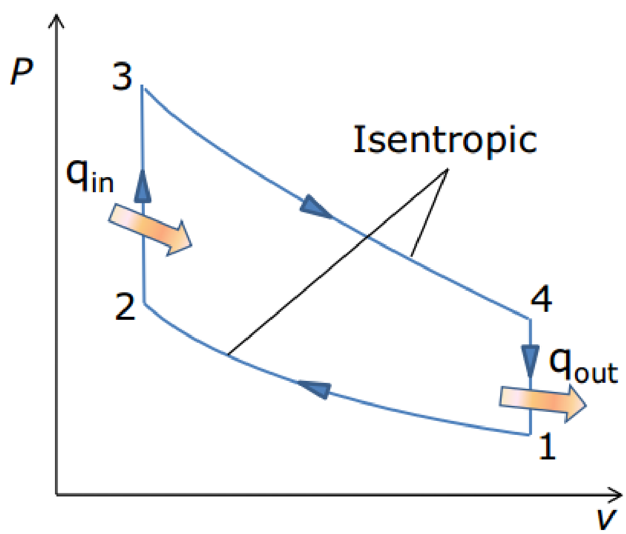
Problem 1

- In an air standard Otto cycle, the compression ratio is 7 and the compression begins at 35°C and 0.1 MPa. The maximum temperature of the cycle is 1100°C. Find (a) the temperature and the pressure at various points in the cycle, (b) the heat supplied per kg of air, (c) work done per kg of air, (d) the cycle efficiency and (e) the MEP of the cycle.



T_1=35°C=308 K
P_1=0.1 Mpa
T_3=1100°C=1373 K
$r=v_1/v_2=7$

- Since process, 1-2 is isentropic,

$$\frac{P_2}{P_1} = \left(\frac{v_1}{v_2}\right)^{\gamma} = 7^{1.4} = 15.24$$

- Hence, P_2=1524 kPa

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1} = 7^{1.4-1} = 2.178$$

- Hence, T_2=670.8 K

- For process, 2-3,

$$\frac{P_2 v_2}{T_2} = \frac{P_3 v_3}{T_3}, \ \therefore P_3 = \frac{T_3}{T_2} P_2 = \frac{1373}{607.8} \times 1524 = 3119.34$$

- P_3=3119.34 kPa.
- Process 3-4 is again isentropic,

$$\frac{T_3}{T_4} = \left(\frac{v_4}{v_3}\right)^{\gamma-1} = 7^{1.4-1} = 2.178$$

$$\therefore T_4 = \frac{1373}{2.178} = 630.39\,\text{K}$$

- Hence, T_2=630.39 K

- Heat input,

$$Q_{in}=c_v(T_3-T_2)$$
$$=0.718(1373-670.8)$$
$$=504.18\ \text{kJ/kg}$$

- Heat rejected,

$$Q_{out}=c_v(T_4-T_1)$$
$$=0.718(630.34-308)$$
$$=231.44\ \text{kJ/kg}$$

- The net work output, $W_{net}=Q_{in}-Q_{out}$

- The net work output,

$$W_{net}=Q_{in}-Q_{out}$$
$$=272.74\ \text{kJ/kg}$$

- Thermal efficiency, $\eta_{th,otto}=W_{net}/Q_{in}$

$$=0.54$$
$$=54\ \%$$

- Otto cycle thermal efficiency,

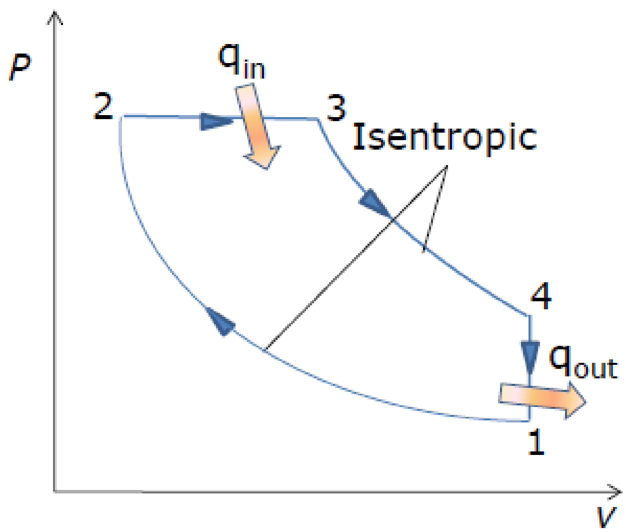
$$\eta_{th,otto}=1-1/r^{\gamma-1}=1-1/7^{0.4}$$
$$=0.54\ \text{or}\ 54\ \%$$

