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TUTORIAL - 8

1. Brayton Cycle

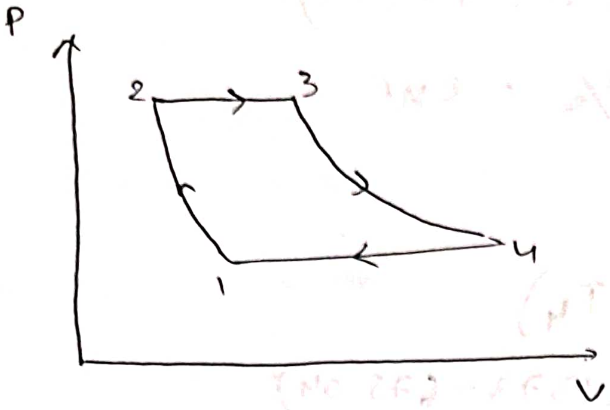
$$\frac{P_2}{P_1} = 12 = \frac{P_3}{P_4}$$

@ state 1: $P_1 = 100kPa$

$T_1 = 293K$

$T_3 = 1100°C = 1373K$

$\dot{m}_a = 10kg/s$



Process 1-2 : isentropic

$$P_1^{1-\gamma} T_1^{\gamma} = P_2^{1-\gamma} T_2^{\gamma}$$

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

$$T_2 = 293 (12)^{\frac{2}{7}}$$

$$T_2 = 595.9K.$$

Process 3-4 : isentropic.

$$P_3^{1-\gamma} T_3^{\gamma} = P_4^{1-\gamma} T_4^{\gamma}$$

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

$$= (12)^{-2/7} \cdot 1373K$$

$$T_4 = 675.04K.$$

Work done in process 1-2 :

$$\dot{W}_{2-3} = \dot{m}\, C_p (T_2 - T_1)$$

$$\dot{W}_c = 10 \times 1.004 \; (595.9 - 293)$$

$$\dot{W}_c = 3041.116 \text{ KJ/s} = \text{KW}$$

Work done in process 3-4 :

$$\dot{W}_{3-4} = \dot{m}\, C_p (T_3 - T_4)$$

$$= 10 \times 1.004 \; (1373 - 675.04)$$

$$\dot{W}_T = 7007.5 \text{ KW}$$

$$\dot{W}_{net} = |\dot{W}_T| - |\dot{W}_c|$$

$$= 7007.5 - 3041.1$$

$$= 3966.4 \text{ KW.}$$

In process 2-3: first law

$$Q_{in} - W = \Delta U$$

[∴ open system
$W = -Vdp$ & $\Delta U = \Delta H$]
↓
isobaric process
∴ $W = 0$

$$\Rightarrow \quad \cancel{q_{in} = \Delta h} \quad Q_{in} = \Delta H$$

$$\dot{Q}_{in} = \dot{m}\, C_p (T_3 - T_2)$$

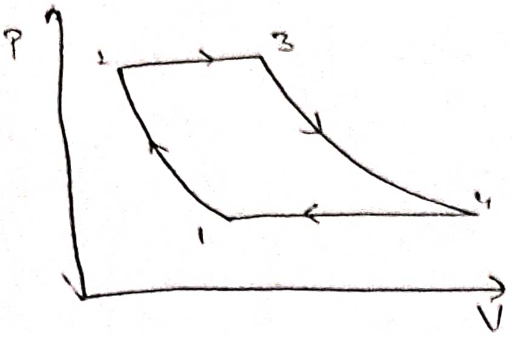
$$= 10 \times 1.004 (1373 - 595.9)$$

$$\dot{Q}_{in} = 7802.084 \text{ KW}$$

$$\eta_{Therm} = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{3966.4}{7802.08} = 0.508$$

