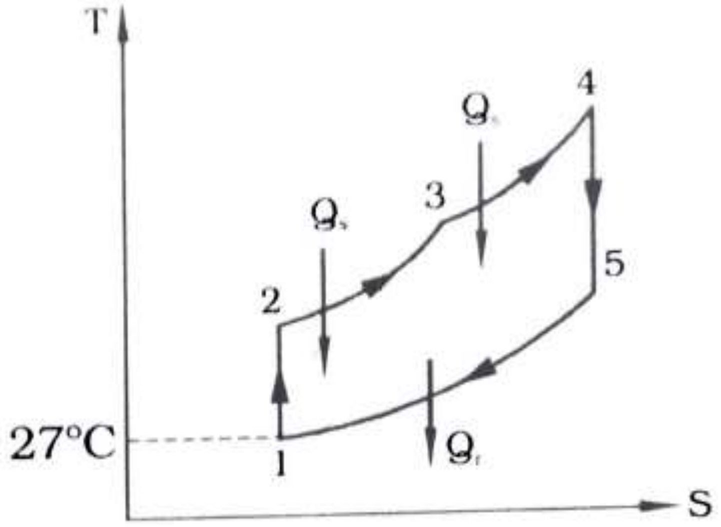
Data Given:

Compression ratio $= R_c = \frac{V_1}{V_2} = 8$; $P_3 = P_4 = 55$ Bar ; $P_1 = 1$ Bar & $T_1 = 27°C = 300$ K

Cut-off = 3% of stroke

Given d = 25 cm = 0.25 m and L = 30 cm = 0.3 m





Problem -3

i.e., Volume at cut-off $= V_4 = V_C + 3\% V_S$ -----(1)

To find Work done/cycle

w.k.t. W.D/cycle $= Q_s - Q_r$

$= [(Q_s)_{2\text{-}3} + (Q_s)_{3\text{-}4}] - Q_r$ -----(2)

where $(Q_s)_{2\text{-}3} = mC_V(T_3 - T_2)$ -----(3)

$(Q_s)_{3\text{-}4} = mC_P(T_4 - T_3)$ -----(4)

and $Q_r = mC_V(T_5 - T_1)$ -----(5)

Problem -3

To find temperatures T_2 T_3 T_4 & T_5

For process 1-2, we have $\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$

$$\frac{300}{T_2} = \left(\frac{1}{8}\right)^{1.4-1} \qquad T_2 = 689.22 \text{ K}$$

For constant volume process 2-3, we have $\frac{P}{T} = \text{const}$

i.e., $\frac{P_2}{T_2} = \frac{P_3}{T_3}$ $\quad \therefore \quad T_3 = T_2 \cdot \frac{P_3}{P_2}$ ----(6)

For process 1-2, we have $\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma}$ $\qquad \frac{P_2}{1} = (8)^{1.4}$ $\qquad P_2 = 18.38$ Bar

Problem -3

$\therefore$ equation (6) becomes, $T_3 = 689.22\left(\frac{55}{18.38}\right)$

$T_3 = 2062.4$ K

For constant pressure process 3-4, we have $\frac{V}{T}$ = constant

i.e., $\frac{V_3}{T_3} = \frac{V_4}{T_4}$

$T_4 = T_3\left(\frac{V_4}{V_3}\right)$

To find V_4 & V_2 From P-V diagram $V_2 = V_C$

w.k.t. compression ratio $= R_c = \frac{V_C + V_S}{V_C}$

$$8 = \frac{V_C + \left[\frac{\pi}{4} d^2 . L\right]}{V_C}$$

$$8V_C = V_C + [\frac{\pi}{4}(0.25)^2 . (0.3)]$$

$$7V_C = 0.0147$$

$\therefore$ $V_C = V_2 = V_3 = 0.0021\ m^3$

Problem -3

From equation (1), we have, $V_4 = 0.0021 + \left(\frac{3}{100}\right)(0.0147)$

$$V_4 = 0.00254 \text{ m}^3$$

$$T_4 = 2062.4\left(\frac{0.00254}{0.0021}\right)$$

$$T_4 = 2494.5 \text{ K}$$

For process 4-5, we have, $\frac{T_4}{T_5} = \left(\frac{V_5}{V_4}\right)^{\gamma-1}$ -----(8

To find V_5 From P-V diagram, $V_5 = V_1$

$$= V_s + V_c = 0.0147 + 0.0021$$

$$V_5 = 0.0168 \text{ m}^3$$

Noe equation (8) becomes, $\frac{2494.5}{T_5} = \left(\frac{0.0168}{0.00254}\right)^{1.4-1}$

$$T_5 = 1171.6 \text{ K}$$

Substituting all the temperatures in equation (3), (4) & (5) we have,

$$(Q_s)_{2\text{-}3} = 1\,(0.718)\,(2062.4 - 689.22)$$

$$= 985.9 \text{ kJ/kg}$$

$$(Q_s)_{3\text{-}4} = 1\,(1.005)\,(2494.5 - 2062.4)$$

$$= 434.26 \text{ kJ/kg}$$

Problem -3

Now equation (2) becomes,

$$W.D/cycle = (985.9 + 434.26) - 625.8$$

$$\therefore \quad \textbf{WD/cycle} = \textbf{794.36 kJ/kg}$$

To find air standard efficiency of the cycle (η)

$$\text{w.k.t. } \eta = \frac{W.D/cycle}{\text{Heat Supplied}} = \frac{Q_s - Q_r}{Q_s}$$

$$= \frac{(985.9 + 434.26) - 625.8}{(985.9 + 434.26)}$$

Approximately η = **0.56 or 56%**

To find power developed for 200 cycles/min

Power developed = m_a (W.D/cycle) (Number of cycles per second) ·····(8)

To find mass of air (m_a)

Under ideal gas condition, we have PV = mRT

$\therefore$ at point 1 on P-V diagram, $P_1V_1 = m_aRT_1$

$$\therefore \quad m_a = \frac{P_1V_1}{RT_1} = \frac{(1 \times 10^2 kPa)(0.0168\, m^3)}{(0.287\, kJ/kg\,K)(300\, K)}$$

$$m_a = 0.0195 \text{ kg}$$

Problem -3

Power developed = m_a (W.D/cycle) (Number of cycles per second) -----(8)

∴ Equation (8) becomes, Power developed = $(0.0195 \text{ kg})\left(Q_s - Q_r \dfrac{\text{kJ}}{\text{kg}}\right)\left(\dfrac{200}{60 \text{ sec}}\right)$

$$= (0.0195)(794.36)\left(\frac{200}{60}\right) \text{ kJ/sec}$$

Power developed = 51.6 kW

4. An engine working on Dual combustion cycle takes in air at 1 bar & 30ºC. The clearance is 8% of the stroke & cut-off takes place at 10% of the stroke. The maximum pressure in the cycle is limited to 70 bar. Find temperature & pressure at salient points & air standard efficiency

Data

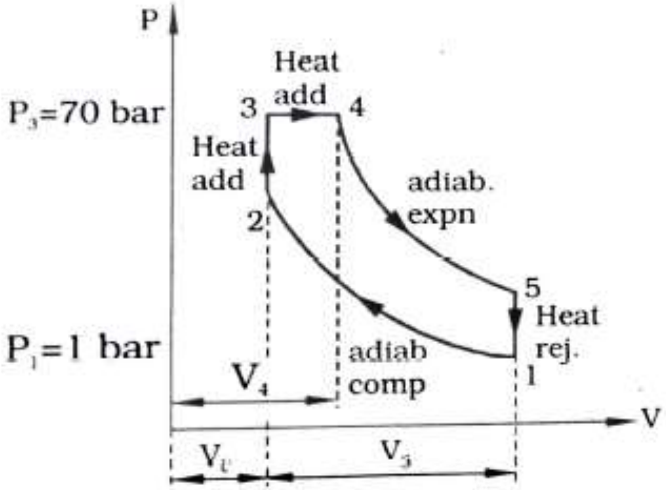
$$P_1 = 1 \text{ Bar}, T_1 = 30°C = 303 \text{ K}$$

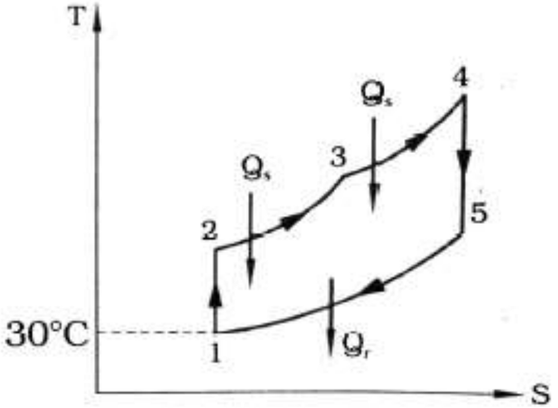
$$\text{Clearance volume} = V_C = V_2 = V_3 = 8\% \, V_S = 0.08\,(V_1 - V_C)$$

$$\text{or } V_C = 0.08\,(V_1 - V_2) \quad \text{-----(1)}$$

∴ stroke at which cut-off takes place = k = 10% = 0.1

$$P_3 = P_4 = 70 \text{ Bar}$$





Problem -4

To find pressure and temperature at all points

It is easier to proceed calculations, if one knows the value of compression ratio (R_c)

Consider equation (1) $V_c = 0.08\,(V_1 - V_2)$ but $V_C = V_2 = V_3$

$$\therefore \quad V_2 = 0.08\,V_1 - 0.08\,V_2$$

$$1.08\,V_2 = 0.08\,V_1$$

$$\text{or} \quad \frac{V_1}{V_2} = \frac{1.08}{0.08}$$

$$= 13.5 = R_C \text{ (compression ratio)}$$

For adiabatic process 1-2, we have, $\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$ $\frac{303}{T_2} = \left(\frac{1}{13.5}\right)^{1.4-1}$ $T_2 = 858.17\text{ K}$

Problem -4

Also, for process 1-2, we have $\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^{\gamma}$

$$\frac{1}{P_2} = \left(\frac{1}{13.5}\right)^{1.4}$$

$$P_2 = 38.23 \text{ Bar}$$

For constant volume process 2-3, we have $\frac{P}{T}$ = Constant

$$\text{i.e.,} \quad \frac{P_2}{T_2} = \frac{P_3}{T_3}$$

$$\therefore \quad T_3 = \frac{T_2 . P_3}{P_2} = \frac{(858.17)(70)}{38.23}$$

$$T_3 = 1571.3 \text{ K}$$

w.k.t. Cut-off ratio $\rho = \frac{T_4}{T_3}$

$$\therefore \quad T_4 = T_3 \, \rho$$

To find ρ Given $k = 0.1$

w.k.t. $\rho = 1 + k(R_C - 1)$

$$= 1 + 0.1(13.5 - 1)$$

Cut-off ratio $\rho = 2.25$

∴ Equation (2) becomes $T_4 = 1571.3\ (2.25)$

$$T_4 = 3535.4 \text{ K}$$

Problem -4

To fond T_5 For adiabatic process 4-5, we have $\frac{T_4}{T_5} = \left(\frac{V_5}{V_4}\right)^{\gamma-1}$

$$\frac{3535.4}{T_5} = \left(\frac{V_1}{V_4}\right)^{1.4-1}$$

$$\frac{3535.4}{T_5} = \left(\frac{V_1}{V_3}\cdot\frac{V_3}{V_4}\right)^{0.4}$$

$$= \left(\frac{V_1}{V_2}\cdot\frac{1}{\rho}\right)^{0.4} \qquad (\because\ V_3 = V_2 \text{ and } \frac{V_3}{V_4} = \frac{1}{\rho})$$

