An ideal Otto cycle has a compression ratio of 8. At the begining of compression process, air is at 95 kPa and 27°C, and 750 kJ/kg of heat is transferred to air during the constant volume heat addition process.

Taking into account the variation of specific heats with temp. determine

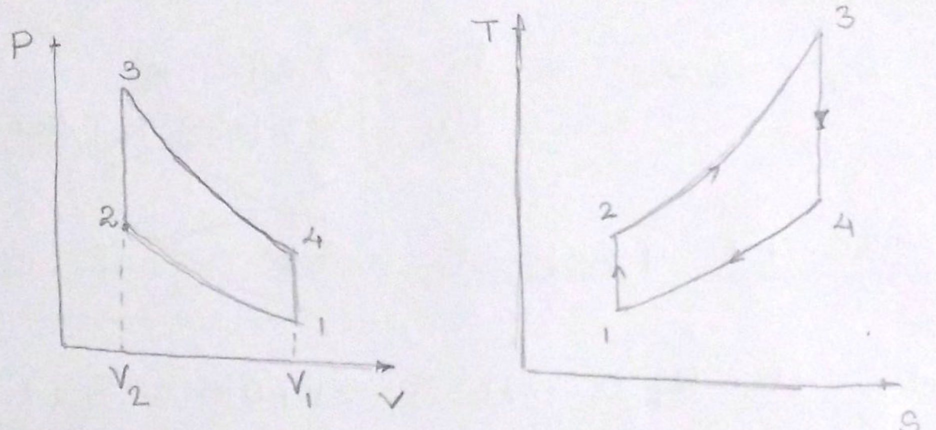
a) pr. & temp. at the end of heat addition

b) the net work output

c) the thermal efficiency

d) Mean effective pr.

→



1-2: Isentropic compression.

@ $T_1 = 27+273 = 300K$, $u_1 = 214.07$ kJ/kg.

$v_{r_1} = 621.2$

$r = \frac{V_1}{V_2} = 8 = \frac{v_{r_1}}{v_{r_2}} \rightarrow v_{r_2} = \frac{621.2}{8} = 77.65$

@ 77.65 $\left.\begin{array}{l} T_2 = 673.1\ K \\ u_2 = 491.2\ kJ/kg \end{array}\right\}$ $\frac{670-680}{78.61-75.50} = \frac{670-x}{78.61-77.65}$

$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \rightarrow P_2 = P_1 \cdot \left(\frac{T_2}{T_1}\right)\left(\frac{V_1}{V_2}\right) = 95 \times \frac{673.1}{300} \times 8 = 1705.19$ kPa

2-3. Isochoric heat addition.

$Q_{2-3} - \cancel{W_{2-3}}^{0} = \Delta U$

$750 = u_3 - 491.2 \rightarrow u_3 = 1241.2$ kJ/kg

@ $u_3 = 1241.2$ kJ/kg.

$T_3 = 1539$ K $\Big\} \rightarrow$ Ans
$v_{r_3} = 6.588$

$$\frac{P_2 \cancel{V_2}}{T_2} = \frac{P_3 \cancel{V_3}}{T_3} \rightarrow P_3 = P_2 \cdot \frac{T_3}{T_2}$$

$$= 1705.19 \times \frac{1539}{673.1}$$

$P_3 = \underline{3898.81}$ kPa — Ans

Process 3-4 Isentropic expansion

$$\frac{v_{r_4}}{v_{r_3}} = \frac{V_1}{V_2} \rightarrow v_{r_4} = 8 \times v_{r_3} = 8 \times 6.588 = \underline{52.70}$$

@ $v_{r_4} = 52.70 \rightarrow T_4 = 774.5$ K
$u_4 = 571.69$ kJ/kg

Process 4-1 Isochoric heat rejection.

$$q_{out} = u_4 - u_1 = 571.69 - 214.07 = 357.62 \text{ kJ/kg}$$

Now

b) $W_{net} = q_{in} - q_{out} = 750 - 357.62 = 392.4$ kJ/kg.

c) $$\eta_{th} = \frac{W_{net}}{q_{in}} = \frac{392.4}{750} = \underline{52.3\%}$$

d) MEP — ?

