Tutorial 3

1.

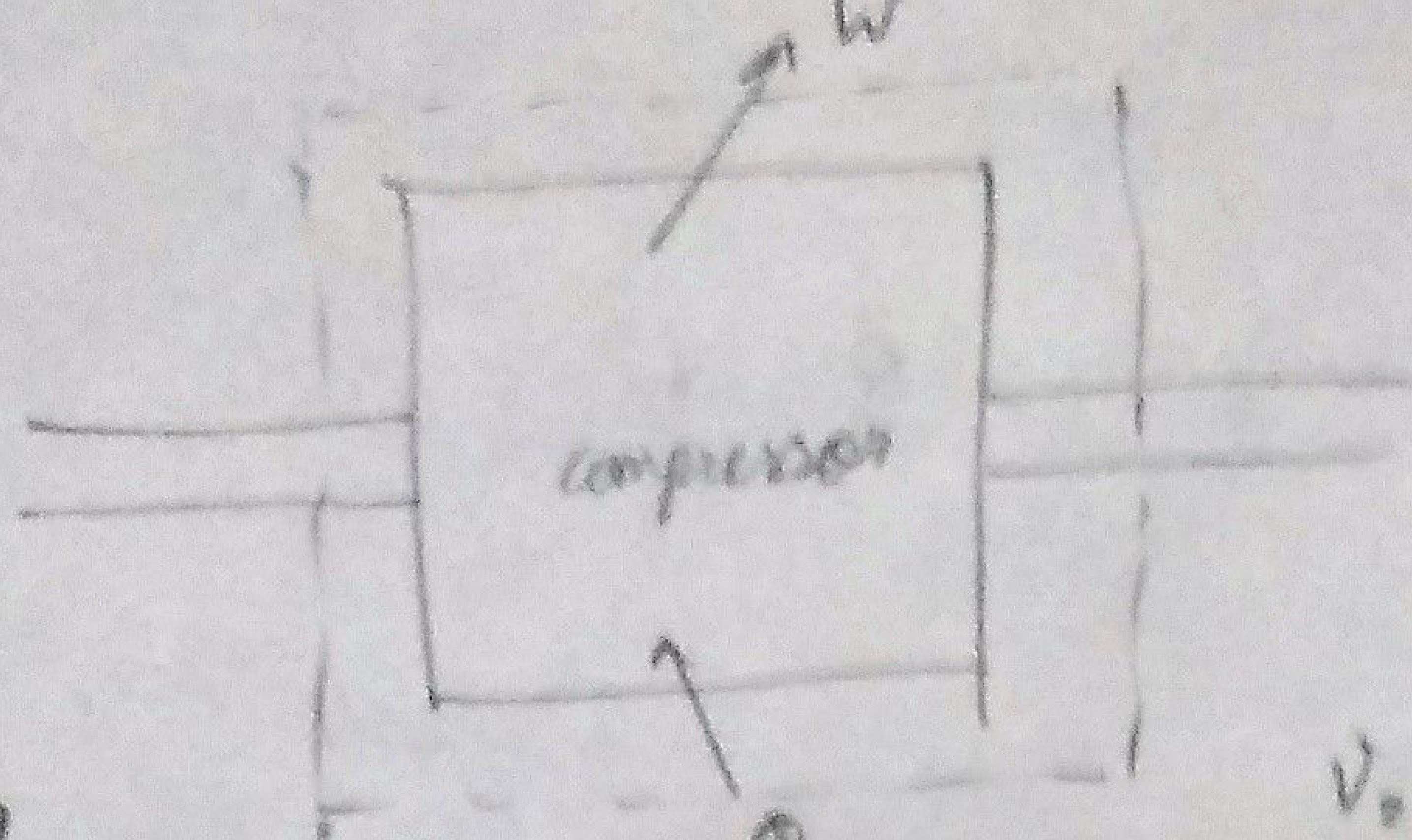
flow is steady

$\dot{m} = 0.5\ kg/s$

$V_1 = 10 m/s$

$P_1 = 100 kPa$

$v_1 = 1 m^3/kg$



$V_2 = 8 m/s$

$P_2 = 700 kPa$

$v_2 = 0.2 m^3/kg$

$= -58 kW$

$$(u_1 + 100)\frac{kJ}{kg} = u_2$$

$$\dot{m}\left(u_1 + P_1 v_1 + \frac{V_1^2}{2}\right) + \dot{Q} = \dot{m}\left(u_2 + P_2 v_2 + \frac{V_2^2}{2}\right) + \dot{W}$$