$$\frac{3535.4}{T_5} = \left(\frac{13.5}{2.25}\right)^{0.4} \qquad (\because\ \frac{V_1}{V_2} = R_c = 13.5)$$

$$T_5 = 1726.5 \text{ K}$$

Problem -4

Also, for process 4-5, we have $\frac{T_4}{T_5} = \left(\frac{P_4}{P_5}\right)^{\frac{\gamma-1}{\gamma}}$

$$\frac{3535.4}{1726.5} = \left(\frac{70}{P_5}\right)^{\frac{1.4-1}{1.4}}$$

$$P_5 = 5.7 \text{ Bar}$$

Thus, P_1 = 1Bar, P_2 = 38.23 Bar, $P_3 = P_4$ = 70 Bar, P_5 = 5.7 Bar

T_1 = 303 K, T_2 = 858.17 K, T_3 = 1571.3 K, T_4 = 3535.4 K, T_5 = 1726.5 K

Problem -4

To find air standard efficiency (η)

w.k.t. $\text{efficiency} = \eta = \dfrac{\text{Work done}}{\text{Heat supplied}} = \dfrac{Q_s - Q_r}{Q_s}$ -----(3)

where $Q_s = (Q_s)_{23} + (Q_s)_{3.4}$

$= mC_V(T_3 - T_2) + mC_P(T_4 - T_3)$

$Q_s = 1\,(0.718)\,(1571.3 - 858.17) + 1\,(1.005)\,(3534.4 - 1571.3)$

$Q_s = 2484.94\ \text{kJ/kg}$

$Q_r = mC_V(T_5 - T_1) = 1\,(0.718)\,(1726.5 - 303)$

$Q_r = 1022\ \text{kJ/kg}$

Equation (3) becomes, $\eta = \dfrac{2484.94 - 1022}{2484.94}$

$\therefore \quad \eta = \mathbf{58.8\%}$

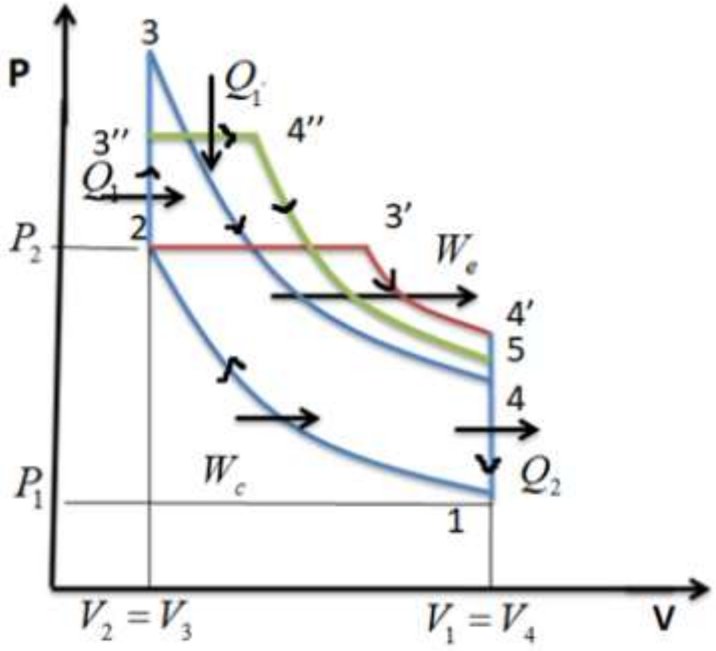
Comparison of Otto, Diesel and Dual Cycles

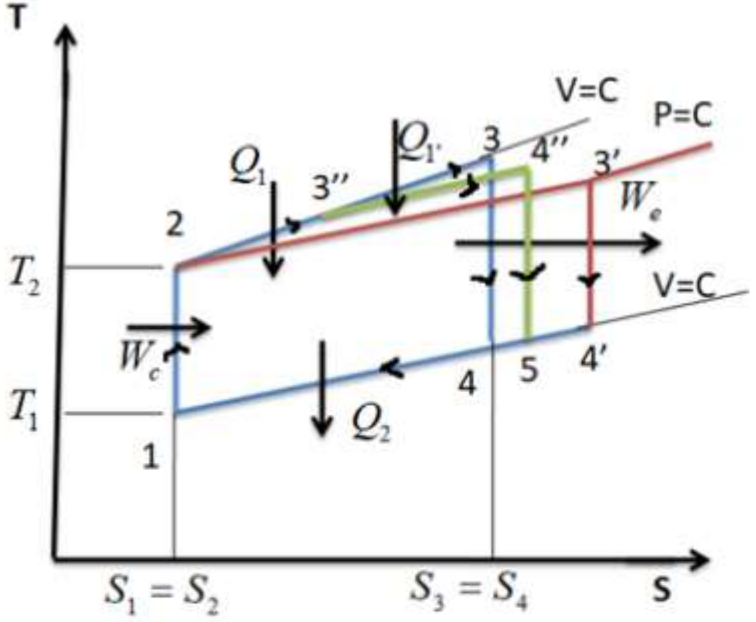
For same compression ratio and heat supplied

1-2-3-4 -1 is Otto cycle

1-2-3'-4'-1 is diesel cycle

1-2-3''-4''-5-1 is dual cycle





$$\text{w.k.t.} \quad \eta_{air} = \frac{\text{Work done}}{\text{Heat supplied}}$$

$$= \frac{Q_s - Q_r}{Q_s} = 1 - \frac{Q_r}{Q_s}$$

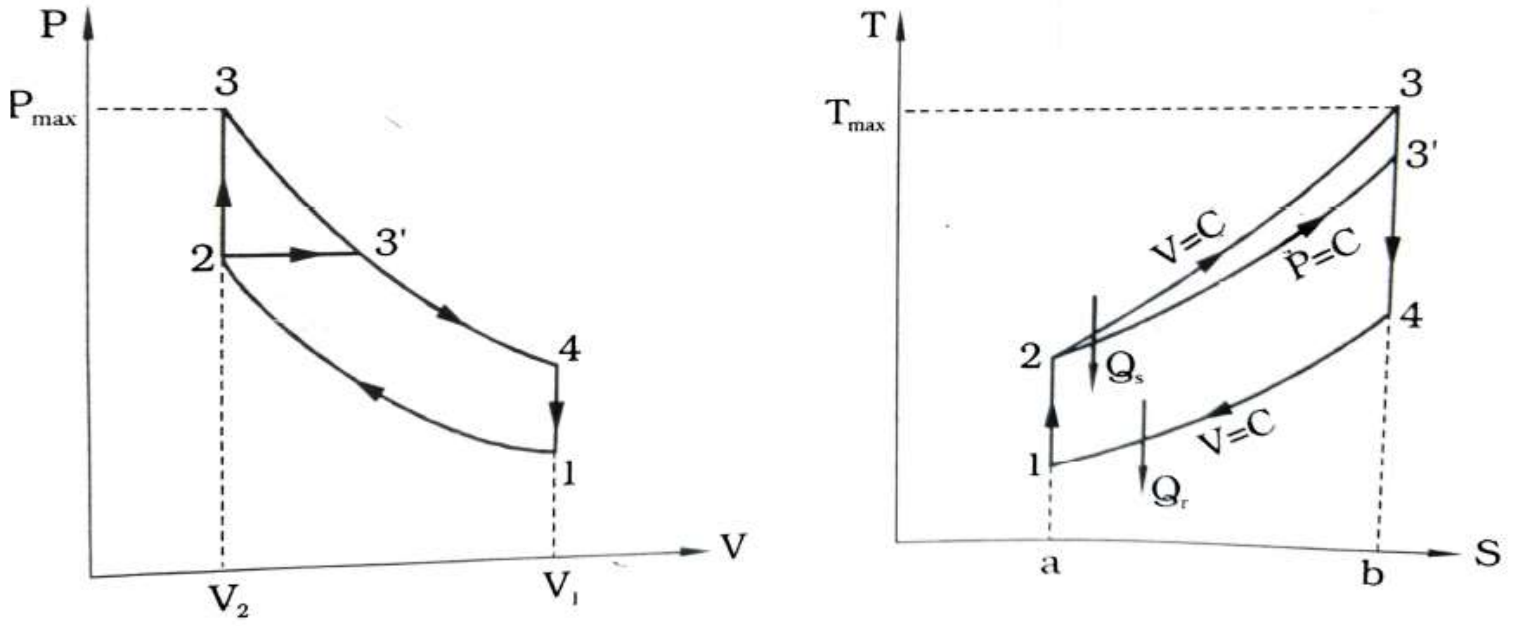
$$\therefore \eta_{otto} > \eta_{Dual} > \eta_{Diesel}$$

Comparison of Otto, Diesel and Dual Cycles

Same compression ratio and heat rejection

w.k.t. $\eta_{air} = \dfrac{\text{Work done}}{\text{Heat supplied}}$

$$= \frac{Q_s - Q_r}{Q_s} = 1 - \frac{Q_r}{Q_s}$$



Otto Cycle : 1-2-3-4

Diesel Cycle : 1-2-3'-4

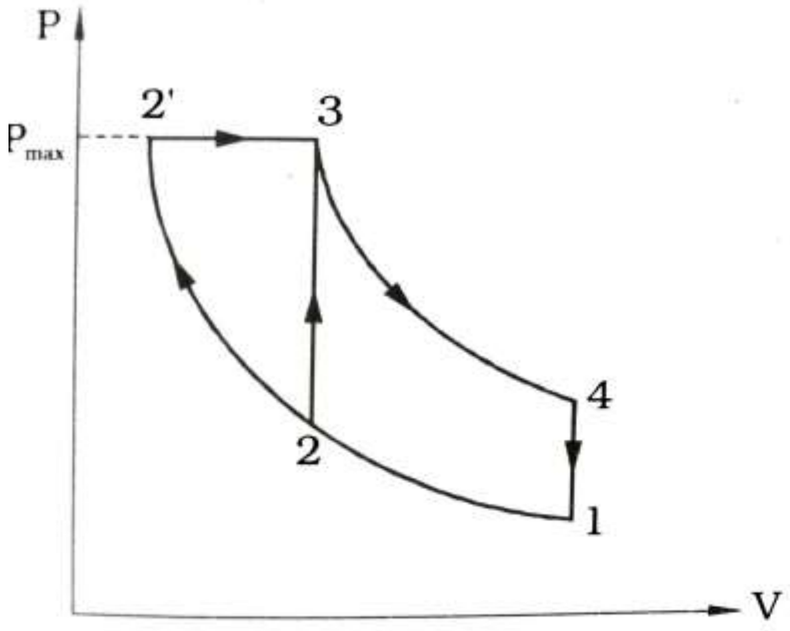
Otto cycle has a comparatively higher efficiency than Diesel cycle

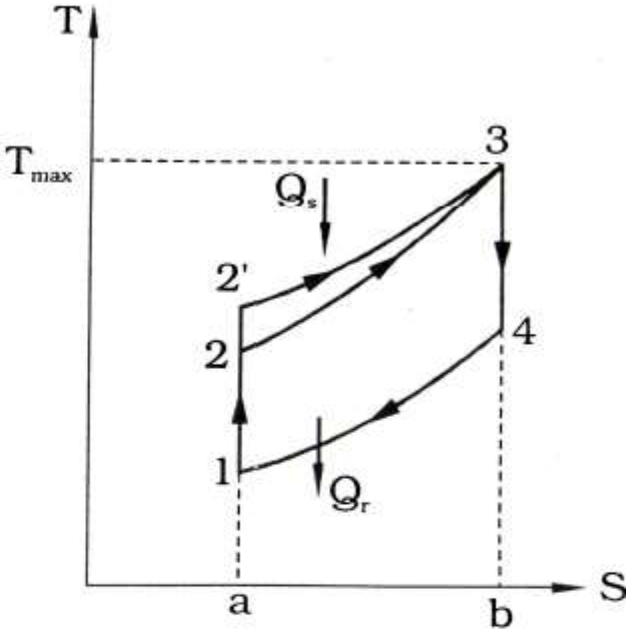
Comparison of Otto, Diesel and Dual Cycles

