Assignment -2
of
BME (Part-A)

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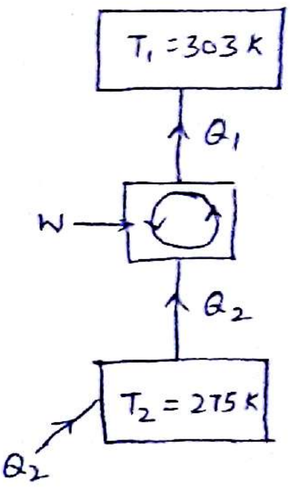
Q1. A household refrigerator is maintained at a temperature of 2°c. Every time the door is opened, warm material is placed inside, introducing an average of 420 KJ, but making only a small change in the temperature of the refrigerator. The door is opened 20 times a day, & the refrigerator operates at 15% of the ideal COP. The cost of work is ₹ 2.50/kWh. What is the monthly bill for this refrigerator? Atmosphere temperature is 30°C.

Ans :- Temperature of atmosphere = $T_1 = 273+30$
$= 303$ K



Temperature of freezer = $273+2$
$T_2 = 275$ K

COP for ideal refrigerator →

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

$$= \frac{275}{28}$$

$$= 9.82$$

COP of this refrigerator => $9.82 \times \frac{15}{100} = 1.473$

Work done by refrigerator in 1 day $= \frac{420 \times 20}{1.473}$

$= 5702.64$ KJ

Work done by refrigerator in 30 days = 5702.64×30

$= 171079.42$ KJ

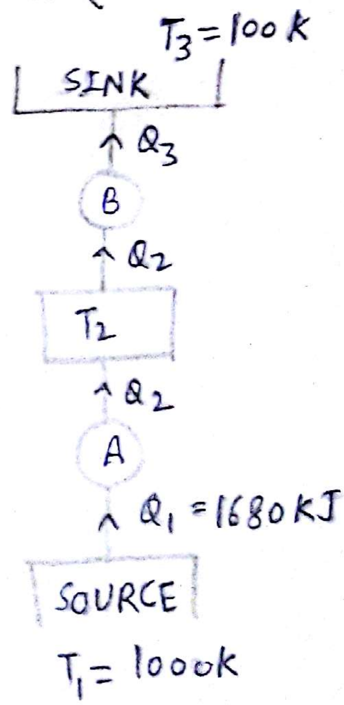
In KWh = $\dfrac{171079.42}{3.6 \times 10^3} = 47.522$ KWh

$\therefore$ Total Cost $= 47.522 \times 2.5$

$=$ ₹ 118.80

Q2. Two carnot engines A & B are connected in series b/w 2 thermal reservious maintained at 1000K & 100 K respectively. Engine A recieves 1680KJ of heat from high-temperature reservious & rejects heat to the Carnot engine B. Engine B takes in heat rejected by engine A & rejects heat to low-temperature reservious. If engines A & B have equal thermal efficiency, determine a) heat rejected by engine B b) the temp. at which heat is rejected by engine A & c) the work done during process by engine A & B. If engines A & B deliver equal work, determine d) amount of heat taken in by engine B & e) the efficiencies of engines A & B.

a) By using property of reversible heat engine :-



$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2} \quad \text{and} \quad \frac{T_2}{T_3} = \frac{Q_2}{Q_3}$$

