# *Internal Combustion Engines*

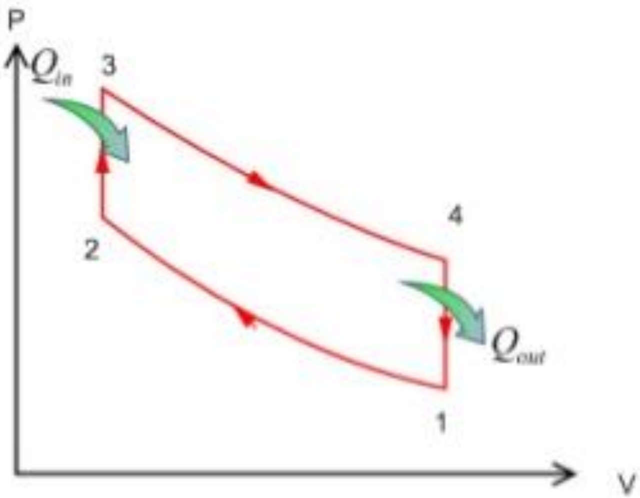
## Lecture-4

**Swarnendu Sen**
**Professor**
**Department of Mechanical Engineering**
**Jadavpur University**
**Kolkata – 700032**
**E-mail: sen.swarnendu@gmail.com**

# Example Problem

An Otto cycle having a compression ratio of 9:1 uses air as the working fluid. Initially $P_1$ = 95 kPa, $T_1$ = 17°C, and $V_1$ = 3.8 liters. During the heat addition process, 7.5 kJ of heat are added. Determine all $T$'s, $P$'s, $\eta_{th}$, the back work ratio and the mean effective pressure.

***Solution:***




Data given:

$$T_1 = 290K$$

$$V_1 / V_2 = 9$$

$$Q_{23} = 7.5kJ$$

$$P_1 = 95kPa$$

$$V_1 = 3.8\,Litres$$

**Process 1–2 (isentropic compression)**

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1} \Rightarrow T_2 = 290(9)^{0.4} = 698.4K$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{k-1} \Rightarrow P_2 = 95(9)^{1.4} = 2059kPa$$

**Process 2–3 (Const. volume heat addition)**

$$1^{st}\ law: Q_{net} - \cancel{W_{net}}^{0} = \Delta U$$

$$Q_{23} = mC_v(T_3 - T_2)$$

$$IGL: \quad P_1 v_1 = RT_1 \Rightarrow v_1 = \frac{0.2871(290)}{95} = 0.875\,\tfrac{m^3}{kg}$$

$$q_{23} = \frac{Q_{23}}{m} = Q_{23}\frac{v_1}{V_1} = 1727\,\tfrac{kJ}{kg}$$

$$Back\ to\ IGL:$$

$$q_{23} = C_v(T_3 - T_2)$$

$$= 0.718(T_3 - 698.4)$$

$$T_3 = 3103.7K$$

$$But\ V_3 = V_2$$

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

$$P_3 = 9.15\,MPa$$

**Process 3–4 (isentropic expansion)**

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{k-1} \Rightarrow T_4 = T_3(1/9)^{0.4} = 1288.8K$$

$$\frac{P_4}{P_3} = \left(\frac{V_3}{V_4}\right)^{k} \Rightarrow P_4 = P_3(1/9)^{1.4} = 422\,kPa$$

## $Process\ 4-1\ (Const.volume\ heat\ rejection)$

$$Q_{41} = mC_v\left(T_4 - T_1\right)$$

$$q_{41} = C_v\left(T_4 - T_1\right)$$

$$= 0.718\left(1288.8 - 290\right)$$

$$= 717.1 \tfrac{kJ}{kg}$$

Then:

$$W_{net} = q_{in} - q_{out}$$

$$= q_{23} - q_{41}$$

$$= 1009.6 \tfrac{kJ}{kg}$$

$$\eta_{th,Otto} = \frac{W_{net}}{q_{in}} = 0.585\left(58.5\%\right)$$

What else?

$$MEP = \frac{W_{net}}{V_{\max} - V_{\min}} = \frac{w_{net}}{v_{\max} - v_{\min}}$$

$$= \frac{w_{net}}{v_1 - v_2} = \frac{w_{net}}{v_1\left(1 - v_2 / v_1\right)}$$

$$= \frac{w_{net}}{v_1\left(1 - \frac{1}{r}\right)} = \frac{1009.6}{0.875\left(1 - 1/9\right)} = 1298\,kPa$$

$$r_{bw} = \frac{w_{compr}}{w_{expans}} = \frac{\Delta u_{12}}{-\Delta u_{34}} = \frac{\not{C_v}\left(T_2 - T_1\right)}{\not{C_v}\left(T_3 - T_4\right)}$$

$$= 0.225\left(22.5\%\right)$$

# Example Problem 2

An air-standard Diesel cycle has a compression ratio of 18 and a cut-off ratio of 2.5. The state at the beginning of compression is fixed by P = 0.9 bar ant T = 300K. Calculate:

i. the thermal efficiency of the cycle,

ii. the maximum pressure, $P_{max,}$ and

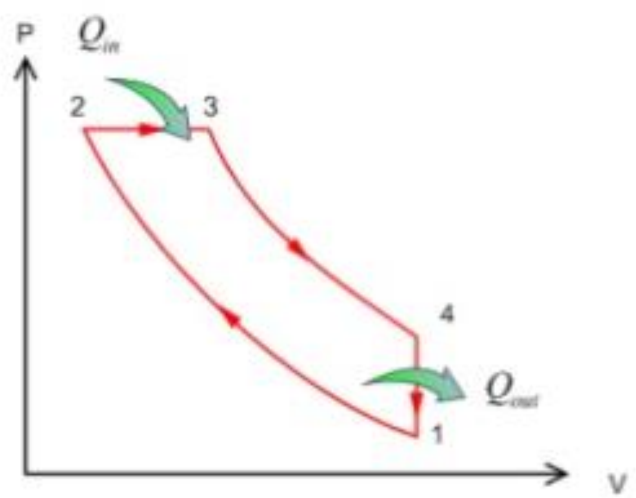
iii. The mean effective pressure.