For Same maximum pressure, maximum temperature and heat rejection

w.k.t. $\eta_{air} = \dfrac{\text{Work done}}{\text{Heat supplied}}$

$$= \frac{Q_s - Q_r}{Q_s} = 1 - \frac{Q_r}{Q_s}$$





Otto Cycle : 1-2-3-4

Diesel Cycle : 1-2'-3-4

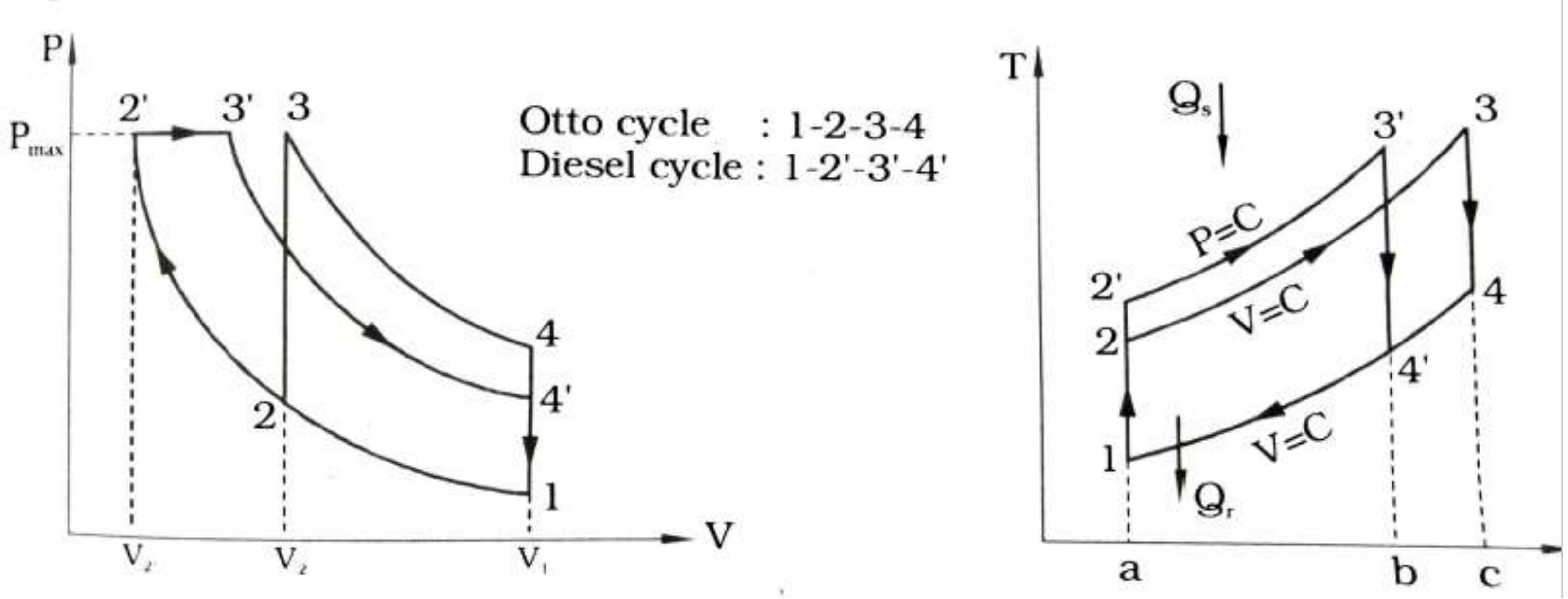
Diesel cycle has a comparatively higher efficiency than Otto cycle

Comparison of Otto, Diesel and Dual Cycles

- **For Same maximum pressure and heat input**

w.k.t. $\eta_{air} = \dfrac{\text{Work done}}{\text{Heat supplied}}$

$$= \frac{Q_s - Q_r}{Q_s} = 1 - \frac{Q_r}{Q_s}$$



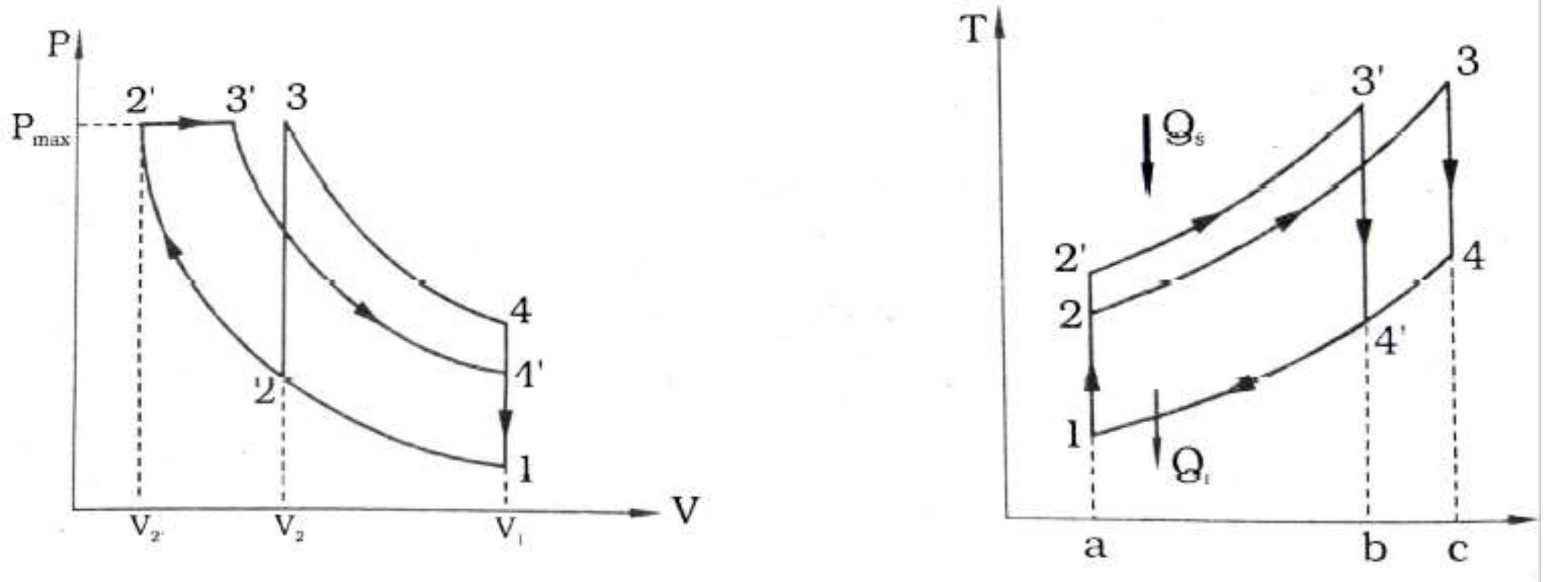
Diesel cycle is more efficient than Otto cycle

Comparison of Otto, Diesel and Dual Cycles

For Same maximum pressure and work output

w.k.t. $\eta_{air} = \dfrac{\text{Work done}}{\text{Heat supplied}}$

$$= \frac{Q_s - Q_r}{Q_s} = 1 - \frac{Q_r}{Q_s}$$



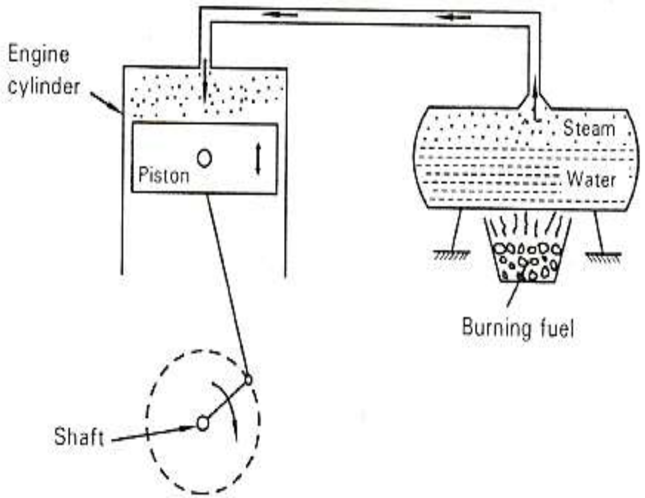
Otto cycle : 1-2-3-4
Diesel cycle : 1-2'-3'-4'

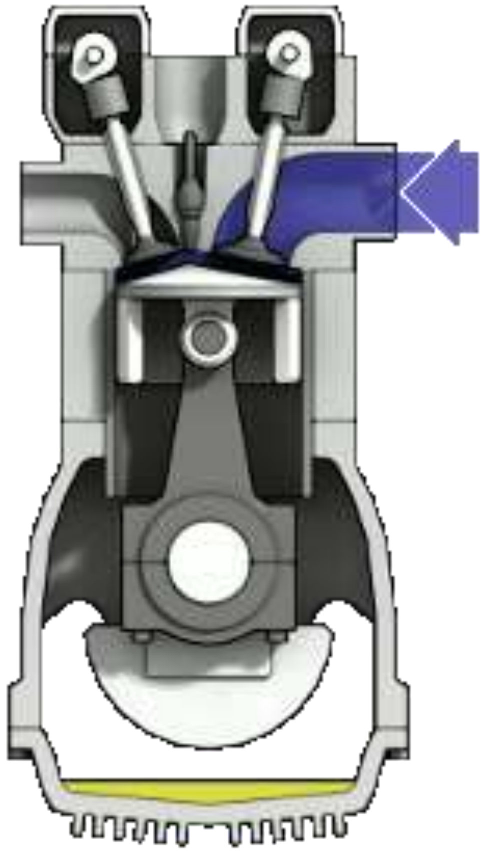
Diesel cycle is more efficient than Otto cycle

I.C ENGINE

Heat engine can be defined as a device or machine that converts the chemical energy of a fuel into heat energy by combustion of fuel, and utilizes this heat energy to perform useful mechanical work (usually in the form of rotation of shaft)