$$\dot{W} = -\dot{m}\left(u_2 - u_1 + P_2 v_2 - P_1 v_1 + \frac{V_2^2 - V_1^2}{2}\right) + \dot{Q}$$

$$\dot{W} = -0.5\left(100 + (7\times0.2 - 1\times1)100 + \frac{(64-100)10^{-3}}{2}\right) - 58$$

$$\dot{W} = -127.99 kW$$

From mass balance,

$$\dot{m} = \frac{A_1 V_1}{v_1} = \frac{A_2 V_2}{v_2} \qquad \frac{A_1}{A_2} = \frac{v_1}{v_2}\frac{V_2}{V_1} = \frac{1}{0.2}\times\frac{8}{10} = 4$$

$$\frac{d_1}{d_2} = 2$$

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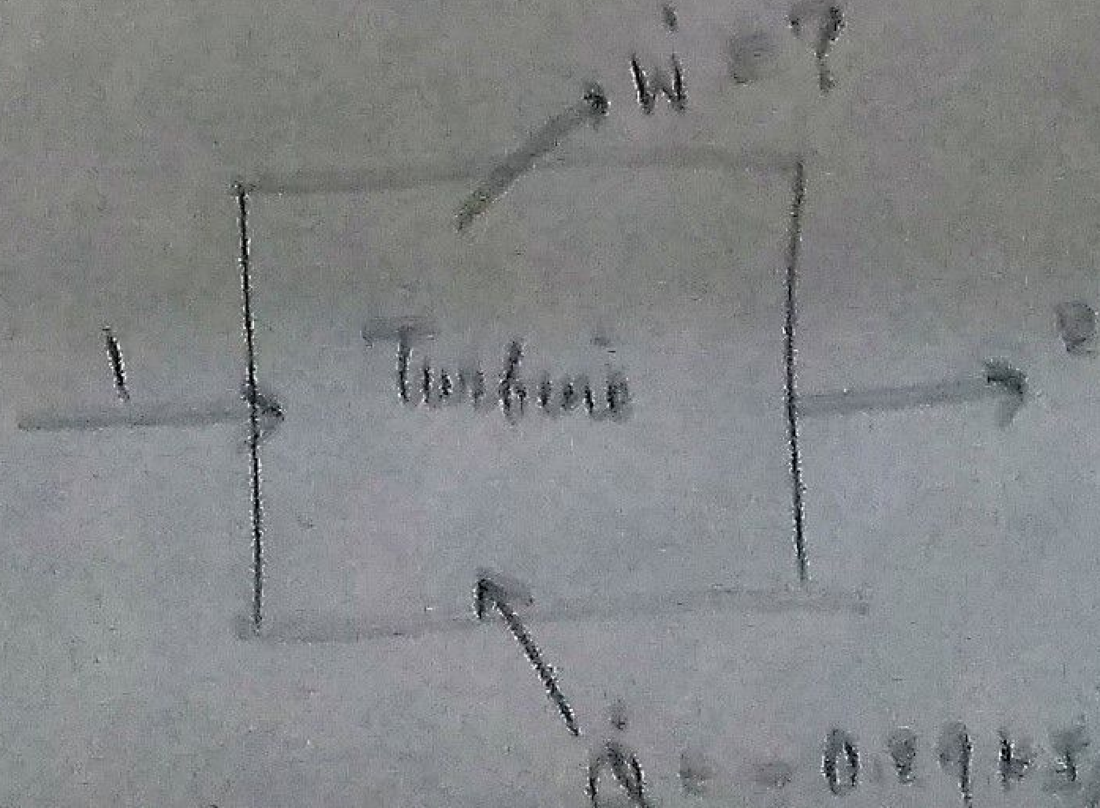
4. $\dot{m}_1 = \dot{m}_2 = 0.42\ kg/s$