$$W_{net} = P_{mep} \times (v_1 - v_2)$$
$$= P_{mep} \times v_1 \cdot \left(1 - \frac{v_2}{v_1}\right)$$
$$392.4 = P_{mep} \times 0.906 \left(1 - \frac{1}{8}\right)$$

$P_{mep} = 494.99$

$\boxed{P_{mep} \approx 495 \text{ kPa}}$

$P_1 V_1 = mRT$

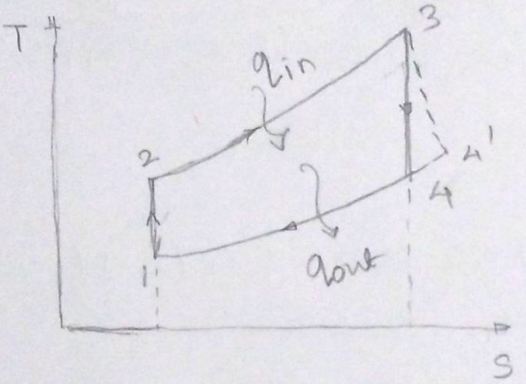
$\underset{kPa}{95} \times \frac{V_1}{m} = 0.287 \times 300$

$v_1 = 0.906$

$$\frac{v_1}{v_2} = \frac{V_1}{V_2} = 8$$

A simple ideal Brayton cycle operates with air with min. & max. temp. of 27°C & 770°C. It is designed to so that the max. cycle pr. is 2500 kPa and the min. cycle pr. is 100 kPa. Determine a) the net work produced per unit mass of air and the cycle's thermal efficiency if all the components are ideal; and b) the thermal efficiency and the second law efficiency of the cycle if the turbine has an isentropic efficiency of 90 percent.

→



a) Ideal

St.1 $T_1 = 27+273 = 300\,K$ $\quad \frac{P_2}{P_1} = r_p = \frac{2500}{100} = 25$

$P_1 = 100$ kPa

St.2 $\frac{T_2}{T_1} = (r_p)^{\gamma-1/\gamma} \rightarrow T_2 = 300 * \left(\frac{2500}{100}\right)^{0.286} = 753.\,K$

$P_2 = 2500$ kPa.

St.3 $P_3 = 2500$ kPa, $T_3 = 770+273 = 1043\,K$

St.4

$\frac{T_3}{T_4} = (\underset{25}{r_p})^{0.286} \rightarrow T_4 = 415.41\,K$

$q_{in} = C_p.(T_3 - T_2) = 1.005\,(1043 - 753) = 291.45$ kJ/kg

$q_{out} = C_p\,(T_4 - T_1) = 1.005\,(415.41 - 300) = 115.99$ kJ/kg

$$w_{net} = q_{in} - q_{out}$$
$$= 291.45 - 115.99$$
$$= 175.46 \text{ kJ/kg}$$

$$\eta_{th} = \frac{w_{net}}{q_{in}} = \frac{179.46}{291.45} = \underline{60.20\%}$$

b) $\underline{\eta_T = 90\%}$ actual with turbine $\eta_T = 90\%$

process 3-4

$$\eta_T = \frac{T_3 - T_4'}{T_3 - T_4} \rightarrow 0.90 = \frac{1043 - T_4'}{1043 - 415.41}$$

$$T_4' = \underline{478.17} \text{ K}$$

$$q_{out} = C_p(T_4' - T_1) = 1.005(478.17 - 300)$$
$$q_{out} = 179. \text{ K}.$$

$$w_{net} = q_{in} - q_{out} = 291.45 - 179.$$
$$w_{net} = 112.39 \text{ kJ/kg}$$