$$= 50.8\ \%$$

2 Brayton Cycle



$\dot{W}_{net} = 100$ MW

Given $P_1 = 100$ kPa $T_1 = 300$K

$T_3 = 1600$K $\qquad \frac{P_2}{P_1} = 14 = \frac{P_3}{P_4}$

Process 1-2 : isentropic

$$P_1^{1-\gamma} T_1^{\gamma} = P_2^{1-\gamma} T_2^{\gamma}$$

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

$$T_2 = 300 \,(14)^{2/7}$$

$$\boxed{T_2 = 637.6\text{ K}}$$

Process 3-4 : isentropic

$$P_3^{1-\gamma} T_3^{\gamma} = P_4^{1-\gamma} T_4^{\gamma}$$

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

$$T_4 = 1600 \,(14)^{-2/7}$$

$$\boxed{T_4 = 752.75\text{ K}}$$

~~Now $\dot{W}_c = \dot{W}_{23}$~~

$$w_{net} = \cancel{w_c - w_T} \quad w_T - w_c$$

$$= \cancel{c_p(T_2 - T_1) - c_p(T_3 - T_4)} = c_p(T_3 - T_4) - c_p(T_2 - T_1)$$

$$\dot{W}_{net} = \dot{m}_a \, w_{net}$$

$$\Rightarrow \dot{m}_a = \frac{\dot{W}_{net}}{\cancel{c_p(T_2 - T_1 - T_3 + T_4)} \; c_p(T_3 - T_4 - T_2 + T_1)}$$

$$= \cancel{\frac{100 \times 10^3 \text{ kJ/s}}{1.005\,(282.65) \text{ kJ/kg}} = 0.35 \times 10^3 \text{ kg/s}}$$

$$\cancel{\dot{m}_a = 350 \text{ kg/s}}$$

$$\cancel{\dot{W}_c = \dot{m}\, c_p (T_2 - T_1)}$$

$$\cancel{= 350 \times 1.005 \,(}$$

$$\dot{m}_a = \frac{100 \times 10^3 \text{ kW}}{1.004\,(509.65) \text{ kJ/kg}} = 195 \text{ kg/s}$$

$\dot{W}_c = \dot{m}\, c_p (637.6 - 300)$

$\dot{W}_c = 195 \times 1.004\ (337.6)$

$\dot{W}_c = 66.095$ KW

$\dot{W}_{net} = \dot{W}_T - \dot{W}_c$

$\dot{W}_T = \dot{W}_{net} + \dot{W}_c$

$\dot{W}_T = 100 + 66095$

$\dot{W}_T = 166.095$ KW

Fraction of work used $= \dfrac{\dot{W}_c}{W_T}$

$= \dfrac{66.095}{166.095}$

$= 0.397$

In process 2-3

$\dot{Q}_{in} = \dot{m} c_p (T_3 - T_2)$

$\dot{Q}_{in} = 195 \times 1.004 (1600 - 637.6)$

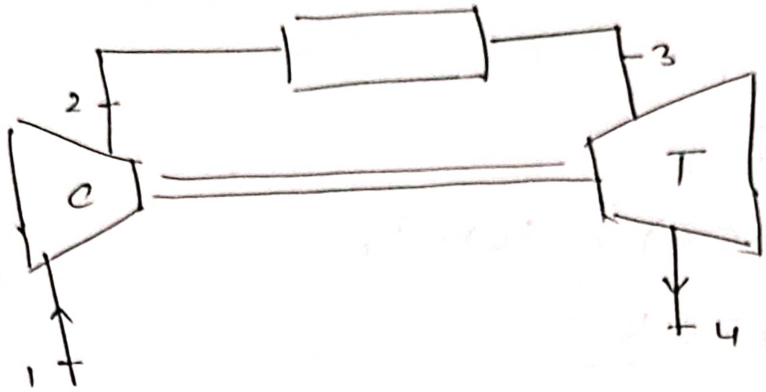
$\dot{Q}_{in} = 188.4$ KW.

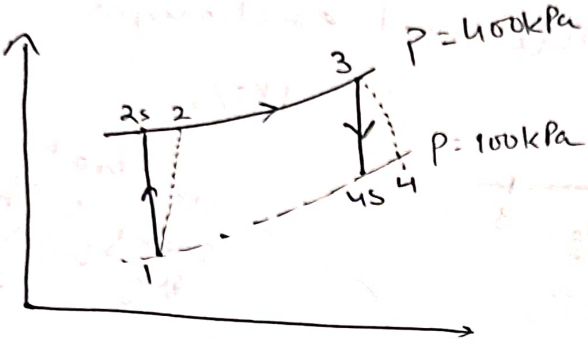
$\eta_{Therm} = \dfrac{\dot{W}_{net}}{\dot{Q}_{in}}$

$= \dfrac{100}{188.4}$

$= 0.530 = 53\%$ efficiency.