$\dot{Q} = -0.29 kJ/s$

$P_2 = 20 kPa$

$h_2 = 2512 kJ/kg$

$V_2 = 100 m/s$

$z_2 = 0$

$P_1 = 1.2 MPa$

$T_1 = 188°C$

$h_1 = 2765 kJ/kg$

$V_1 = 33.3 m/s$ $\quad z_1 = 3$

$$\dot{m}_1\left(h_1 + \frac{V_1^2}{2} + gZ_1\right) + \dot{Q} = \dot{m}_2\left(h_2 + \frac{V_2^2}{2} + gZ_2\right) + \dot{W}$$

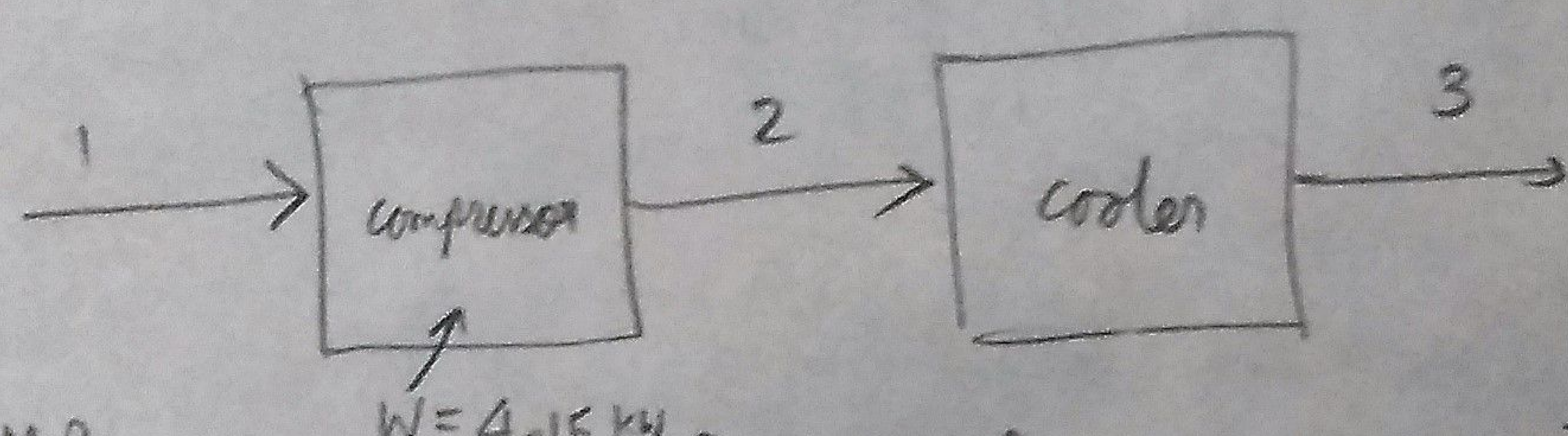
$$0.42\left(2785 + \frac{33.3^2}{2000} + \frac{9.806\times3}{1000}\right) - 0.29$$

$$= 0.42\left(2512 + \frac{100^2}{2000} + 0\right) + \dot{W}$$

$$1170 = 1057 + \dot{W}$$

$\dot{W} = 112.5$ kW (Power output of turbine)

6.



$P_1 = 0.11$ MPa $\quad$ $P_2 = 1.5$ MPa $\quad$ $T_3 = 25°C$

$T_1 = 20°C$ $\quad$ $T_2 = 111°C$

Assumptions : flow is steady
Kinetic energy of the flow is negligible

(a) $A_1V_1 = \frac{2}{60}\ m^3s^{-1}$ (given)

$$\frac{A_1V_1}{v_1} = \dot{m}_1 \qquad \frac{288T_1}{P_1} = v_1 = 0.76\ kg/m^3$$

$$\dot{m}_1 = 0.043$$

$$h_1 = c_pT_1 = 1.005T_1\ kJ/kg$$

$$h_2 = c_pT_2 = 1.005T_2\ kJ/kg$$

$$\dot{m}_1(h_1 + 0 + 0) + \dot{Q} = \dot{m}_2(h_2 + 0 + 0) + \dot{W}$$

$$0.0436(111.55 - 20.1) - 4.15 = \dot{Q}$$

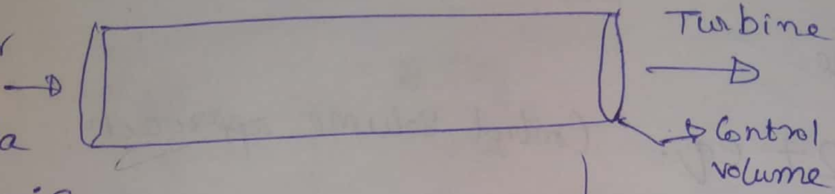
$\dot{Q} = -0.1622$ kW (for compressor)