- Internal combustion engine
- External combustion engine





CLASSIFICATION OF IC ENGINE

(1) According to the type of fuel used:

a) Petrol engine

b) Diesel engine

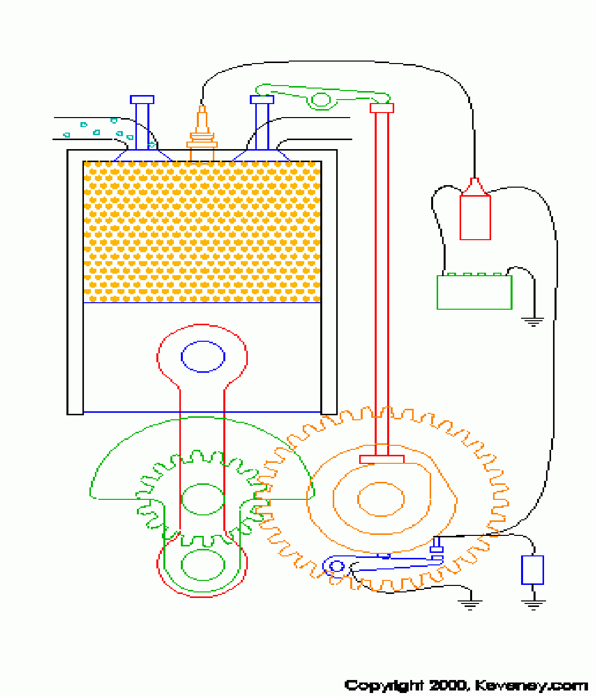
c) Gas engine

d) Bi-fuel (Bio-fuel) engine

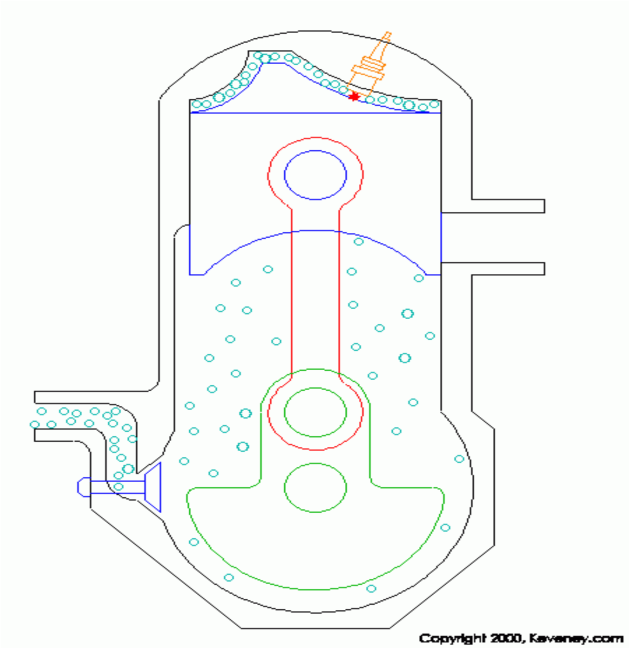
CLASSIFICATION OF IC ENGINE

(2) According to the number of strokes per cycle:

- 4-stroke engine



- 2-stroke engine



CLASSIFICATION OF IC ENGINE

(3) According to the method of ignition:

a) Spark Ignition (SI) engine

b) Compression Ignition (CI) engine

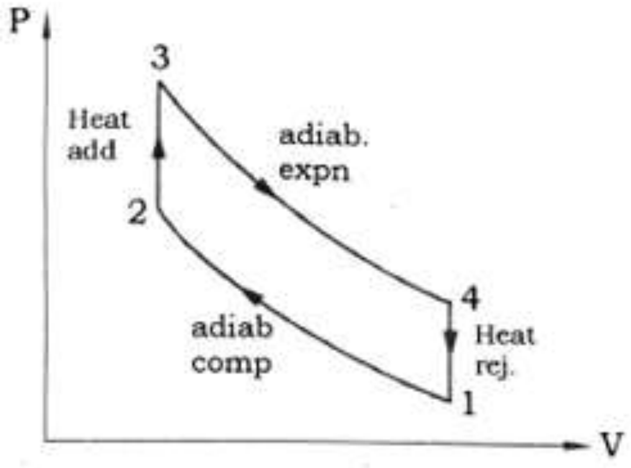
CLASSIFICATION OF IC ENGINE

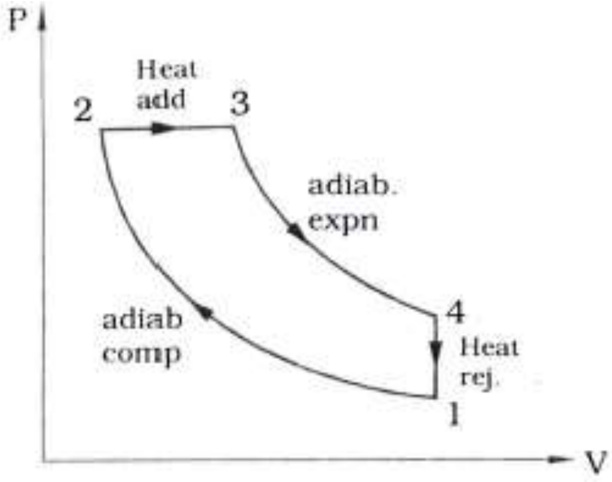
(4) According to the cycle of combustion:

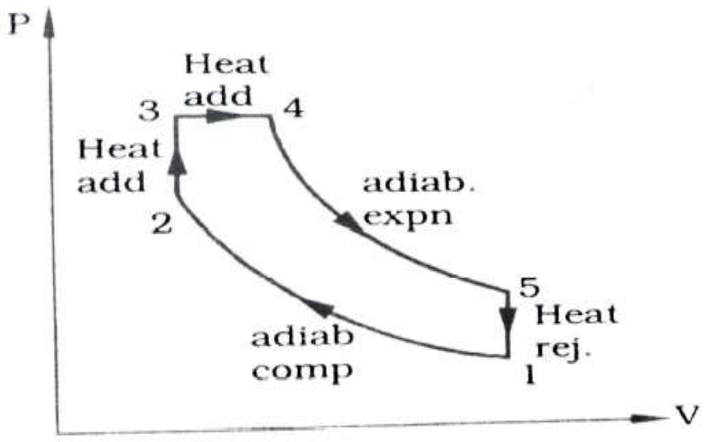
a) Otto cycle engine

b) Diesel cycle engine

c) Dual combustion cycle engine





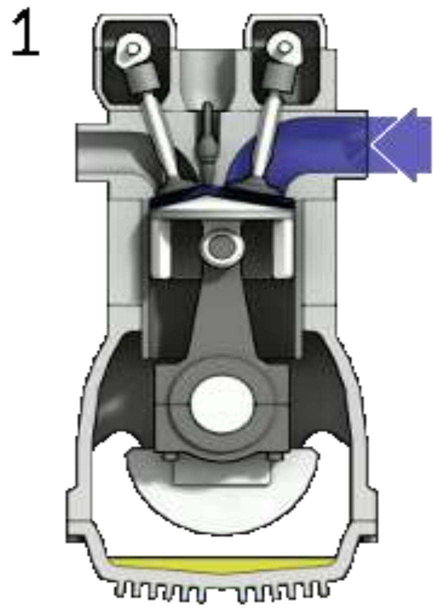


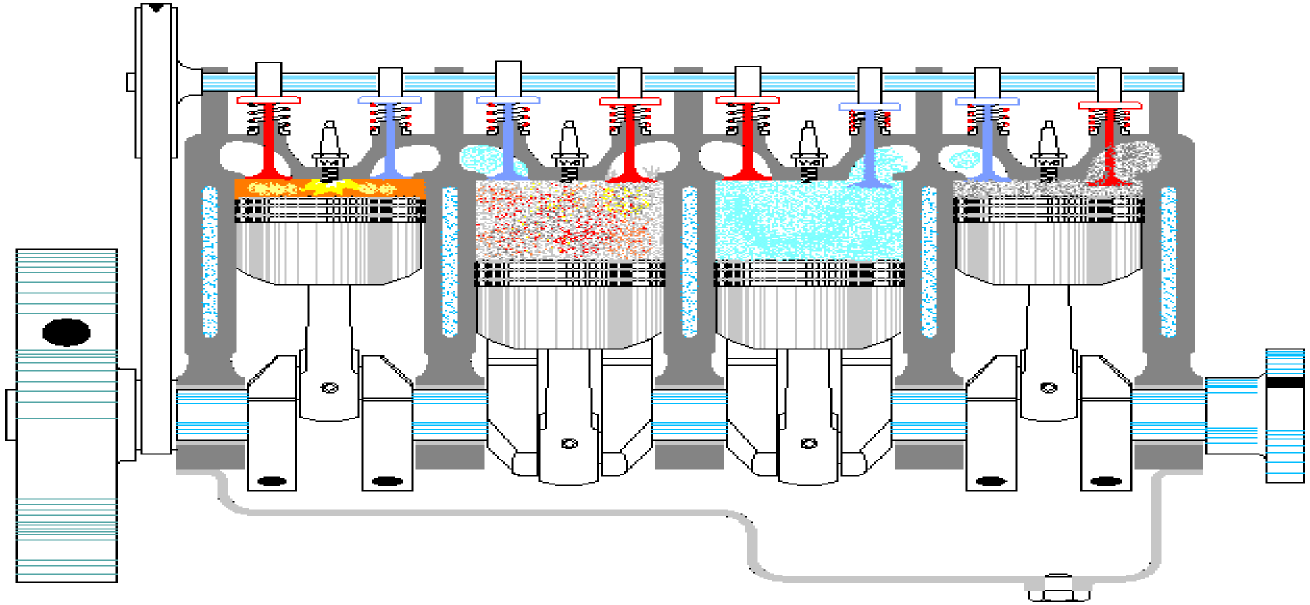
CLASSIFICATION OF IC ENGINE

(5) According to the number of cylinders used:

a) Single cylinder engine

b) Multi-cylinder engine

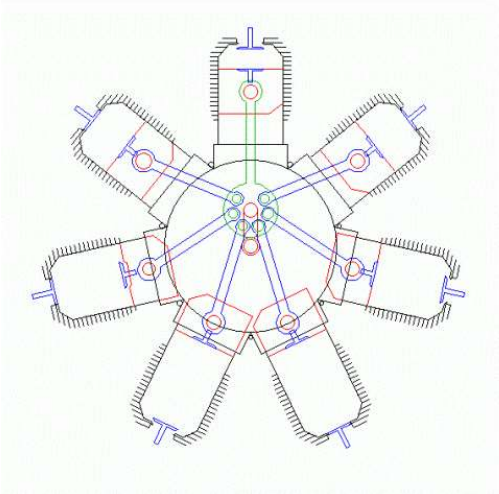




CLASSIFICATION OF IC ENGINE

(6) According to the arrangement of cylinders:

a) Vertical engine
b) Horizontal engine
c) Inline engine
d) Radial engine
e) V-engine
f) Opposed type engine



CLASSIFICATION OF IC ENGINE

(7) According to the method of cooling:

a) Air cooled engine

b) Water cooled engine

(8) According to their uses:

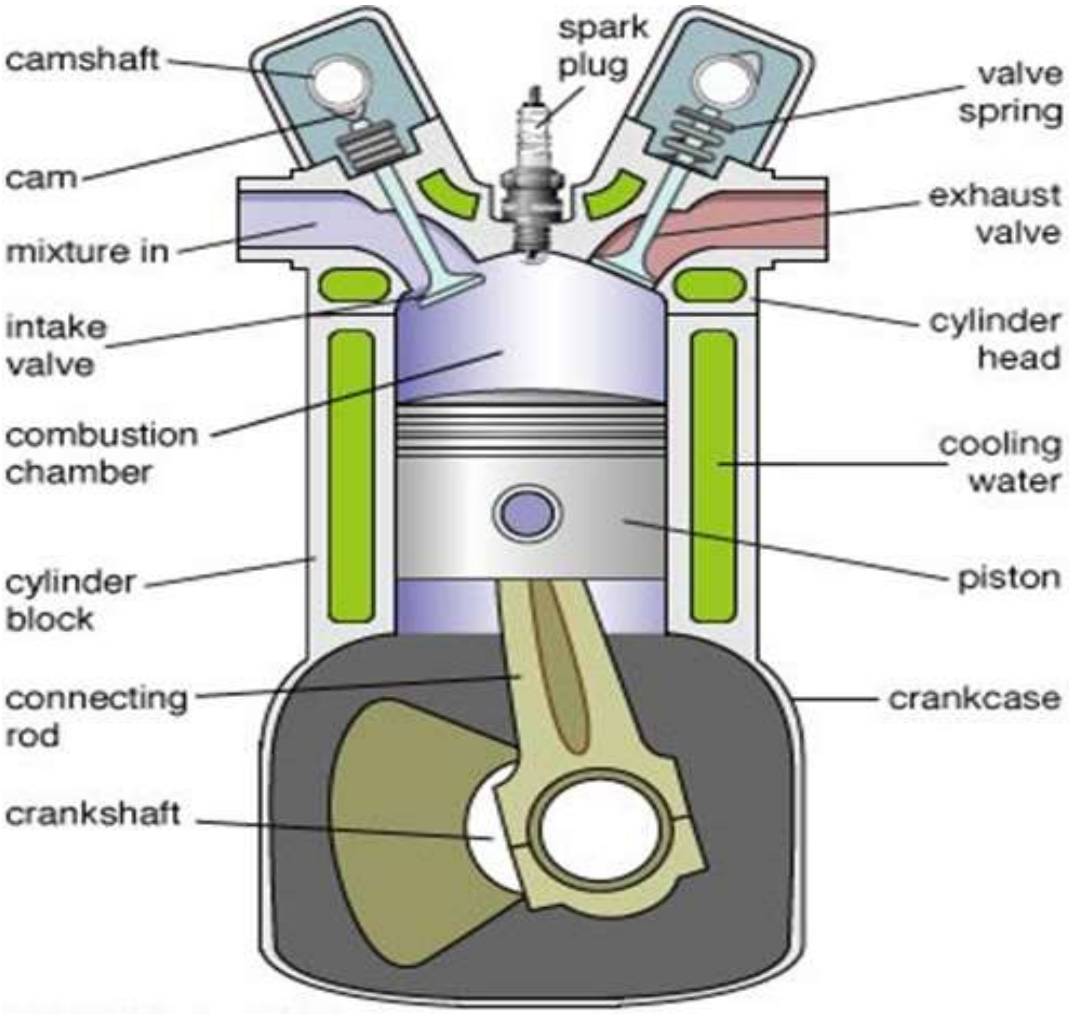
a) Stationary engine

b) Automobile engine

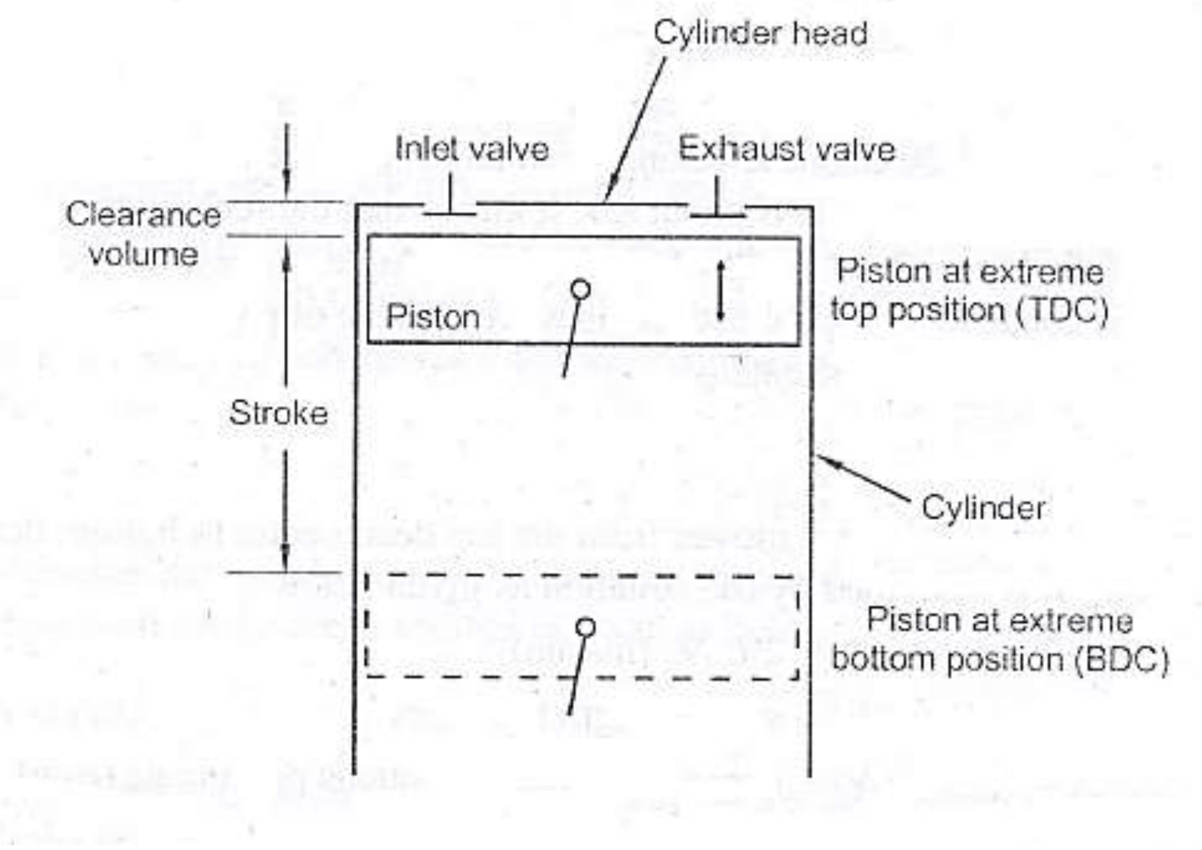
c) Marine engine

d) Aircraft engine, etc

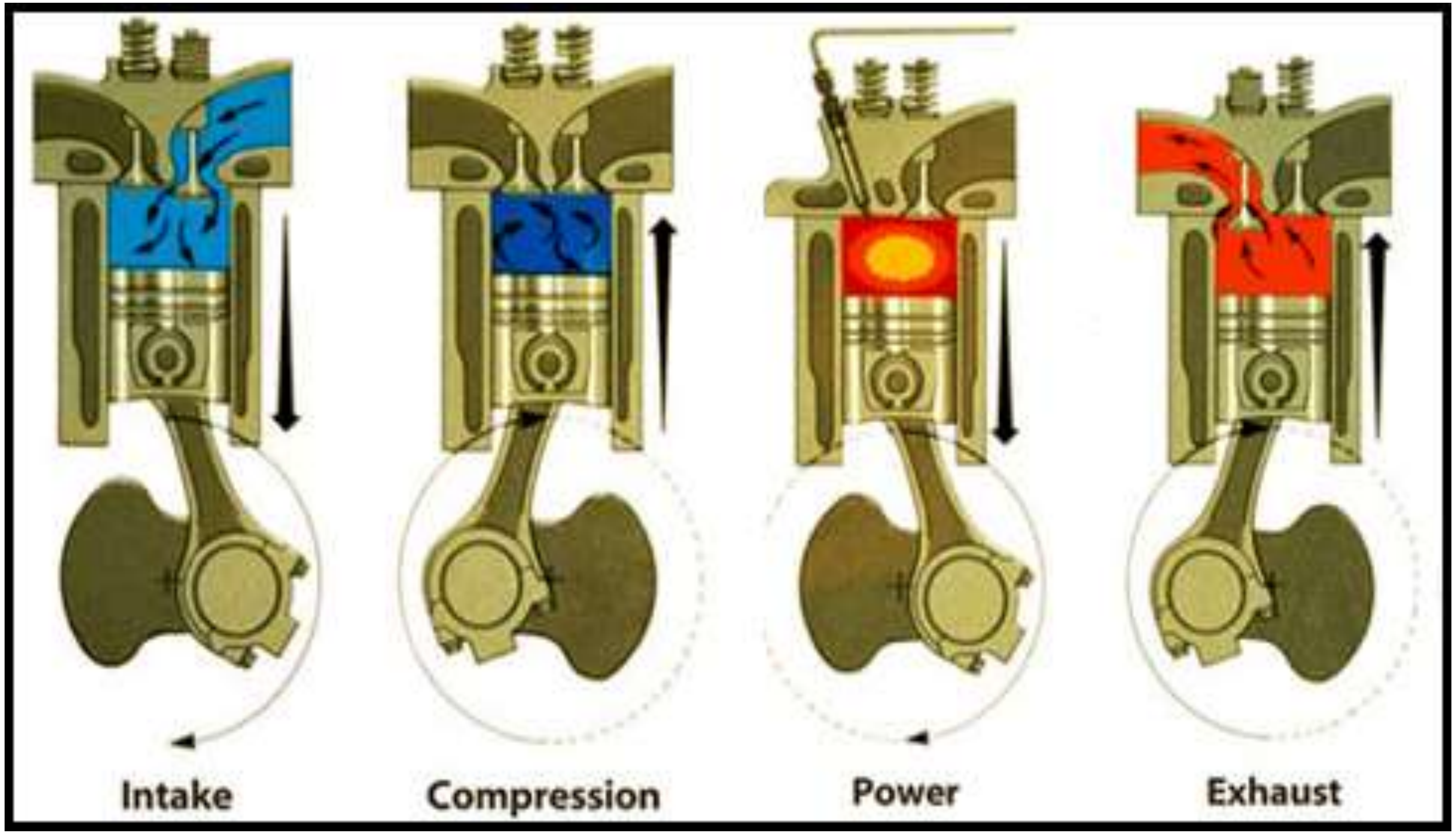
PARTS OF IC ENGINE

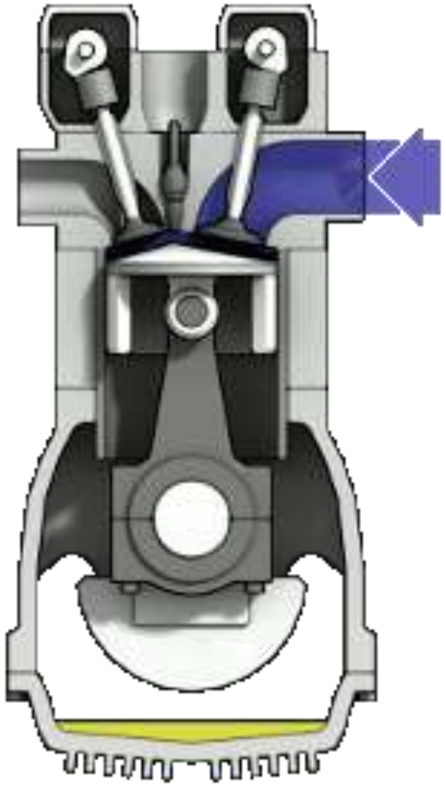


IC ENGINE TERMINOLOGY

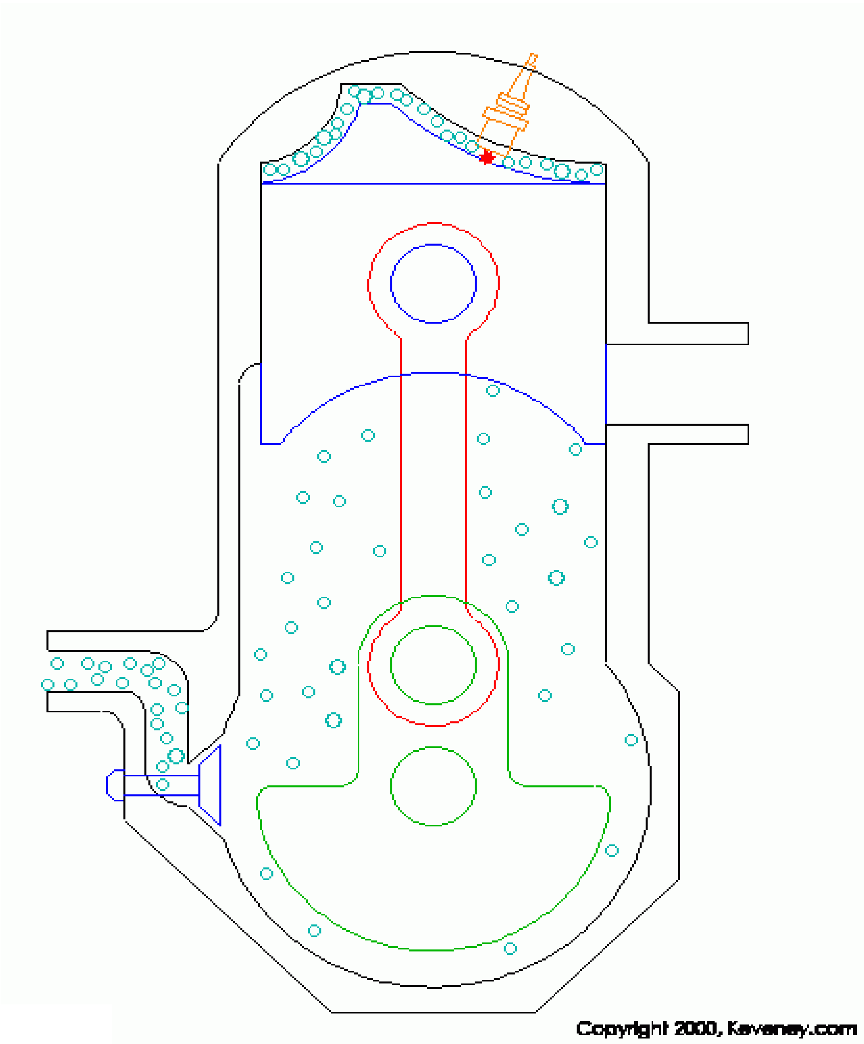


Four - Stroke (4-s) Engine





2-stroke engine



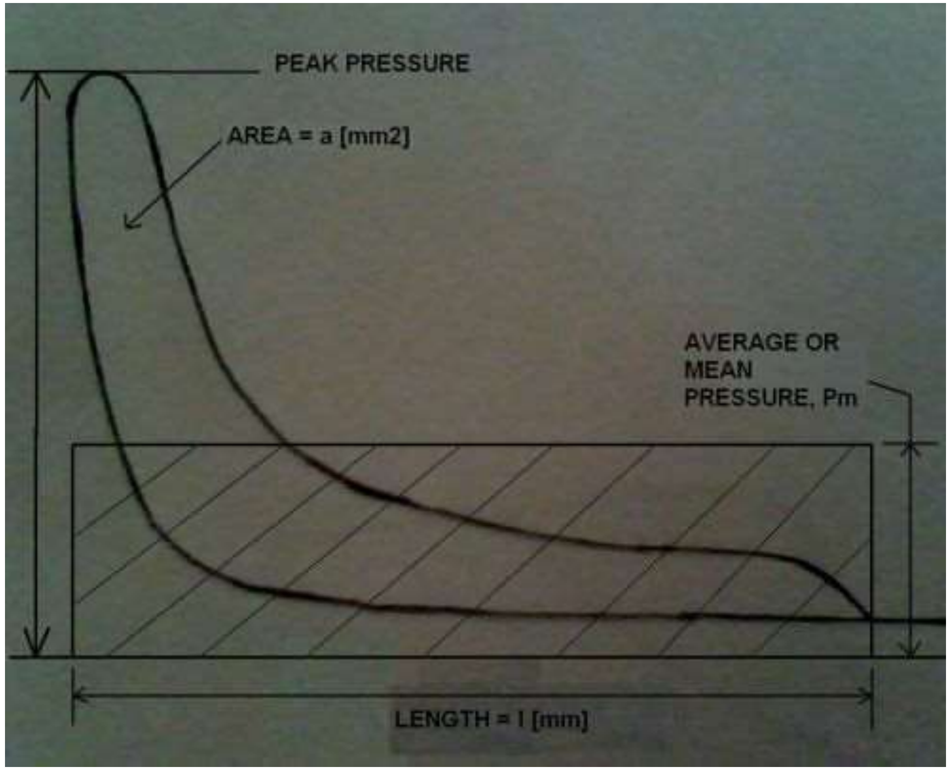
Performance Parameters

- **Mean Effective Pressure (MEP) - P_m**

It is expressed in Bar (1Bar = 10^5 N/m^2)

$$MEP = P_m = \frac{\begin{pmatrix} \text{spring value of the spring used} \\ \text{in the indicator } (S) \text{ in bar / m} \end{pmatrix} \times \begin{pmatrix} \text{net area of the indicator} \\ \text{diagram } (a) \text{ in } m^2 \end{pmatrix}}{\text{length of the indicator diagram } (l) \text{ in m}}$$

$$P_m = \frac{Sa}{l} \text{ Bar}$$



Performance Parameters

Indicated Power (IP)

$$\text{Indicated Power} = \frac{p_m\, L\, A\, N}{60 \times 2 \times 1000} \ \text{kW}$$

p_m = Mean Effective Pressure, N/m^2

L = Length of Stroke, m

A = Area of Cross section of the Cylinder, sq m

N = RPM of the Crankshaft.

n = Number of cycles per minute.

Brake Power (BP)

BP is given by, $BP = \frac{2\pi NT}{60\times 1000} kW$

where N = speed of engine in *rpm*

T = Torque in *N-m*

Torque (T) is measured by using either *belt* or *rope brake dynamometer*.

Friction Power (FP)

$$FP = IP - BP \ \ kW$$

Performance Parameters

Mechanical Efficiency

$$\eta_{mech} = (BP/IP) \times 100$$

Thermal Efficiency

$$\eta_{th} = \frac{power\ output}{heat\ supplied} \times 100$$

w.k.t. Heat supplied $= (m_f) \times CV$

where m_f = mass of fuel in kg/sec.

CV = calorific value of fuel in kJ/kg.

$$\text{Indicated thermal effiiciency} = \eta_{ITH} = \frac{IP}{m_f \times CV} \times 100$$

$$\text{Brake thermal efficiency} = \eta_{BTH} = \frac{BP}{m_f \times CV} \times 100$$

Performance Parameters

Specific Fuel Consumption

$$\text{i.e., SFC} = \frac{m_f(kg/hr)}{Power\ developed\ (kW)}\ \ kg/kW\text{-}hr$$

where m_f = mass of fuel (kg/hr)

Power developed can be based on IP or BP.

SFC based on IP is termed indicated specific fuel consumption (ISFC), and is given by the equation

$$\text{ISFC} = \frac{Fuel\ consumed\ in\ kg/hr}{IP\ in\ kW}\ \ kg/kWhr$$

While SFC based on BP is termed brake specific fuel consumption (BSFC), and is given by the equation

$$\text{BSFC} = \frac{Fuel\ consumed\ in\ kg/hr}{BP\ in\ kW}\ \ kg/kWhr$$

1. A single cylinder 4-stroke diesel engine gave the following results while running at full load. Area of the indicator diagram 300 mm², length of diagram 40 mm, spring constant 1 bar/mm, speed of the engine 400rpm, load on the brake drum 370 N, Spring balance reading 50 N, diameter of brake drum 1.2 m, fuel consumption 2.8 kg/hr. CV of fuel 41800 kJ/kg, diameter of the cylinder 160 mm, stroke of the piston 200 mm. determine a) IMEP b) BMEP c) BP d) BSFC e) Brake thermal & Indicated thermal efficiencies.

Data Given:

area of indicator card = 300 mm², length of diagram = l = 40 mm

spring constant = s = 1 bar/mm, engine speed = 400 rpm

brake load = W = 370 N, spring reading = S = 50 N

Drum diameter = D = 1.2 m $\quad \therefore$ Drum radius = $\frac{D}{2} = 0.6$ m

Fuel consumption = m_f = 2.8 kg/hr = 7.77×10^{-4} kg/sec

CV of fuel = 41800 kJ/kg

diameter of cylinder = d = 160 mm = 0.16 m $\quad \therefore$ $A = \frac{\pi}{4} d^2 = 0.020$ m²