3 An open gas power cycle





@ State 1:

$T_1 = 300K$

$P_1 = 100 kPa$

@ State 3:

$T_3 = 900 K$

$P_3 = 400 kPa$

$P_2 = 400 kPa$ $\quad P_4 = 100 kPa$

Process 1-2s : isentropic

$$P_1^{1-\gamma} T_1^{\gamma} = P_{2s}^{1-\gamma} T_{2s}^{\gamma}$$

$$T_{2s} = T_1 \left(\frac{P_1}{P_{2s}}\right)^{1-\gamma/\gamma}$$

$$T_{2s} = 300 (4)^{2/7}$$

$$T_{2s} = 445.8 K.$$

Process 3-4s : isentropic

$$P_3^{1-\gamma} T_3^{\gamma} = P_{4s}^{1-\gamma} T_{4s}^{\gamma}$$

$$T_{4s} = T_3 \left(\frac{P_3}{P_{4s}}\right)^{1-\gamma/\gamma}$$

$$= 900 (4)^{-2/7}$$

$$T_{4s} = 605.6 K.$$

given $\eta_{isen, c} = \frac{\text{Rev. work}}{\text{Actual work}}$

$$0.8 = \frac{\cancel{c_p}(T_{2s} - T_1)}{\cancel{c_p}(T_2 - T_1)}$$

$$0.8 T_2 - 0.8 \underset{\times 300}{T_1} = 445.8 - 300$$

$$0.8T_2 - 240 = 145.8$$

$$T_2 = 482.25 K$$

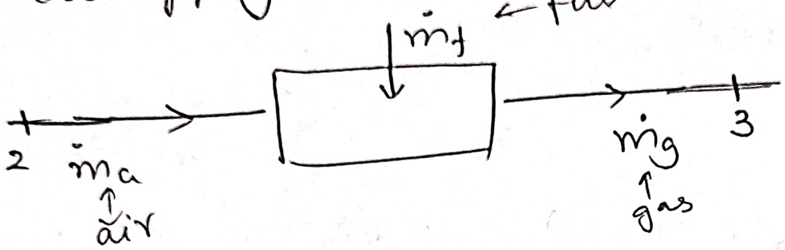
$$\eta_{isen,T} = \frac{\text{Act. Work}}{\text{Rev. work}}$$

$$0.85 = \frac{\cancel{c_p}(T_3 - T_4)}{\cancel{c_p}(T_3 - T_{4s})}$$

$$0.85(900 - 605.6) = 900 - T_4$$

$$\boxed{T_4 = 649.7\ K}$$

Now applying SFEE in the heat exchanger



$\dot m_f = 1\ Kg/s$

Cause heat is being supplied by burning fuel

Mass balance

$$\dot m_g = \dot m_a + \dot m_f$$

$$\dot Q = \dot m_f \times \text{Calorific value}$$

Energy balance

$$\dot m_a h_2 + \dot Q = \dot m_g h_3$$

$$\dot m_a\, C_p T_2 + \dot m_f \times CV = \cancel{\dot m_g}(\dot m_f + \dot m_a)\, C_p T_3$$

$$\dot m_a \times 1.005 \times 482.25 + 1 \times 42 = 1 \times 1.005 \times 900 + \dot m_a \times 1.005 \times 900$$

$$484.6\ \dot m_a + 42000\ \tfrac{KJ}{s} = 904.5\ \tfrac{KJ}{s} + 904.5\ \dot m_a$$