(b) $\dot{m}\, C_p (T_3 - T_2) = \dot{Q}_{cooler}$ (heat loss rate at constant pressure)

$$-0.043 \times 1.005 \times 10^3 (111 - 25) = \dot{Q}_{cooler}.$$

$$\dot{Q}_{cooler} = -3.716 \text{ KW}$$

(2)



Boiler

$P = 4\,MPa$

$T = 400^\circ C$

$h = 3213.6\ \frac{kJ}{kg}$

$v = 0.073\ m^3/kg$

heat loss = 8.5 kJ/kg

Turbine

$P = 3.5\,MPa$

$T = 392^\circ C$

$h = 3202.6\ \frac{kJ}{kg}$

$v = 0.084\ m^3/kg$

Calculate steam flow rate?

Steady state operation.

$$\dot m_1 = \dot m_2$$

$$\cancel{\frac{dm}{dt}} \quad \rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

$$\frac{A_1 V_1}{v_1} = \frac{A_2 V_2}{v_2}$$

$$V_1 = V_2\left(\frac{0.073}{0.084}\right)$$

$$V_1 = 0.869\,V_2$$

$$\frac{dE}{dt} = 0 \Rightarrow \frac{V_1^2}{2} + z_1 g + u_1 = \frac{V_2^2}{2} + z_2 g + u_2$$

No change in gravitational potential

$$\Rightarrow \frac{V_1^2}{2} + u_1 = \frac{V_2^2}{2} + u_2 \quad (1)$$

From 1st law of thermodynamics.

$$\frac{dQ}{dt} = \frac{dW}{dt}$$

$$\frac{dQ}{dt} = \dot m (P_2 v_2 - P_1 v_1)$$

$$\frac{dQ}{dm} = P_2 V_2 - P_1 V_1 \quad — (2)$$

$$\frac{V_1^2}{2} + u_1 + P_1 V_1 = \frac{V_2^2}{2} + u_2 + P_2 V_2 + P_1 V_1 - P_2 V_2$$

$$\frac{V_1^2}{2} + h_1 = \frac{V_2^2}{2} + h_2 - \frac{dQ}{dm}$$

$$\frac{V_1^2 - V_2^2}{2} = (3202.6 - 3213.6) - (-8.5)$$

$$= -2.5 \times 10^3$$

$$\left[(0.869)^2 - 1\right] \frac{V_2^2}{2} =$$

$$V_2^2 = 20.4248 \times 10^3$$

$$V_2 = \cancel{4.519}\ 142.915$$

$$m_2^\circ = \rho_2 A_2 V_2$$

$$= \cancel{4.519} \times \frac{\pi}{4} (0.2)^2 \times 142.915$$

$$\overline{0.084}$$

Mass flow rate $= 53.45\ kg/s$.

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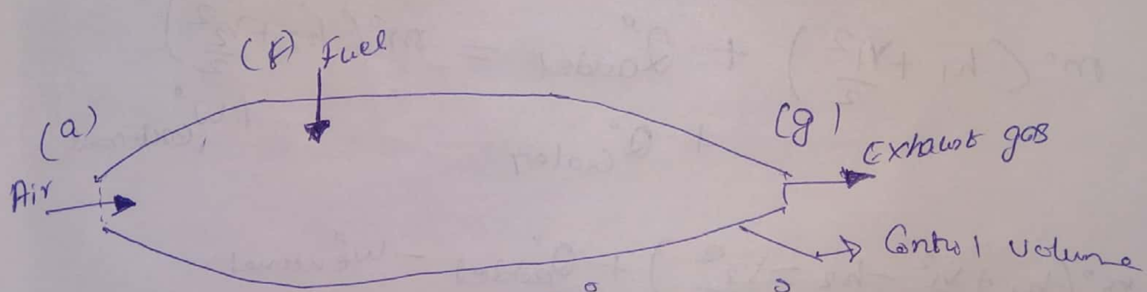
(3)



$$m^\circ_{air}\left(h_a + \frac{V_a^2}{2}\right) + Q^\circ_{added} - Q^\circ_{lost} = m^\circ_{exhaust_g}\left(h_g + \frac{V_g^2}{2}\right)$$