$$\eta_{th} = \frac{w_{net}}{q_{in}} = \frac{112.39}{291.45}$$

$$\eta_{th} = \underline{38.56}\ \%$$

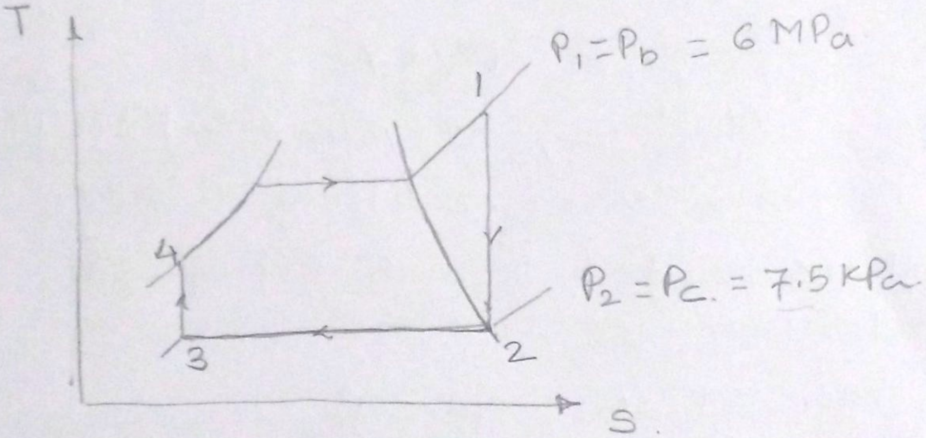
* Second law $\eta_{II} = \frac{\eta_{th,\,actual}}{\eta_{th,\,carnot}}$

$$\eta_{carnot} = 1 - \frac{T_L}{T_H} = 1 - \frac{300}{1043.} = \underline{71.24\%}$$

$$\eta_{II} = \frac{38.56\%}{71.24\%} = \underline{54.13\%}.$$

Steam enters the turbine of steam power plant that operates on a simple ideal Rankine cycle at a pressure of 6 MPa, and it leaves as saturated vapour at 7.5 kPa. Heat is transferred to the steam in the boiler at a rate of 40,000 kJ/s. Steam is cooled in the condenser by the cooling water from a nearby river, which enters the condenser at 15°C. Show the cycle on a T-s dia. and determine:-
a) turbine inlet temp b) power output & thermal η c) the min. mass flow rate of the cooling water required.

→



Assumptions

1) Steady operating of each device.
2) $\Delta KE \approx 0$, $\Delta PE \approx 0$.

@ $P_1 = 6$ MPa → 6000 kPa

* Temp is not given.

@ $P_2 = 7.5$ kPa

& $T_2 = T_3 = 15 + 273 = 288$ K.

$v_3 = v_f = 0.001008$

$h_2 = h_g = 2574.0$ kJ/kg

$h_3 = h_f = 168.75$ kJ/kg

$S_2 = S_g = 8.2501$ kJ/kg·K

Now ⓐ

$S_2 = S_1 = 8.2501$
& $P_1 = 6$ MPa

A-6

$h_1 \approx 4850$ kJ/kg
& $T_1 \approx 1090°C$

$h_4 = h_3 + W_p$
$= h_3 + v_1 (P_b - P_c)$.
$= 168.75 + 0.001008 (6000 - 7.5)$
$= 174.75$ kJ/kg

b) $W_T = (h_1 - h_2)$

$= 4850 - 2574$

$W_T = 2275$ kJ/kg

$w_{net} = W_T - W_p = 2275 - 6$ ← $174.75 - 168.75$

$w_{net} = 2269$ kJ/kg

<u>OR</u>

$q_{in} = h_1 - h_4 = 4850 - 174.75 = 4675.25$

$q_{out} = h_2 - h_3 = 2574 - 168.75 = 2405.25$

$w_{net} = 2270$ kJ/kg.

$\eta_{th} = \frac{2270}{4675.25} = 48.6\%$

$0.486 = \frac{\dot{W}_{net}}{40{,}000 \text{ kJ/s}} \rightarrow \dot{W}_{net} = 19440$ KW — Ans

c) $\dot{m}_w$ is min. when cooling water will be heated to sat temp of condenser pr.