$$41095.5 = 419.9\ \dot m_a$$

$$\dot m_a = 97.86\ \frac{Kg}{s}$$

$$\Rightarrow \dot m_g = 98.86\ Kg/s$$

$\dot{W}_{Turbine} = \dot{m}_a C_p (T_3 - T_4)$

$= 98.86 \times 1.005 \quad (900 - 649.7)$

$\dot{W}_{Turbine} = \cancel{24.619 \text{ kW}} \; 24.868 \text{ MW}$

$\dot{W}_{com} = \dot{m}_a C_p (T_2 - T_1)$

$= 17.924 \text{ MW}$

$\dot{W}_{net} = \dot{W}_T - \dot{W}_c$

$= 24.868 - 17.924$

$= 6.944 \text{ MW}$

$\dot{W}_{net} = 6944 \text{ kW}$

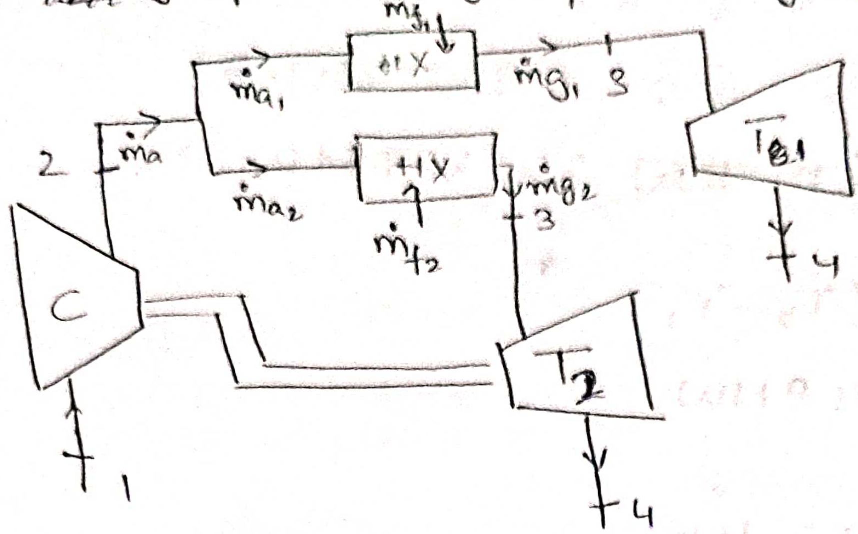
$\dot{Q}_{in} = \cancel{\dot{m} C_p (T_3 - T_2)} \; \dot{m}_f \times CV$

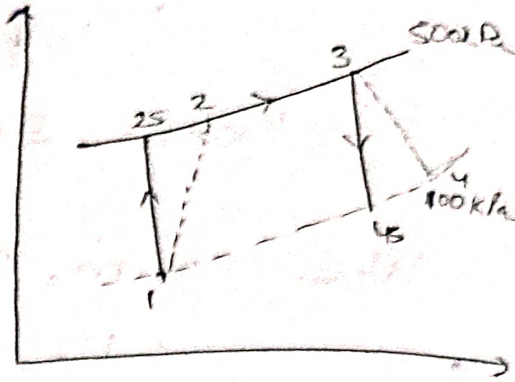
$= 42000 \text{ kW}$

$\eta_{Ther} = \dfrac{\dot{W}_{net}}{\dot{Q}_{in}} = \dfrac{6944}{42000} = 0.165$

$= 16.5\%$

4. ~~[illegible]~~ Open air gas power cycle





650
273
953

$T_1 = 288K$

$T_3 = 953K$.

First finding T_2 & T_4.