stroke = L = 200 m = 0.2m

Problem -1

w.k.t. $\text{IMEP} = P_m = \frac{s.a}{l} = \frac{1 \times 300}{40}$

$$P_m = \text{IMEP} = 7.5 \text{ Bar}$$

$$BP = \frac{2\pi NT}{60 \times 1000} \text{ kW}$$

$$T = (W - S)R = (370-50) \times 0.6 = 192 \text{ Nm}$$

$$BP = \frac{2 \times \pi \times 400 \times 192}{60 \times 1000}$$

$$BP = n\, P_{mb}\, L\, A\, N\, k \left(\frac{10}{6}\right)$$

$$8.04 = 1 \times P_{mb} \times 0.2 \times 0.02 \times 400 \times \frac{1}{2} \times \frac{10}{6}$$

$$\text{BMEP} = P_{mb} = 6.03 \text{ Bar}$$

w.k.t. $\text{BSFC} = \frac{\text{Fuel consumed in kg / hr}}{BP}$

$$= \frac{2.8}{8.04}$$

$$\text{BSFC} = 0.348 \text{ kg/kW-hr}$$

Problem -1

$$\text{w.k.t. } \eta_{BTH} = \frac{BP}{m_f \times cv}$$

$$= \frac{8.04}{7.77 \times 10^{-4} \times 41800}$$

$$\eta_{BTH} = \mathbf{24.7\%}$$

$$\eta_{ITH} = \frac{IP}{m_f \times cv}$$

$$\text{w.k.t. } IP = n P_m L A N k \left(\frac{10}{6}\right) = 1 \times 7.5 \times 0.2 \times 0.02 \times 400 \times \frac{1}{2} \times \frac{10}{6}$$

$$IP = 10 \text{ kW}$$

$$\eta_{ITH} = \frac{IP}{m_f \times cv}$$

$$\eta_{ITH} = \frac{10}{7.77 \times 10^{-4} \times 41800}$$

$$\eta_{ITH} = \mathbf{30.79\%}$$

2. Following observations were recorded during a test on 4- stroke Diesel engine: cylinder Dia.= 25cm, stroke=40cm, speed=250 rpm, brake load = 70 kg, brake drum diameter=2m, MEP= 6bar, diesel oil consumption = 0.1 m³/min, sp.gr. Of fuel = 0.78, CV of fuel = 43900 kJ/kg. Determine a) IP b) BP c) FP d) Mechanical efficiency e) Brake thermal efficiency f) Indicated thermal efficiency

Data Given:

$$\text{4-S engine} = k = \frac{1}{2}, \text{ Cylinder diameter} = 25 \text{ cm} = 0.25 \text{ m}$$

$$\text{Cross-sectional area of cylinder} = A = \frac{\pi}{4}d^2 = \frac{\pi}{4}(0.25)^2 = 0.049 \text{ m}^2$$

$$\text{Stroke} = L = 40 \text{ cm} = 0.4 \text{ m, Speed } N = 250 \text{ rpm}$$

$$\text{Brake load} = 70 \text{ kg} = 70 \times 9.81 = 686.7 \text{ N}$$

$$\text{Brake drum diameter} = D = 2 \text{ m} \quad \therefore \text{ Radius } R = 1\text{m}$$

$$\text{MEP} = P_m = 6 \text{ bar, Oil consumption} = 0.1 \text{ m}^3/\text{min}$$

$$\text{CV of fuel} = 43900 \text{ kJ/kg}$$

$$\text{Specific gravity of fuel} = 0.78$$

$$\text{Mass of fuel} = m_f = \frac{0.1 \times 0.78}{60} = 1.3 \times 10^{-3} \text{ kg/sec.}$$

Problem -2

$$IP = n P_m L A N k \left(\frac{10}{6}\right)$$

IP = 24.5 kW

$$BP = \frac{2\pi NT}{60 \times 1000} \text{ kW}$$

$$BP = \frac{2 \times \pi \times 250 \times 686.7}{60000}$$

BP = 17.97 kW

$$FP = IP - BP = 24.5 - 17.97$$

FP = 6.53 kW

Problem -2

$$\text{w.k.t. } \eta_{mech} = \frac{BP}{IP} = \frac{17.97}{24.5}$$

$$\eta_{mech} = 73.3\%$$

$$\text{w.k.t. } \eta_{BTH} = \frac{BP}{m_f \times cv} = \frac{17.97}{(1.3 \times 10^{-3}) \times (43900)}$$

$$\eta_{BTH} = 31.4\%$$

$$\text{w.k.t. } \eta_{ITH} = \frac{IP}{m_f \times cv}$$

$$= \frac{24.5}{(1.3 \times 10^{-3}) \times (43900)}$$

$$\eta_{ITH} = 42.9\%$$

1. **Which of the following is not an assumption while analyzing Air standard cycles?**

   a. The working medium follows the law pV=mRT
   b. Working medium has constant specific heats
   c. Working medium does not undergo any chemical change throughout the cycle
   d. Heat is supplied and rejected in irreversible manner

Ans: d

2. For perfect gas

a. $c_p - c_v = R$
b. $c_p + c_v = R$
c. $c_p / c_v = R$
d. $c_p \times c_v = R$

Where c_p & c_v are specific heats at constant pressure and volume.