or $$\frac{Q_1}{T_1} = \frac{Q_2}{T_2} = \frac{Q_3}{T_3}$$

or $$\frac{Q_1}{T_1} = \frac{Q_3}{T_3}$$

Put values :-

$$\frac{1680}{1000} = \frac{Q_3}{100}$$

$Q_3 = 168$ KJ , i.e, heat rejected by engine B

b) As we know,

$$\eta_A = \eta_B$$

$$\Rightarrow \frac{Q_1 - Q_2}{Q_1} = \frac{Q_2 - Q_3}{Q_2}$$

Put values :-

$$\frac{1680 - Q_2}{1680} = \frac{Q_2 - 168}{Q_2}$$

$$\cancel{1680 Q_2} - Q_2^2 = \cancel{1680 Q_2} - 168 \times 1680$$

$$Q_2 = \sqrt{282240}$$

$$Q_2 = 531.26 \text{ KJ}$$

We have,

$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$

Put values :-

$$T_2 = \frac{531.26 \times 1000}{1680}$$

$$T_2 = 316.22 \text{ K}$$

Temp at which heat is rejected by engine A = 316.22 K

c) Work done by engine A $= Q_1 - Q_2$

$$= 1680 - 531.26$$

$$= 1148.74 \text{ KJ}$$

Work done by engine B $= Q_2 - Q_3$

$$= 531.26 - 168$$

$$= 363.26 \text{ KJ}$$

d) Given,

$$W_A = W_B$$

$$Q_1 - Q_2 = Q_2 - Q_3$$

$$2Q_2 = Q_1 + Q_3$$

$$Q_2 = \frac{Q_1 + Q_3}{2} = \frac{1680 + 168}{2} = 924 \text{ KJ}$$

e) $\eta_A = \frac{W_A}{Q_1} = \frac{Q_1 - Q_2}{Q_1}$

$= \frac{1680 - 924}{1680} \times 100 = 45\%$

$\eta_B = \frac{W_B}{Q_2} = \frac{Q_2 - Q_3}{Q_2}$

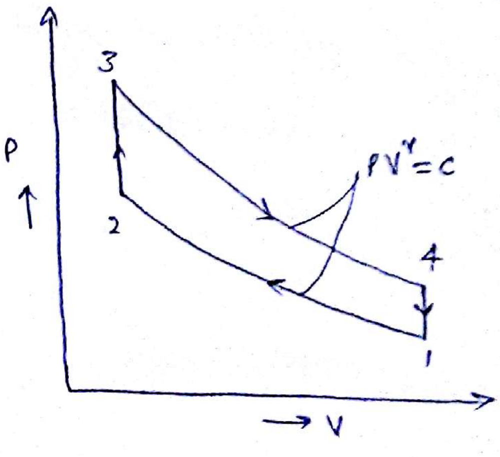
$= \frac{924 - 168}{924} \times 100 = 81.8\%$

Q3. An engine working on the Otto cycle has an air standard cycle efficiency of 56%. & rejects 544 kJ/kg of air. The pressure & temperature of air at the beginning of compression are 0.1 MPa & 60°C respectively. compute a) the compression ratio of engine b) the work done per kg of air c) the pressure & temperature at the end of compression d) the maximum pressure in the cycle.

Ans:- Given, $\eta = 0.56$, $Q_2 = 544$ kJ/kg

$T_1 = 60°C$, $P_1 = 0.1$ MPa

$\gamma_{air} = 1.4$



a) $r_k = ?$

We know,

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

$$\frac{1}{r_k^{\gamma - 1}} = 0.44$$

$$(r_k)^{0.4} = \frac{1}{0.44}$$

$$(r_k)^{0.4} = 2.27$$

$$\boxed{r_k = 7.78}$$

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b) Work done per kg of air $= Q_1 \times \eta$

And we have, $\eta = 1 - \frac{Q_2}{Q_1}$

$$\frac{Q_2}{Q_1} = 1-\eta$$

$$Q_1 = \frac{Q_2}{1-\eta} = \frac{Q_2}{1-0.56} = \frac{Q_2}{0.44}$$

$$\therefore \quad W_{net} = \frac{Q_2}{0.44} \times 0.56$$

$$= \frac{544 \times 0.56}{0.44}$$

$$= 692.36 \text{ KJ/kg}$$

c) for process 1-2 (compression)