- $v_1 = RT_1/P_1$
  $= 0.287 \times 308/100 = 0.844\ m^3/kg$

- $MEP = W_{net}/(v_1 - v_2) = 272.74/v_1\,(1-1/r)$
  $= 272.74/0.844(1-1/7)$
  $= 360\ kPa$

Problem 2

- In a Diesel cycle, the compression ratio is 15. Compression begins at 0.1 Mpa, 40°C. The heat added is 1.675 MJ/kg. Find (a) the maximum temperature in the cycle, (b) work done per kg of air (c) the cycle efficiency (d) the temperature at the end of the isentropic expansion (e) the cut-off ratio and (f) the MEP of the cycle.



T_1=40°C=313 K
P_1=0.1 Mpa
Q_{in}=1675 MJ/kg
$r=v_1/v_2$=15

$$v_1 = \frac{RT_1}{P_1} = \frac{0.287 \times 313}{100} = 0.898\,\mathrm{m^3/kg}$$

$$v_2 = v_1/15 = 0.898/15 = 0.06\,\mathrm{m^3/kg}$$

- It is given that Q_{in} = 1675 MJ/kg

$$Q_{in} = c_p(T_3 - T_2)$$

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1} = 15^{0.4} = 2.954$$

$$T_2 = 313 \times 2.954 = 924.66\,\mathrm{K}$$

$$Q_{in} = 1675 = 1.005(T_3 - 924.66)$$
$$\therefore T_3 = 2591.33 \text{ K} = T_{\max}$$

- Hence, the maximum temperature is 2591.33 K

$$\frac{P_2}{P_1} = \left(\frac{v_1}{v_2}\right)^{\gamma} = 15^{1.4} = 44.31$$
$$\therefore P_2 = 4431 \text{kPa}$$
$$\frac{P_2 v_2}{T_2} = \frac{P_3 v_3}{T_3} \rightarrow v_3 = \frac{T_3}{T_2} v_2 = \frac{2591.33}{924.66} \times 0.06 = 0.168 \text{ m}^3/\text{kg}$$

$$r_c = \frac{v_3}{v_2} = \frac{0.168}{0.06} = 2.8$$

- The cut-off ratio is 2.8.

$$T_4 = T_3\left(\frac{v_3}{v_4}\right)^{\gamma-1} = 2591.33 \times \left(\frac{0.168}{0.898}\right)^{0.4}$$
$$= 1325.37 \text{K}$$
$$\text{Q}_{\text{out}} = c_v(T_4 - T_1) = 0.718(1325.4 - 313) = 726.88 \text{kJ/kg}$$
$$\text{Net work done}, W_{net} = Q_{in} - Q_{out} = 1675 - 726.88$$
$$= 948.12 \text{ kJ/kg}$$

- Therefore, thermal efficiency,

$$\eta_{th} = W_{net}/Q_{in}$$
$$= 948.12/1675 = 0.566 \text{ or } 56.6\%$$

- The cycle efficiency can also be calculated using the Diesel cycle efficiency determined earlier.

