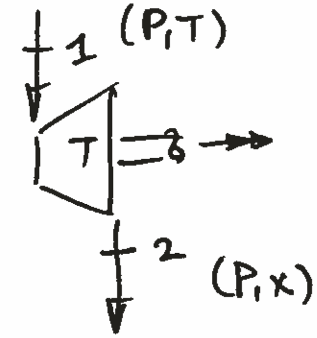
Open System Energy Balance:

(Control Volume analysis)



- Mass conservation

$$\dot{m}_{in} + \dot{m}_{gen} = \dot{m}_{out} + \dot{m}_{stored} \quad \text{— (1)}$$

$\rightarrow$ $\dot{m} = \rho A V$ ← velocity $= A v / v$

- Open System Energy conservation

$$\rightarrow \dot{E}_{in} + \dot{E}_{gen} = \dot{E}_{out} + \dot{E}_{stored} \quad \text{— (2)}$$

$\rightarrow$ SF, SS, EE

$$(2) \Rightarrow \cancel{\frac{dE}{dt}}^{\,0} = \dot{Q} - \dot{W} + \dot{m}_1 \left(h_1 + \frac{V_1^2}{2} + g z_1\right) - \dot{m}_2 \left(h_2 + \frac{V_2^2}{2} + g z_2\right) \quad \text{— (3)}$$

$\dot{E}_{stored} = 0$
{Steady state}

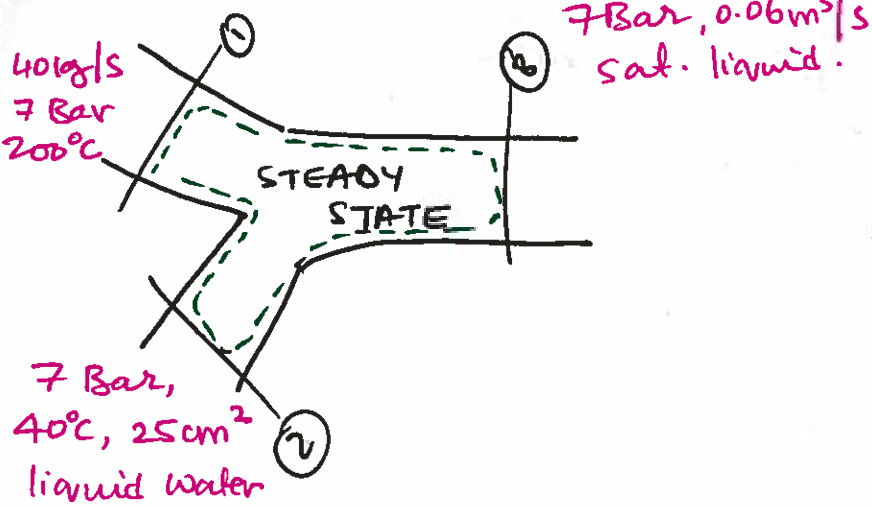
$\rightarrow$ Closed system E. Balance: Special case of SFEE

$$\dot{m}_1 = 0 = \dot{m}_2 \ , \quad dE/dt = 0$$

$$0 = \dot{Q} - \dot{W}$$

"Under what conditions can you recover Bernoulli EQN from the SFEE" [ms 4.1] } ms: Moran + Shapiro

A feedwater heater operating at steady state has two inlets and one exit. At inlet 1, water vapor enters at $p_1 = 7$ bar, $T_1 = 200°C$ with a mass flow rate of 40 kg/s. At inlet 2, liquid water at $p_2 = 7$ bar, $T_2 = 40°C$ enters through an area $A_2 = 25\ cm^2$. Saturated liquid at 7 bar exits at 3 with a volumetric flow rate of 0.06 m^3/s. Determine the mass flow rates at inlet 2 and at the exit, in kg/s, and the velocity at inlet 2, in m/s.



☐ GIVEN: States of water @ 1, 2, 3, $A_2 = 25\ cm^2$, $\dot{V}_3 = 0.06\ m^3/s$.

☐ TO FIND:

→ $\dot{m}_2$, $\dot{m}_3$

→ v_2 (velocity)

☐ SOLUTION:

- Relevant properties @ 3 locations:

@1: $P_1 = 7\text{Bar} = 7\text{Atm.}$, $T_1 = 200°C$
$= 0.7\text{MPa}$

$$v_1 = \frac{1}{2}(\underbrace{0.35212}_{(6\text{Bar},\ 200°)} + \underbrace{0.\cancel{26}088}_{(8\text{Bar},\ 200°C)}) \Rightarrow \boxed{v_1 = 0.306\ m^3/kg}$$

[Table A6]

@2: Compressed liquid water 7Bar } $v_2 \simeq v_f\,(T_{sat} @ 7\text{Bar})$

$$\boxed{v_2 \simeq 0.001108\ m^3/kg}$$

[Table A-5]