***Solution:***

Data given:

$$\frac{V_1}{V_2} = 18$$

$$\frac{V_3}{V_2} = 2.5$$



$$\text{Process } 1-2 \, (isentropic\ compression)$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1} \Rightarrow T_2 = 300(18)^{0.4} = 953.3K$$

$$\text{Process } 2-3 \, (Const.\ pressure\ heat\ addition)$$

$$P_2 = P_3 \Rightarrow \frac{V_2}{T_2} = \frac{V_3}{T_3} \Rightarrow T_3 = T_2\left(\frac{V_3}{V_2}\right) = 2383.3\,K$$

$$\text{Process } 3-4 \, (isentropic\ expansion)$$

$$\frac{V_4}{V_3} = \frac{V_1}{V_2} \cdot \frac{V_2}{V_3} = 18(1/2.5) = 7.2$$

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{k-1} \Rightarrow T_4 = 2383.3(1/7.2)^{0.4} = 1082\,K$$

$$Q_{in} = Q_{23} = mC_P(T_3 - T_2) \Rightarrow q_{in} = C_p(T_3 - T_2) = 1437.15\,\tfrac{kJ}{kg}$$

$$Q_{out} = Q_{41} = mC_P(T_4 - T_1) \Rightarrow q_{out} = C_p(T_4 - T_1) = 561.48\,\tfrac{kJ}{kg}$$

$$w_{net} = q_{in} - q_{out} = 875.67\,\tfrac{kJ}{kg}$$

What we need?

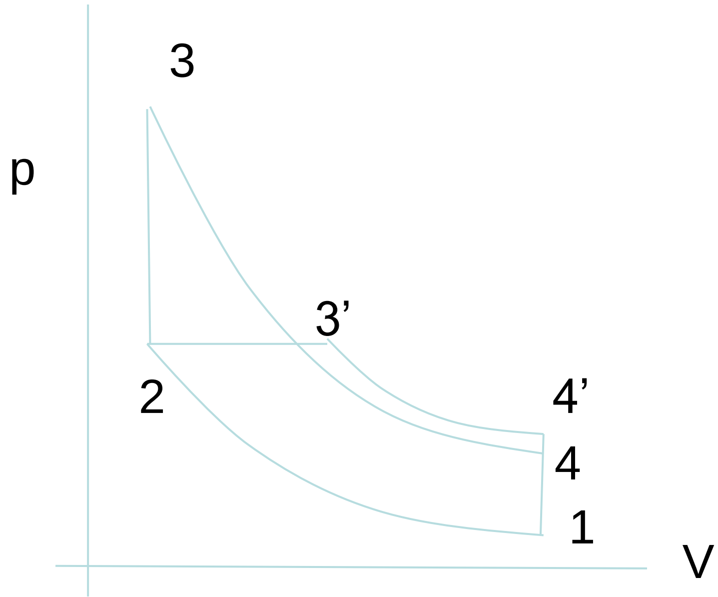
$$(i)\ \eta_{th,diesel} = \frac{w_{net}}{q_{in}} = \underline{\underline{0.6093(60.93\%)}}$$

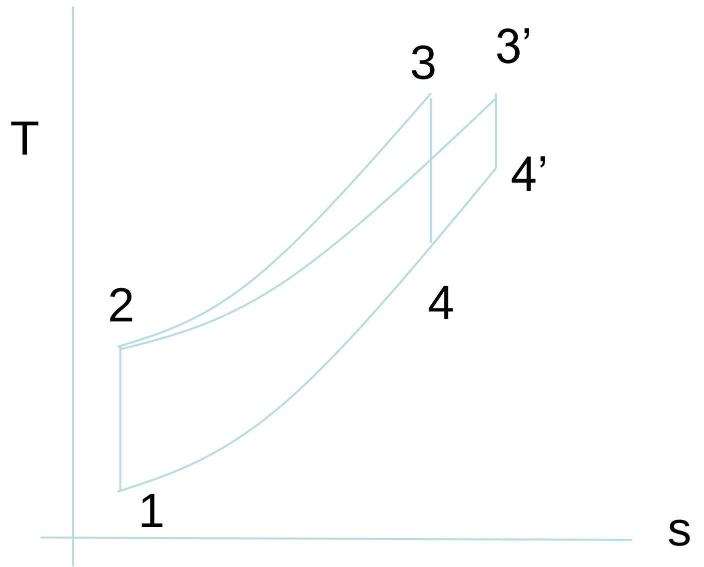
$$(ii)\ P_{max} = P_2 = P_3$$

$$\left(\frac{P_2}{P_1}\right) = \left(\frac{T_2}{T_1}\right)^{\frac{k-1}{k}} \Rightarrow P_2 = \underline{\underline{5148\,kPa\,(P_{max})}}$$

$$(iii)\ MEP = \frac{w_{net}}{V_1(1-1/r)} = \frac{875.67}{0.9566(1-1/18)} = \underline{\underline{969.1\,kPa}}$$

# Comparison of Otto and Diesel Cycles with Same Heat input and Compression Ratio




- Isobars are flat on T-s. 2-3' is flat and longer
- 4'-1 is longer and heat rejection is higher in Diesel cycle
- Otto is more efficient

# Thank You