@ 7.5 kPa $T_{sat} = 40.29°C$

$\dot{W}_{net} = \dot{Q}_{in} - \dot{Q}_{out}$

$19440 = 40000 - \dot{Q}_{out}$

$\dot{Q}_{out} = 20560$ KW

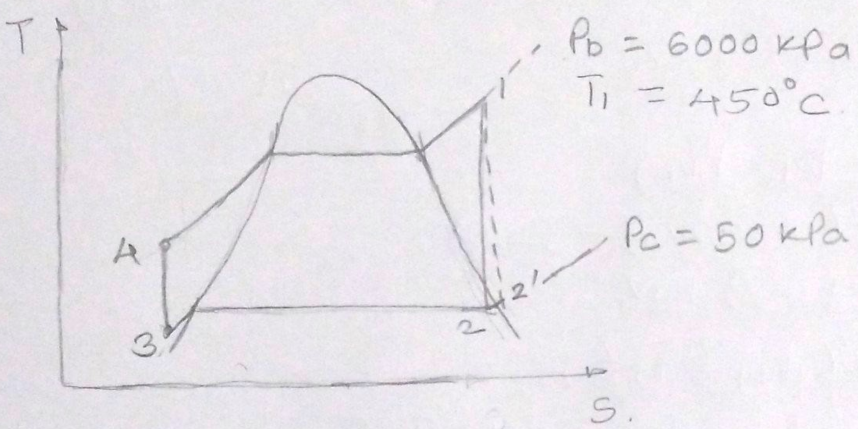
$\dot{Q}_{out} = \dot{m}_w C_{p_w} (\Delta T)$

$20560 = \dot{m}_w \cdot 4.187 (40.29 - 15)$

$\dot{m}_w = 194.17$ kg/s — Ans.

A simple Rankine cycle uses water as the working fluid. The boiler operates at 6,000 kPa and the condenser at 50 kPa. At the entrance to the turbine, the temp. is 450°C. The isentropic efficiency of the turbine is 94%, pr. & pump losses are negligible, and the water leaving the condenser is subcooled by 6.3°C. The boiler is sized for a mass flow rate of 20 kg/s. Determine the rate at which heat is added in the boiler, the power required to operate the pump, the net power produced by the cycle, & the thermal efficiency.

→



@ $P_1 = 6000$ kPa, $T_1 = 450°c$

$h_1 = 3302.9$ kJ/kg

$s_2 = 6.7219$ kJ/kg.K.

@ $P_2 = P_c = 50$ kPa, $T_2 = T_{sat} - 6.3 = 81.32 - 6.3 = \underline{75°c}$

∴ @ $75°c$

$v_f = 0.001026$

$h_3 = h_{f_3} = 313.99$.

@ $P_2 = P_c = 50$ kPa

$s_{f_2} = 1.0912$

$s_{fg_2} = 6.5019$.

$h_{fg_2} = 2304.7$

$h_{f2} = 340.54$

$s_1 = s_2 = s_f + x_2 s_{fg}$

$x_2 = \underline{0.87}$

$h_2 = h_{f_2} + x_2 \cdot h_{fg_2}$

$= 340.54 + 0.87 \times 2304.7$

$\underline{\underline{h_2}} = 2345.63$ kJ/kg

$h_2' \rightarrow ?$

$\eta_T = \dfrac{h_1 - h_2'}{h_1 - h_2} \rightarrow 0.94 = \dfrac{3302.9 - h_2'}{3302.9 - 2345.63}$

$h_2' = 2403.1$ $\underline{\text{kJ/kg}}$

$h_4 = h_3 + w_p$

$= h_3 + v(\Delta P)$

$= 313.99 + \underbrace{0.001026(6000 - 50)}_{\underline{\underline{w_p = 6.1}}\ \text{kJ/kg}}$

$= 320$ kJ/kg

$\dot{Q}_{in} = \dot{m}(h_1 - h_4)$

$= 20(3302.9 - 320)$

$= 59658$ kW

$\dot{W}_T = \dot{m}(h_1 - h_2')$

$= 20(3302 - 2403)$

$\dot{W}_T = 17980$ kW

$\dot{W}_p = \dot{m}\, w_p$

$= 20 \times 6.1$

$\dot{W}_p = 122$ kW

$\dot{W}_{net} = \dot{W}_T - \dot{W}_p = 17858$ $\underline{\text{kW}}$

$\eta_{th} = \dfrac{W_{net}}{\dot{Q}_{in}} = \dfrac{17858}{59658} = \underline{\underline{29.93\%}}$