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

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

$$T_1 = 60+273 = 333 \text{ K}$$

$$T_2 = 333 \times (7.78)^{0.4}$$

$$T_2 = 756.54 \text{ K}$$

Also, we have, $P_2 = P_1 \, r_K^{\gamma}$

$$P_2 = 0.1 \times (7.78)^{1.4}$$

$$= 1.769 \text{ MPa}$$

d) As clear from P-V diagram,

Maximum P will be P_3,

We have, $Q_1 = C_V (T_3 - T_2)$

$$\frac{544}{0.44 \times 0.718} = T_3 - 756.54$$

$$T_3 = 2478.49 \text{ K}$$

As process 2-3 is isochoric,

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

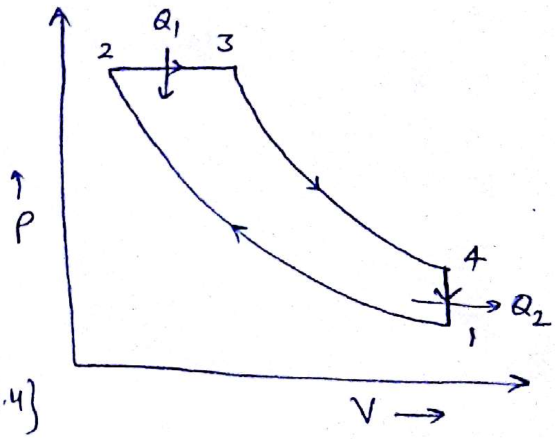
$$P_3 = \frac{2478.49}{756.54} \times 1.769$$

$$= 5.795 \text{ MPa}$$

Q4. In an air standard 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 of the cycle b) the work done per kg of air c) the cycle efficiency d) the temperature at the end of isentropic expansion, e) the cut-off ratio f) the maximum pressure g) m.e.p of the cycle

a) For process 1-2,

we have,



$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$

$$\frac{P_2}{P_1} = r_k^{\gamma}$$

$$\frac{P_2}{P_1} = (15)^{1.4} \qquad \{r_k = 15, \gamma = 1.4\}$$

$$P_2 = (0.1) \times 44.31 \qquad \{P_1 = 0.1 \text{ MPa}\}$$

$$P_2 = 4.43 \text{ MPa}$$

from diagram, $P_2 = P_3 = P_{max}$

Also, $T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$

$$T_2 = T_1 \times r_k^{\gamma-1}$$

$$T_2 = 313 \times (15)^{0.4} \qquad \{T_1 = 40 + 273 = 313 \text{ K}\}$$

$$T_2 = 924.65 \text{ K}$$

We have, $Q_1 = \cancel{m}\, c_p (T_3 - T_2)$

$$1.675 = 1.005\,(T_3 - 924.65) \qquad \{\because Q_1 = 1.675 \text{ kJ/kg}$$

$$T_3 = 1.666 + 924.65$$

$$T_3 = 926.316 \text{ K}$$

$$T_{max} = 926.316 \text{ K}$$

(e) $$r_c = \frac{T_3}{T_2} = \frac{926.316}{924.65}$$

$$= 1.001$$

($\cancel{f}$) Efficiency :-

$$\eta = 1 - \frac{1}{\gamma}\,\frac{1}{r_k^{\gamma-1}}\,\frac{r_c^{\gamma}-1}{r_c-1}$$

$$= 1 - \frac{1}{1.4}\,\frac{1}{(15)^{0.4}}\,\frac{(1.001)^{1.4}-1}{1.001-1}$$

$$= 1 - \frac{0.0010002}{(15)^{0.4} \times 0.001}$$

$$= 1 - 0.3385$$

$$= 0.6615$$

or $\eta = 66.15\ \%$

d) We have, $$T_4 = T_3\,\frac{r_c^{\gamma-1}}{r_k^{\gamma-1}}$$

$$T_4 = 926.316 \left(\frac{1.001}{15}\right)^{0.4}$$

$$= 313.68 \text{K}$$

b) Work done / kg $= Q_1 \times \eta$

$$= 1.675 \times 0.6615$$

$$= 1.108 \text{ MJ/kg}$$

g) $$m.e.p = \frac{W_{net}}{V_1 - V_2} = \frac{1.108}{V_1 - V_2}$$

$$V_1 = \frac{RT_1}{P_1} = \frac{0.287 \times 313}{100} = 0.898 \ m^3/kg$$

$$V_2 = \frac{RT_2}{P_2} = \frac{0.287 \times 924.65}{443} = 0.599 \ m^3/kg$$

$$m.e.p = \frac{1.108}{0.898 - 0.599} = \frac{1.108}{0.299}$$

$$= 3.705 \ kPa$$