Ans: a

3. In Air standard cycle, the W/Q (W = Work transfer from the cycle, Q = Heat transfer to the cycle) ratio is known as

a. Specific consumption
b. Specific work transfer
c. Air standard efficiency
d. Work ratio

Ans: c

4. The Carnot cycle consists of

a. Two isothermal and two adiabatic processes
b. Two isothermal and two constant volume processes
c. Two isothermal and two constant pressure processes
d. Two isothermal and two isenthalpic processes

Ans: a

5. In which of the following cycle heat is added at constant volume?

a. Otto cycle
b. Diesel cycle
c. Dual cycle
d. Carnot cycle

Ans:a

6. In which of the following cycle heat is added at constant pressure?

a. Otto cycle
b. Diesel cycle
c. Dual cycle
d. Carnot cycle

Ans: b

7. The efficiency of the Otto cycle is independent of

a. Heat supplied
b. Compression ratio
c. Ratio of specific heats
d. None of the above

Ans: d

8. For same compression ratio

a. Diesel cycle has lower efficiency than Otto cycle
b. Diesel cycle has higher efficiency than Otto cycle
c. Diesel cycle and Otto cycle have equal efficiencies
d. Depends upon the load on engine

Ans: a

9. Which of the following is also known as Limited pressure cycle?

a. Otto cycle
b. Diesel cycle
c. Dual cycle
d. Carnot cycle

Ans: c

10. What is the formula for compression (r_k) ratio of the Otto cycle?

a. r_c = Volume of cylinder at the beginning of compression / Volume of cylinder at the end of compression

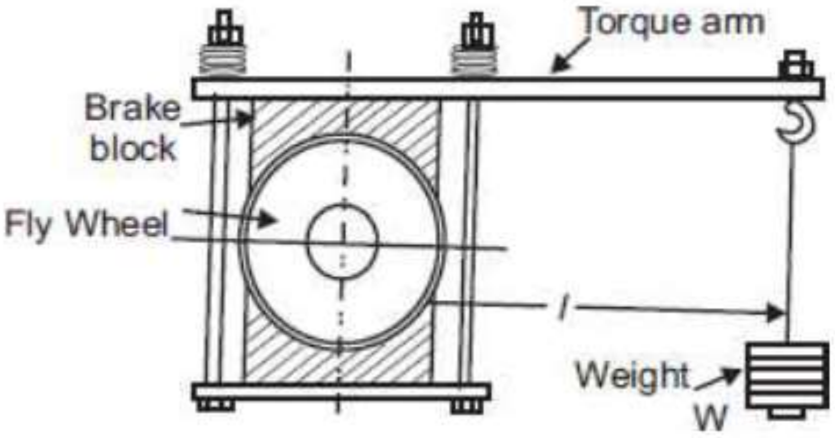
b. r_c = Volume of cylinder at the end of compression / Volume of cylinder at the beginning of compression

c. r_c = Volume of cylinder at the end of compression / clearance volume

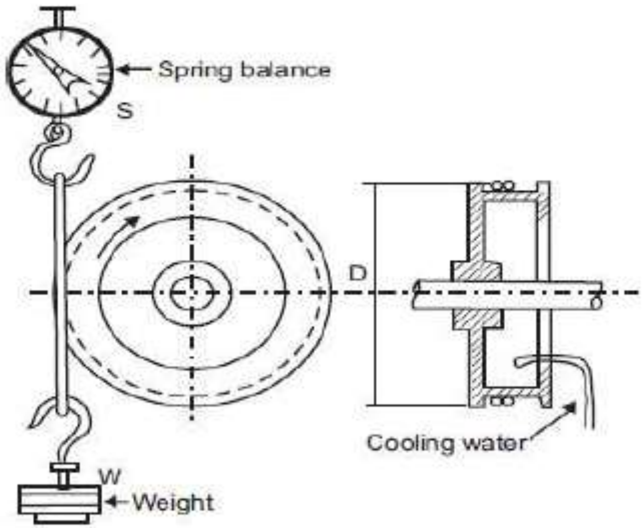
d. none of the above

Ans: a

Measurement of brake power



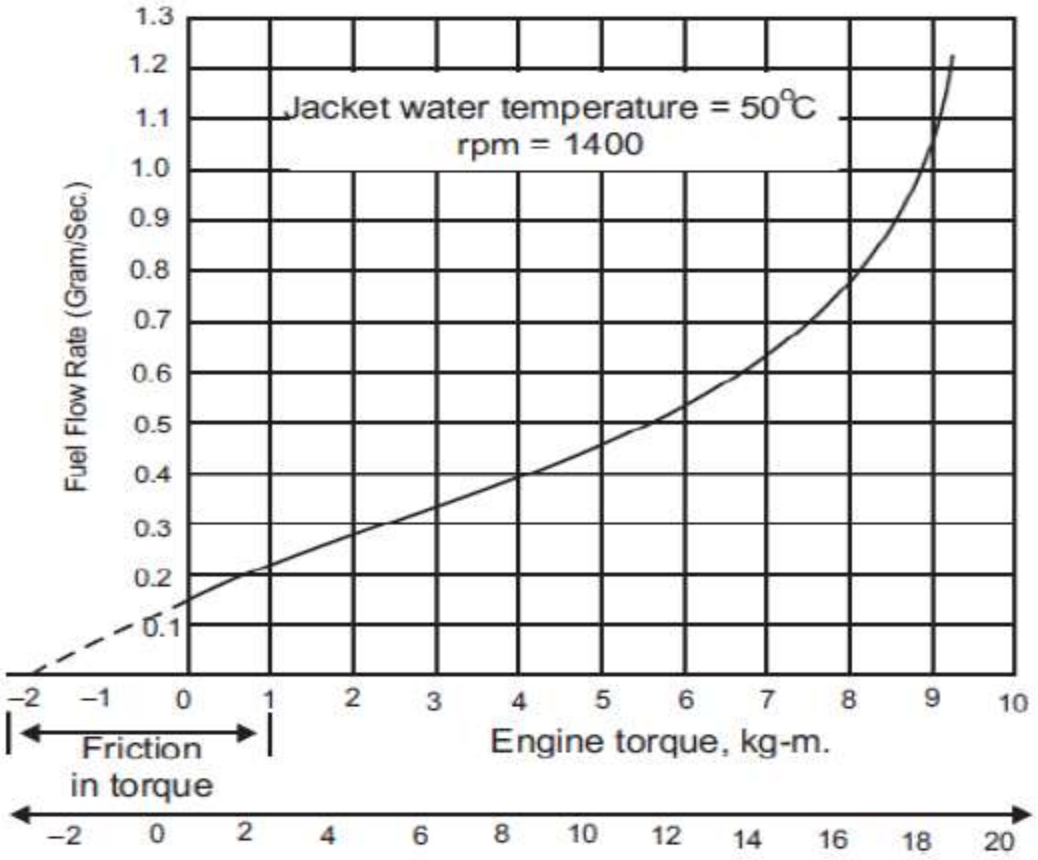
(B) Rope brake dynamometer:
(A) Prony brake dynamometer:



$$BP = \frac{2\pi NT}{60 \times 1000} \text{ kW}$$

Measurement of Friction power

- *Willan's line method.*
- *•Morse test.*
- *•Motoring test.*



Morse test.

- The Morse test is applicable only to multicylinder engines.

- With all cylinder firing = BP kW
- Cut off at 1st cylinder = BP1 kW
- Cut off at 2nd cylinder = BP2 kW
- Cut off at 3rd cylinder = BP3 Kw

IP1 = BP-BP1, IP3 = BP-BP3

$$IP = IP_1 + IP_2 + IP_3$$

3. A test was conducted in a 4-stroke single cylinder SI engine having 7cm diameter and 9cm stroke. The fuel supply to the engine is 0.065 kg/m. The B.P measurements are given below with constant speed of an engine. With all cylinder firing = 16.9 kW, Cut off at 1st cylinder = 8.46 kW, Cut off at 2nd cylinder = 8.56 kW, Cut off at 3rd cylinder = 8.6 kW, Cut off at 4th cylinder = 8.5 kW. If clearance volume 69.5 cm3. Find Indicate Power, Indicated thermal efficiency also compare the thermal efficiencies. Take CV = 43500 kJ/kg

Data Given:

4S, SI engine

D	= 7 cm		V_c	=	69.5
L	= 9 cm		BP_1	=	8.46 kW
mf	= 0.065 kg/min		BP_2	=	8.56 kW
CV	= 43500 KJ/kg		BP_3	=	8.6 kW
BP	= 16.9 kW		BP_4	=	8.5 kW

Find

(i) IP (ii) In thη (iii) $\eta_{rel} = \dfrac{In.th\,\eta}{Air\ Std\ \eta}$

Problem -3

$IP_1 = BP - BP_1$

$IP_1 = 16.9 - 8.46$

$IP_1 = 8.44$ Kw

$IP_2 = BP - BP_2$

$= 16.9 - 8.56$

$IP_2 = 8.34$ kW

$IP_3 = BP - BP_3$

$= 16.9 - 8.6$

$IP_3 = 8.3$ kW

$IP = IP_1 + IP_2 + IP_3 + IP_4$

$= 8.44 + 8.34 + 8.3 + 8.4$

$IP = 33.48$ kW

$$\text{In th}_{\eta} = \frac{IP \times 60}{mf \times CV} = \frac{33.48 \times 60}{0.065 \times 43500}$$

$\eta_{In}\ th = 71.04\%$

Problem -3

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

$$\text{r(compression ratio)} = \frac{\text{Total Volume}}{\text{Volume}}$$

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

$$V_s = \frac{\pi}{4} D^2 L$$

$$= \frac{\pi}{4} \times 7^2 \times 9$$

$$= 346.36 \text{ cm}^3$$

$$r = \frac{69.6 + 346.36}{69.6} = 5.98$$

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

$$\eta_{air} = 1 - \frac{1}{(5.98)^{0.4}}$$

$$\eta_{air} = 51.09\%$$

$$\eta_{rel} = \frac{\eta_{In.th}}{\eta_{air}}$$

$$. = 1.39\%$$

4. Following are the particulars of a 4-cylinder 4-S petrol engine having bore 6cm, stroke 9cm and a rated speed 2800rpm. The engine is tested at this speed against brake which has a torque arm of 0.37m. The net brake load is 160N and the fuel consumption is 8.986 lt/hr. The specific gravity of petrol used is 0.74 and it has a lower CV of 44100 KJ/kg. A Morse test is carried out and the cylinders are cut out in the order 1,2,3,4 with corresponding brakes loads of 110, 107, 104, and 110N respectively. Calculate for this speed (a) The engine torque (b) BMEP (c) η_{BT} (d) SFC (e) η_{mech} (f) IMEP