@3: Saturated liquid $\Big\}$ $\boxed{v_3 = 0.001108\ m^3/kg}$ (TAS)

Mass conservation $\Big\}$ $\dot{m}_1 + \dot{m}_2 = \dot{m}_3$

$$\therefore \dot{m}_2 = \dot{m}_3 - \dot{m}_1$$

$$= \frac{\dot{V}_3}{v_3} - \dot{m}_1 = \frac{0.06}{0.001108} - 40$$

$$\boxed{\dot{m}_2 = 14.15\ kg/s}$$ ← Please check

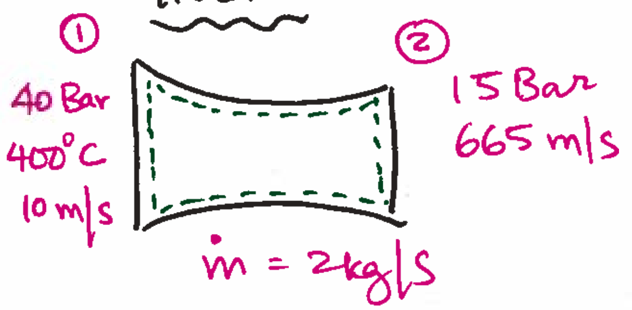
$$\because \dot{m}_2 = \rho_2 A_2 V_2 = \frac{A_2 V_2}{v_2} \Rightarrow V_2 = \frac{\dot{m}_2 v_2}{A_2}$$

$$V_2 = \frac{(14.15)(0.001108)}{(25 \times 10^{-4})} \Rightarrow \boxed{V_2 = 6.27\ m/s}$$

[ms 4.3]

Steam enters a converging–diverging nozzle operating at steady state with $p_1 = 40$ bar, $T_1 = 400°C$, and a velocity of 10 m/s. The steam flows through the nozzle with negligible heat transfer and no significant change in potential energy. At the exit, $p_2 = 15$ bar, and the velocity is 665 m/s. The mass flow rate is 2 kg/s. Determine the exit area of the nozzle, in m^2.

GIVEN:



II To FIND: Exit area of nzl.

II SOLUTION:

SFEE:

(No boundary movement)

$$\cancel{\frac{dE}{dt}\Big|_{CV}}^{\,0} = \cancel{\dot{Q}}^{\,0} - \cancel{\dot{W}}^{\,0} + \dot{m}\left(h_1 + \frac{V_1^2}{2} + \cancel{gz_1}\right) - \dot{m}\left(h_2 + \frac{V_2^2}{2} + \cancel{gz_2}\right)$$

Steady state

negligible heat tran

$$\therefore \underbrace{h_1}_{\frac{kJ}{kg}} + \underbrace{\frac{V_1^2}{2}}_{\frac{m^2}{s^2} \to \frac{kJ}{kg}} = h_2 + \frac{V_2^2}{2} \quad \text{—— (I)}$$

$$@1: h_1 = \underbrace{h_1(40\text{ Bar}, 400°C)}_{\text{Sup'ht. steam}} \Rightarrow \boxed{h_1 = 3214.5 \frac{kJ}{kg}}$$

$$(I) \Rightarrow h_2 = h_1 + \left(\frac{V_1^2 - V_2^2}{2 \times 1000}\right)$$

$J \longrightarrow kJ$

$$h_2 = 3214.5 + \left(\frac{10^2 - 665^2}{2000}\right)$$

$$\boxed{h_2 = 2993.44 \ kJ/kg}$$

$$v_2 @ (P_2, h_2) = v_2(15 \text{ Bar}, 2993.44 \ kJ/kg)$$

$$\boxed{v_2 \cong 0.220 \ m^3/kg}$$ [Sup'ht steam]

$$\dot{m}_2 = \dot{m}_1 = \rho_2 A_2 V_2 = \frac{A_2 V_2}{v_2}$$

$$\Rightarrow A_2 \cong \frac{\dot{m}_2 v_2}{V_2} \cong \frac{(0.22)(2)}{665}$$

$$\boxed{A_2 \cong 661 \times 10^{-6} \ m^2 \cong 6.61 \ cm^2}$$

[ms 4.4]

Steam enters a turbine operating at steady state with a mass flow rate of 4600 kg/h. The turbine develops a power output of 1000 kW. At the inlet, the pressure is 60 bar, the temperature is 400°C, and the velocity is 10 m/s. At the exit, the pressure is 0.1 bar, the quality is 0.9 (90%), and the velocity is 30 m/s. Calculate the rate of heat transfer between the turbine and surroundings, in kW.