Process 1-2S : isentropic

$$P_1^{1-\gamma_a} T_1^{\gamma_a} = P_{2s}^{1-\gamma_a} T_{2s}^{\gamma_a}$$

$$T_{2s} = T_1 \left(\frac{P_1}{P_{2s}}\right)^{1-\gamma_a/\gamma_a}$$

$$T_{2s} = 288(5)^{2/7}$$

$$T_{2s} = 456.14\ K$$

Process 3-4s: isentropic

$$P_3^{1-\gamma_g} T_3^{\gamma_g} = P_{4s}^{1-\gamma_g} T_{4s}^{\gamma_g}$$

$$T_{4s} = T_3\left(\frac{P_3}{P_{4s}}\right)^{1-\gamma_g/\gamma_g}$$

$$T_{4s} = \cancel{601.7\ K}\ 953(5)^{-0.34/1.34}$$

$$T_{4s} = \cancel{601.7K}\ 634.23K$$

$\dot m_a = 23\ kg/s$

$$\eta_{isen,c} = \frac{\text{Rev work}}{\text{Actual work}}$$

$$0.76 = \frac{\cancel{c_p}(T_{2s} - T_1)}{\cancel{c_p}(T_2 - T_1)}$$

$$T_2 - 288 = \frac{456.14 - 288}{0.76}$$

$$T_2 = 509.2\ K$$

$$\eta_{isen,\ turbine} = \frac{\text{Actual Work}}{\text{Rev work}}$$

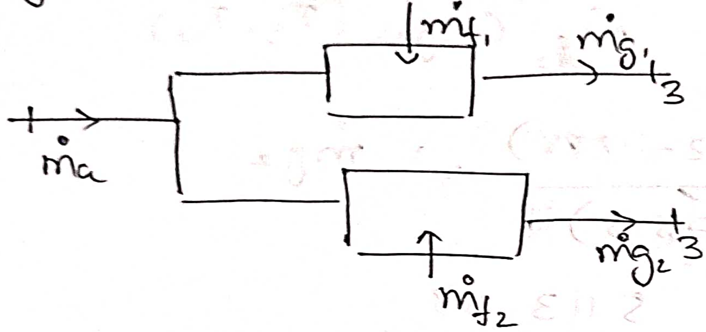
$$0.86 = \frac{\cancel{c_p}(T_3 - T_4)}{\cancel{c_p}(T_3 - T_{4s})}$$

$$0.86\,(953 - 634.23) = 953 - T_4$$

$$T_4 = 953 - 274.14$$

$$T_4 = 678.2\,K$$

Using SFEE for the below part



$$\dot m_{g_1} + \dot m_{g_2} = \dot m_g$$

$$\dot m_{f_1} + \dot m_{f_2} = \dot m_f$$

Mass balance:

$$\dot m_a = 23\,kg/s$$

$$\dot m_a + \dot m_f = \dot m_g$$

Energy balance

$$\dot m_a h_2 + \dot Q = \dot m_g h_3$$

$$\Rightarrow \quad \dot m_a C_{p_{air}} T_2 + \dot m_f \times CV = \dot m_a C_{p_{gas}} T_3 + \dot m_f C_{p_{gas}} T_3$$

$$\Rightarrow 23\,\frac{kg}{s} \times 1.005 \times \frac{kJ}{kg\,K} \times 509.2\,K + 42000\,\frac{kJ}{kg} \times \dot m_f$$

$$= 23\,\frac{kg}{s} \times 1.128\,\frac{kJ}{kg\,K} \times 953\,K + \dot m_f \times 1.128 \times 9$$

$11770.1 \frac{KJ}{s} + 42000\, \dot{m}_f \frac{KJ}{s} = 1074.9\, \dot{m}_f \frac{KJ}{s} + 24724.6 \frac{KJ}{s}$

$40925.1\, \dot{m}_f = 12954.5$

$\boxed{\dot{m}_f = 0.316 \ Kg/s}$

$\dot{m}_g = \dot{m}_a + \dot{m}_f$

$\boxed{\dot{m}_g = 23.316 \ Kg/s}$

Work done by turbine 2 is complelely used by compressor.

$\dot{m}_a \, C_{p,air} (T_2 - T_1) = \dot{m}_{g_2} \, C_{p,gas} (T_3 - T_4)$

$\frac{23 \times 1.005 (509.2 - 288)}{1.128 (953 - 678.8)} = \dot{m}_{g_2}$

$\dot{m}_{g_2} = \frac{5113.03}{309.3}$

$\dot{m}_{g_2} = 16.53 \ Kg/s$

$\dot{m}_{g_1} = \cancel{6.6 \ Kg/s} \ 6.78 \ Kg/s$

Out put power is given by turbine 1.

$\Rightarrow \dot{W}_{T_1} = \dot{m}_{g_1} \, C_{p,gas} (T_3 - T_4)$

$= 6.78 \times 1.128 (953 - 678.8)$

$\dot{W}_T = 2097.03 \ KW.$

Now the

$$\eta_{Ther} = \frac{\dot{W}_{net,out}}{\dot{Q}}$$

$$= \frac{\dot{W}_{T_1}}{\dot{m}_f \times CV}$$

$$= \frac{2097.03}{42000 \times 0.316}$$

$$\approx 0.158$$

$\simeq$ 15.8 % efficiency