$n = 4$; $d = 6$ cm $= 0.06$ m ; $L = 9$ cm $= 0.09$ m, $N = 2800$ rpm, Torque arm $= 0.37$ m,
$W = 160$ N ; $m_f = 8.986$ lt/hr ; Sp. gravity $= 0.74$, CV $= 44100$ kJ/kg, $W_1 = 110$ N,
$W_2 = 107$ N, $W_3 = 104$ N and $W_4 = 110$ N

To find engine torque.

w.k.t. Torque = Load × distance ---- (1)

= (Net brake load) × (Torque arm)

$= 160 \times 0.37$

Engine Torque = T = 59.2 Nm

w.k.t. $BP = nP_{mb}LANk\left(\frac{10}{6}\right)$ ---- (2)

Problem -4

But BP = ?

w.k.t. $BP = \dfrac{2\pi NT}{60 \times 1000} = \dfrac{2 \times \pi \times 2800 \times 5.92}{60000}$

$BP = 17.35$ kW

$\therefore$ Equation (2) becomes, $17.35 = 4 \times P_{mb} \times 0.09 \left(\dfrac{\pi}{4} \times 0.06^2\right) 2800 \times \left(\dfrac{1}{2}\right)\left(\dfrac{10}{6}\right)$

$\therefore$ **BMEP = P_{mb} = 7.3 Bar**

To find η_{BTH}

w.k.t. $\eta_{BTH} = \dfrac{BP}{m_f \times CV}$

Given, m_f = 8.986 lt/hr, and specific gravity = 0.74

$m_f = 8.986 \times 0.74 = 6.65$ kg/hr or 1.847×10^{-3} kg/sec

Problem -4

$\therefore$ Equation (3) becomes, $\eta_{BTH} = \dfrac{17.35}{(1.847 \times 10^{-3})44100}$

$$\eta_{BTH} = 21.3\%$$

To find SFC (i.e., BSFC)

$$\text{w.k.t. } BSFC = \frac{\text{fuel consumed in kg / hr}}{BP} = \frac{6.65}{17.35}$$

$$\mathbf{BSFC = 0.383\ kg/kW\text{-}hr}$$

$\eta_{mech} = ?$

$$\text{w.k.t. } \eta_{mech} = \frac{BP}{IP}$$

Problem -3

But IP = ?

For Morse Test, $IP = (BP - BP_1) + (BP - BP_2) + (BP - BP_3) + (BP - BP_4)$

From equation (1) we have, T = brake load (W) × torque arm (0.37)

$$BP_1 = \frac{2\pi NT_1}{60000} = \frac{2\pi N(W_1 \times 0.37)}{60000} = \frac{2 \times \pi \times 2800(110 \times 0.37)}{60000} = 11.92 \text{ kW}$$

$$BP_2 = \frac{2\pi NT_2}{60000} = \frac{2\pi N(W_2 \times 0.37)}{60000} = \frac{2 \times \pi \times 2800(107 \times 0.37)}{60000} = 11.59 \text{ kW}$$

$$BP_3 = \frac{2\pi NT_3}{60000} = \frac{2\pi N(W_3 \times 0.37)}{60000} = \frac{2 \times \pi \times 2800(104 \times 0.37)}{60000} = 11.27 \text{ kW}$$

Problem -4

$$BP_4 = \frac{2\pi NT_4}{60000} = \frac{2\pi N(W_4 \times 0.37)}{60000} = \frac{2 \times \pi \times 2800(110 \times 0.37)}{60000} = 11.92 \text{ kW}$$

∴ Equation (5) becomes,

$$IP = (17.35 - 11.92) + (17.35 - 11.59) + (17.35 - 11.27) + (17.35 - 11.92)$$

$$IP = 22.7 \text{ kW}$$

∴ Equation (4) becomes, $\eta_{mech} = \dfrac{17.35}{22.7}$

$$\eta_{mech} = \mathbf{76.43\%}$$

Problem -4

To find IMEP (P_m)

$$\text{w.k.t. } IP = nP_m\,LANk\left(\frac{10}{6}\right)$$

$$22.7 = (4)(P_m)0.09\left(\frac{\pi}{4}\times 0.06^2\right)2800\times\frac{1}{2}\times\frac{10}{6}$$

$$\mathbf{P_m = 9.55\ Bar}$$

Heat Balance sheet

- The heat balance sheet from the above data can be drawn as follows:

Particulars	*kJ/s or kJ/min or kJ/hr*	*Percent*
a) Heat supplied by fuel	**----**	**------**
b) Heat absorbed in B.P. **c) Heat taken away by cooling water** **d) Heat carried away by the exhaust gases** **e) Heat unaccounted for (a-(b+c+d))**	**----** **----** **----** **----**	**------** **------** **------** **------**
Total	**----**	**------**

5. The following data is given on a single cylinder 4-S oil engine, Cylinder diameter = 18cm, Stroke = 36cm, Engine speed = 286 rpm , Brake torque = 375 N-m, Indicated mean effective pressure = 7 bar, Fuel consumption = 3.88 lit/hr ,Sp. gravity of fuel = 0.8, Calorific value of fuel = 44500 KJ/kg. Then air fuel ratio used = 25:1, ambient air temperature = 21ºC,Specific heat of gas = 12 kJ/kg-k, Exhaust gas temperature = 415ºC, Cooling water circulated = 4.2 Kg/min, Rise in temperature in cooling water= 28.5ºC, find (1) Mechanical efficiency (2) Indicated thermal efficiency (3) Draw heat balance sheet on % basis.

Given

SS, 4S oil engine

D	=	18×10^{-2} m	$T_a=21^\circ C$
L	=	36×10^{-2} m	$(C_p)_{gas}=1.2$ KJ/kgk
N	=	286 rpm	Tex gas=$415^\circ C$
T	=	375 N	$m_c=4.2$ kg/min
pm	=	7 bar	$(\Delta T)_c=28.5^\circ C$
mf	=	3.88 lit/hr	
specific gravity	=	0.8	
CV	=	44500 KJ/hr	

$$\text{Air-fuel ratio}=\frac{m_a}{m_f}=25$$

$$m_a = 25\times m_f$$

$$m_f = 3.88 \text{ lit/hr}$$

$$= 3.88\times10^{-3} \text{ m}^3\text{/hr}$$

Problem -5

$$\eta_m = \frac{BP}{IP}$$

$$BP = \frac{2\pi NT}{60} KW$$

$$= \frac{2\pi \times 286 \times 375}{60}$$

$$BP = 11.23 \text{ KW}$$

$$N_w = \frac{N}{2} = \frac{286}{2} = 143 \text{ (4 stroke)}$$

$$IP = \frac{100\, pm\, LANw}{60}$$

$$= 15.28 \text{ kW}$$

$$\eta_m = \frac{11.23}{15.28} = 73.19\%$$

$$\eta_{In.th} = \frac{I_p \times 60}{\frac{mf}{60} \times CV} = \frac{I_P \times 3600}{m_f \times C_v} = \frac{15.28 \times 3600}{3.17 \times 44500}$$

Problem -5

To prepare heat balance sheet

Heat supplied by the fuel

$$Q_s = m_f \times CV$$

$$= \frac{3.104}{60} \times 44500$$

$$Q_s = 2302.13 \text{ kJ/min}$$

$\%$ of $Q_s = 100\%$

Heat carried away by C_w

$$Q_c = m_c Q_c (\Delta T)\ c$$

$$= 4.2 \times 4.186\ (28.5)$$

$$Q_c = 501.06 \text{ kJ/min}$$

$$\% \text{ of } Q_c = \frac{501.06}{2302.13} \times 100$$

$$\%\ Q_c = 21.76\%$$

Problem -5

Heat taken by or gas

$$Q_g = m_g.C_{p,g}\,(\Delta T)\ g$$

$$= m_g\,C_{pg}\,(T_g\text{-}T_a)$$

$$= 1.29 \times 1.2\,(415\text{-}21)$$

$$= 609.91 \text{ kJ/min}$$

$$\%\,Q_g = \frac{609.91}{2302.13} \times 100$$

$$Q_g = 26.46\%$$

$$\text{mass of air} = 25 \times \frac{3.104}{60}$$

$$= 1.29 \text{ Kg/min}$$

Unaccounted heat

$$Q_{IP} = 15.28 \times 60$$

$$= 916.8 \text{ KJ/min}$$

$$\%Q_{IP} = 39.8\%$$

$$\text{Unaccounted heat} = Q_s - [Q_{IP}+Q_c+Q_g]$$

$$= 2302.13 - [916.8+501.06+609.91]$$

$$= 274.36 \text{ KJ/min}$$

$$\%\text{ of } Q_{un} = \frac{274.35}{2302.13} \times 100$$

$$= 11.9\%$$

Problem -5

Heat Balance Sheet

SL.No.	Particulars	Heat	
		KJ/hr	%
	Total Heat supply by the fuel	**2302.13**	**100**
1.	Heat to indicated power	916.8	38.82
2.	Heat Rejected to water	501.06	21.26
3.	Heat taken by exhaust gas	609.91	29.49
4.	Unaccountable	284.36	11.9
	Total	**4604.26**	**100%**

6. In a trial of a single cylinder oil engine working on dual cycle, the following observations were made Compression ratio = 15Oil, consumption = 10.2 kg/h, Calorific value of fuel = 43890 kJ/kg, Air consumption = 3.8 kg/min, Speed = 1900 r.p.m, Torque on the brake drum = 186 N-m, Quantity of cooling water used = 15.5 kg/min, Temperature rise = 36ºC, Exhaust gas temperature = 410ºC, Room temperature = 20ºC,cp for exhaust gases = 1.17 kJ/kgK. Calculate : (i) Brake power, (ii) Brake specific fuel consumption and (iii) Brake thermal efficiency. Draw heat balance sheet on minute basis

$n=1$, $r=15$, $m_f=10.2$ kg/h, $C=43890$ kJ/kg, $m_a=3.8$ kg/min, $N=1900$ r.p.m.,

$T=186$ N-m, $m_\omega=15.5$ kg/min, $t_{w2}-t_{w1}=36^\circ C$, $t_g=410^\circ C$, $t_r=20^\circ C$,

(i) Brake Power, B.P:

$$B.P = \frac{2\pi NT}{60\times 1000} = \frac{2\pi\times 1900\times 186}{60\times 1000} = 37\,kW$$

(ii) Brake specific fuel consumption b.s.f.c: $$\text{b.s.f.c.} = \frac{10.2}{37} = 0.2756\,kg/kWh.$$

(iii) Brake thermal efficiency,

$$\eta_{th(B)} = \frac{B.P}{m_f\times C} = \frac{37}{\frac{10.2}{3600}\times 43890} = 0.2975 \text{ or } 29.75\%$$

Problem -6

Heat supplied by fuel $= \frac{10.2}{60} \times 43890 = 7461\,kJ/\min$

(i) Heat equivalent B.P $= 2220$ kJ/min

$= B.P \times 60 = 37 \times 60$

Heat carried away by cooling water

2332 kJ/min

Heat carried away exhaust gases $= m_w \times c_{pg} \times (t_g - t_r)$

$$= \left(\frac{10.2}{60} + 3.8\right) \times 1.17 \times (410 - 20)$$

$$= 1811\,kJ/\min$$

Item	KJ/hr	%
Heat supplied by fuel	7461	100
i. Heat absorbed in B.P	2220	29.8
ii. Heat taken away by cooling water	2332	31.2
iii. Heat carried away exhaust gases	1811	24.3
iv. Heat unaccounted for (by difference)	1098	14.7
Total	7461	100