□ GIVEN: Steady state op. of steam turbine

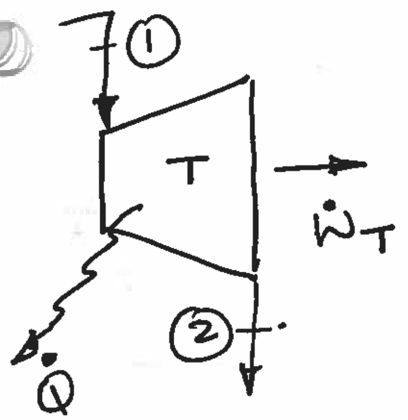
$\dot{m} = 4600\ kg/h$, $\dot{W}_T = 1000\ kW$

$T_1 = 400°C$, $P_1 = 60\ Bar$, $P_2 = 0.1\ Bar$, $x_2 = 90\%$

$V_1 = 10\ m/s$, $V_2 = 30\ m/s$

□ To FIND: Rate of H.T between turbine, surroundings.

□ SOLUTION: Steady state energy balance (SFEE):



$$\cancel{\frac{dE}{dt}} \to 0 = \dot{Q} - \underbrace{\dot{W}}_{\dot{W}_T} + \dot{m}\left(h_1 + \frac{V_1^2}{2} + \cancel{gz_1}\right) - \dot{m}\left(h_2 + \frac{V_2^2}{2} + \cancel{gz_2}\right)$$

$$0 = \dot{Q} - \dot{W}_T + \dot{m}\left(h_1 + \frac{V_1^2}{2}\right) - \dot{m}\left(h_2 + \frac{V_2^2}{2}\right)$$

$$h_1 = h_1(P_1, T_1)$$

$$= h_1(60\ Bar, 400°C) = h_1(6\ MPa, 400°C)$$

$$\Rightarrow \boxed{h_1 = 3178.3\ kJ/kg}\ \text{[Sup'ht. steam table]}$$

$h_2 = h_2(P_2, x_2) \equiv$ Saturated L-V

$= h_2(0.01\,MPa, 90\%)$
OR
$10\,kPa$

$h_2 = h_{f2} + x_2 h_{fg2}$ @ $(10\,kPa)$

~~hfg...~~ $\boxed{h_2 = 2344.7\ kJ/kg}$

$$0 = \dot{Q} - \underbrace{\dot{W}_T}_{+1000\,kW} + \frac{4600}{3600}\left[3178.3\ kJ/kg + \frac{10^2}{2000}\ kJ/kg\right]$$

$$- \frac{4600}{3600}\left[2344.7\ kJ/kg + \frac{30^2}{2000}\ kJ/kg\right]$$

$\boxed{\dot{Q} = \text{-----}}$ [DIY]

[ms 4.5]

Air enters a compressor operating at steady state at a pressure of 1 bar, a temperature of 290 K, and a velocity of 6 m/s through an inlet with an area of 0.1 m². At the exit, the pressure is 7 bar, the temperature is 450 K, and the velocity is 2 m/s. Heat transfer from the compressor to its surroundings occurs at a rate of 180 kJ/min. Employing the ideal gas model, calculate the power input to the compressor, in kW.

□ GIVEN: Air (ideal gas EOS), $P_1 = 1\,\text{Bar}$, $T_1 = 290\,K$, $V_1 = 6\,m/s$

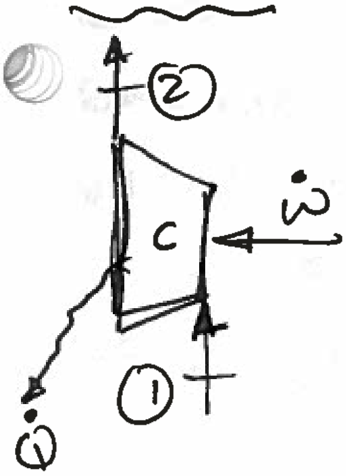
$A_1 = 0.1\,m^2$;

$P_2 = 7\,\text{Bar}$, $T_2 = 450\,K$, $V_2 = 2\,m/s$.

$\dot{Q} = -180\,kJ/min = -3\,kJ/s = -3\,kW$

□ TO FIND: Power input to compressor.

□ SOLUTION: Steady state energy balance for an open system:



$$\cancel{\frac{dE}{dt}}^{=0} = \dot{Q} - \dot{W} + \dot{m}\left(h_1 + \frac{V_1^2}{2} + \cancel{gz_1}\right) - \dot{m}\left(h_2 + \frac{V_2^2}{2} + \cancel{gz_2}\right)$$

$$\dot{W} = \dot{Q} + \dot{m}\left(h_1 + V_1^2/2\right) - \dot{m}\left(h_2 + V_2^2/2\right)$$

Where: $\dot{m} = \dfrac{A_1 V_1}{v_1} = \dfrac{A_1 V_1}{RT_1/P_1} = \dfrac{(0.1)(6)}{\left[\dfrac{287 \times 290}{100 \times 10^3}\right]}$