Note that the internal energy of fuel added is neglected.

$$Q^\circ_{added} = 0.95 \times m^\circ_f \times 45 \frac{MJ}{kg}$$

$$h_a + \frac{V_a^2}{2} + \frac{m_f^\circ}{m_a^\circ} \times 0.95 \times 45 \times 10^6 - 12 \times 10^3 = \left(\frac{m_e^\circ}{m_a^\circ}\right)\left(h_g + \frac{V_g^2}{2}\right)$$

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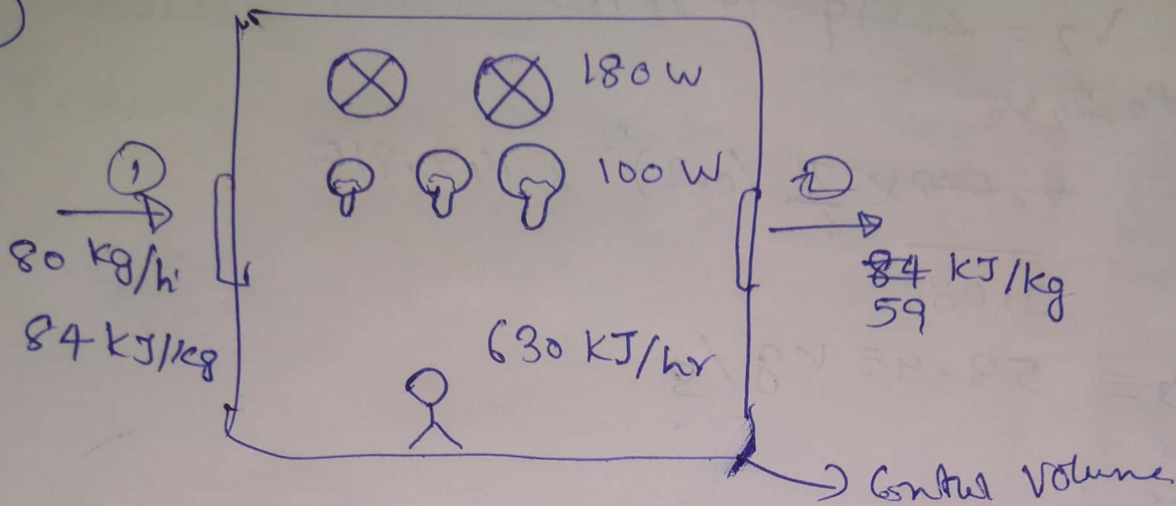
$$m_a^\circ + m_f^\circ = m_e^\circ$$

$$\frac{m_e^\circ}{m_a^\circ} = 1 + 0.02 = 1.02$$

$$260 \times 10^3 + \frac{270^2}{2} + 0.02 \times 0.95 \times 45 \times 10^6 - 12 \times 10^3 = (1.02)\left(950 \times 10^3 + \frac{v_e^2}{2}\right)$$

$$\Rightarrow \boxed{V_e = 578.11 \text{ m/s}}$$

(5)



Assuming steady state.

$$\dot{m}_1 = \dot{m}_2 = \dot{m}$$

$$\dot{m}\left(h_1 + \frac{V_1^2}{2}\right) + \dot{Q}_{added} = \dot{m}\left(h_2 + \frac{V_2^2}{2}\right) + \dot{W}_{external} + \dot{Q}_{cooler}$$

$$\dot{m}\left(h_1 + \frac{V_1^2}{2} - h_2 - \frac{V_2^2}{2}\right) + \dot{Q}_{added} - \dot{W}_{external} = -\dot{Q}_{cooler}$$

Neglecting the velocity of air entering and leaving the room

$$\frac{80}{60\times60}\left(84\times10^3 - 59\times10^3\right) + 4\times\frac{630\times10^3}{60\times60} - \left(-2\times180 - 3\times100\right) = -\dot{Q}_{cooler}$$

$\dot{Q}_{Cooler} = -1915.5 \ W$

$= -1.915 KW.$

This much heat should be removed by Cooler.