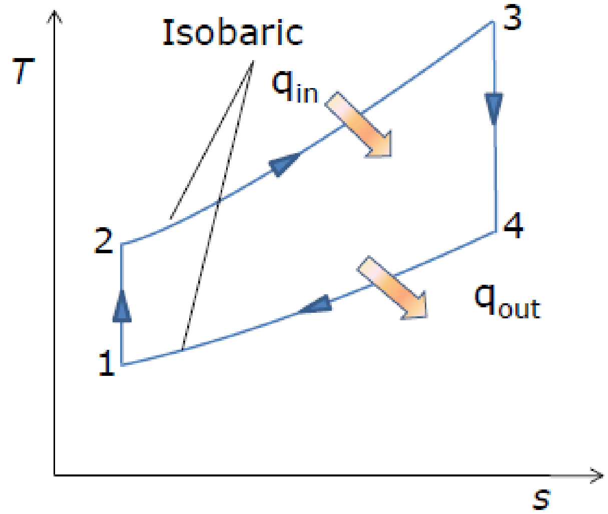
$$MEP = \frac{W_{net}}{v_1 - v_2} = \frac{948.12}{0.898 - 0.06} = 1131.4\,\text{kPa}$$

- The mean effective pressure is 1131. 4 Kpa.

Problem 3

- In a Brayton cycle based power plant, the air at the inlet is at 27°C, 0.1 MPa. The pressure ratio is 6.25 and the maximum temperature is 800°C. Find (a) the compressor work per kg of air (b) the turbine work per kg or air (c) the heat supplied per kg of air, and (d) the cycle efficiency.

Solution: Problem 3



T_1 = 27°C = 300 K
P_1 = 100 kPa
r_p = 6.25
T_3 = 800°C = 1073 K

- Since process, 1-2 is isentropic,

$$\frac{T_2}{T_1} = r_p^{(\gamma-1)/\gamma} = 6.25^{(1.4-1)/1.4} = 1.689$$

$$T_2 = 506.69\,\text{K}$$

$$W_{comp} = c_p(T_2 - T_1) = 1.005(506.69 - 300)$$

$$= 207.72\,\text{kJ/kg}$$

- The compressor work per unit kg of air is 207.72 kJ/kg

- Process 3-4 is also isentropic,

$$\frac{T_3}{T_4} = r_p^{(\gamma-1)/\gamma} = 6.25^{(1.4-1)/1.4} = 1.689$$

$$T_4 = 635.29\,\text{K}$$

$$W_{turb} = c_p(T_3 - T_4) = 1.005(1073 - 635.29)$$

$$= 439.89\,\text{kJ/kg}$$

- The turbine work per unit kg of air is 439.89 kJ/kg

- Heat input, Q_{in},

$$Q_{in} = c_p(T_3 - T_2) = 1.005(1073 - 506.69)$$

$$= 569.14\,\text{kJ/kg}$$

- Heat input per kg of air is 569.14 kJ/kg
- Cycle efficiency,

$$\eta_{th} = (W_{turb} - W_{comp})/Q_{in}$$

$$= (439.89 - 207.72)/569.14$$

$$= 0.408 \text{ or } 40.8\%$$

Exercise Problem 1

- A gasoline engine receives air at 10°C, 100 kPa, having a compression ratio of 9:1 by volume. The heat addition by combustion gives the highest temperature as 2500 K. use cold air properties to find the highest cycle pressure, the specific energy added by combustion, and the mean effective pressure.
- Ans: 7946.3 kPa, 1303.6 kJ/kg, 0.5847, 1055 kPa

Exercise Problem 2

- A diesel engine has a compression ratio of 20:1 with an inlet of 95 kPa, 290 K, with volume 0.5 L. The maximum cycle temperature is 1800 K. Find the maximum pressure, the net specific work and the thermal efficiency.
- Ans: 6298 kPa , 550.5 kJ/kg, 0.653

Exercise Problem 3

- A large stationary Brayton cycle gas-turbine power plant delivers a power output of 100 MW to an electric generator. The minimum temperature in the cycle is 300 K, and the maximum temperature is 1600 K. The minimum pressure in the cycle is 100 kPa, and the compressor pressure ratio is 14 to 1. Calculate the power output of the turbine. What fraction of the turbine output is required to drive the compressor? What is the thermal efficiency of the cycle?
- Ans: 166.32 MW, 0.399, 0.530