$[R = R_{sp,air} = 287\ J/kg\text{-}K]$

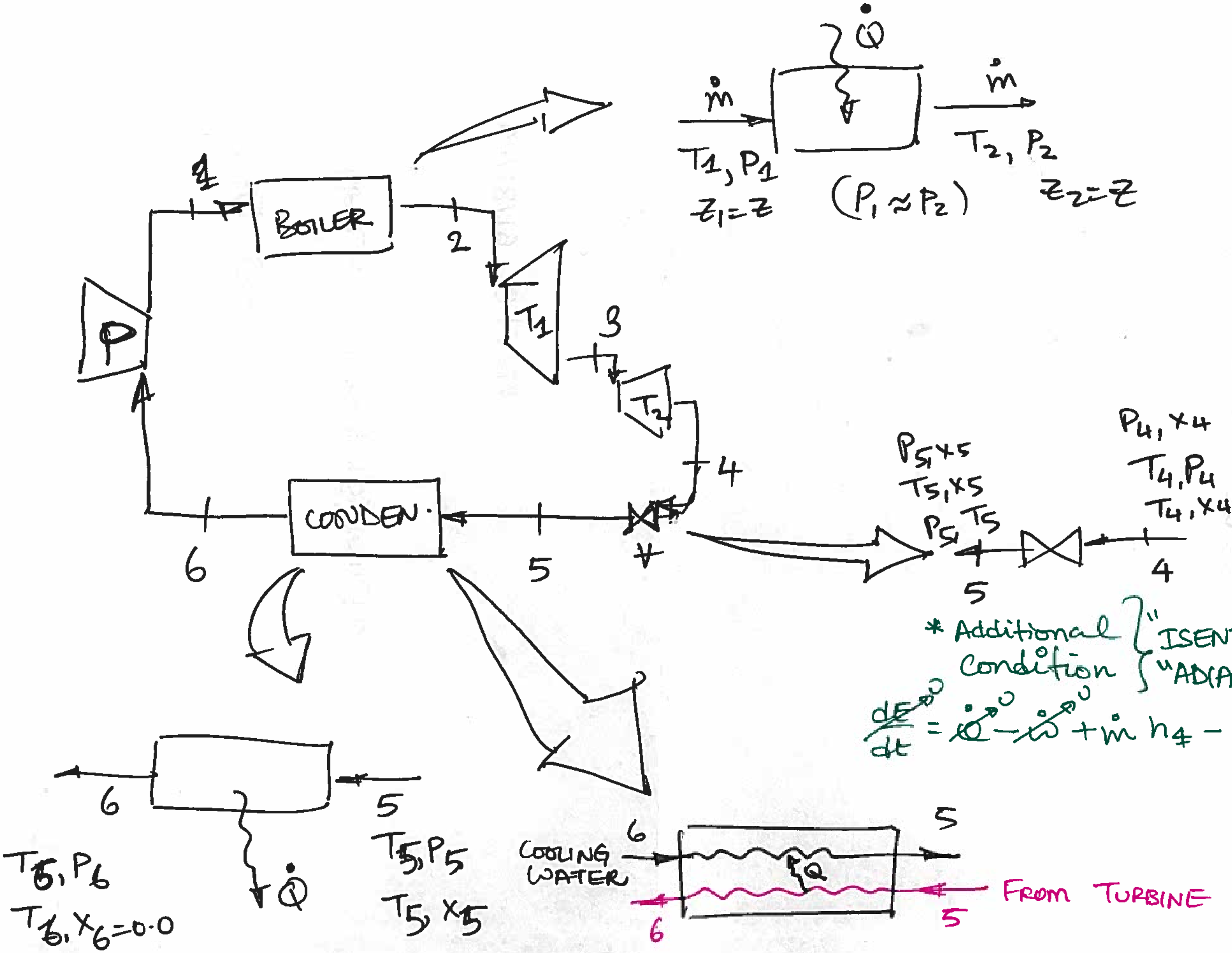
$$\boxed{\dot{m} = 0.721\ kg/s}$$

Use Table A-17 for air properties $\left.\right\}$ $h_1 = h_1(290\text{K}) = 290.16\ \text{kJ/kg}$

$h_2 = h_2(450\text{K}) = 451.8\ \text{kJ/kg}$

$$\dot{W} = \dot{Q} + \dot{m}\left(h_1 + \frac{V_1^2}{2000}\right) - \dot{m}\left(h_2 + \frac{V_2^2}{2000}\right)$$

$$\boxed{\dot{W} = -119.4\ \text{kW}}$$



* Additional Condition { "ISENTHALPIC" "ADIABATIC"

$$\cancel{\frac{dE}{dt}}^{\,0} = \cancel{\dot{Q}}^{\,0} - \cancel{\dot{W}}^{\,0} + \dot{m}\,h_4 - \dot{m}\,h_5$$