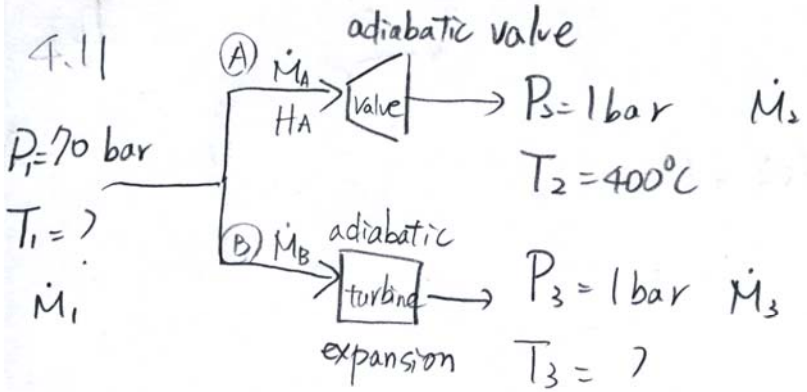
4.11 (1)



(Sol) a) From mass balance

$$\frac{dM}{dt} = \dot{M}_1 + \dot{M}_2 + \dot{M}_3 = 0 \Rightarrow \dot{M}_1 = -\dot{M}_2 - \dot{M}_3$$

Take valve as the system

$$\dot{M}_A = -\dot{M}_2 \quad -①$$

Take turbine as the system.

$$\dot{M}_B = -\dot{M}_3 \quad -②$$

From energy balance

Take valve as the system

$\frac{dU}{dt} = 0$ for steady state; adiabatic: $\frac{dQ}{dt} = 0$; No shaft work: $\dot{W}_s = 0$; $\frac{dU}{dt} = 0$

$$\frac{dU}{dt} = \dot{M}_A \hat{H}_A + \dot{M}_2 \hat{H}_2 + \frac{dQ}{dt} + \dot{W}_s - P\frac{dU}{dt} = 0$$

$$\Rightarrow \dot{M}_A \hat{H}_A = -\dot{M}_2 \hat{H}_2$$

$\because \dot{M}_A = -\dot{M}_2$ – eqn ①

$\Rightarrow \hat{H}_A = \hat{H}_2$ (2)

from Mollier Diagram. $\hat{H}_2$ (1 bar 400°c) = 3278 kJ/kg

$= \hat{H}_A$ (40 bar, T_1)

$\Rightarrow T_1 \approx 447$ °c. #

b) Take turbine as the system

From energy balance (o S.S, o adia)

$$\frac{dU}{dt} = \dot{M}_B \hat{H}_B + \dot{M}_3 \hat{H}_3 + \dot{Q} + \dot{W}$$

from eq'n ② $\dot{M}_B = -\dot{M}_3$

$$\Rightarrow \dot{W} = \dot{M}_3 \hat{H}_B - \dot{M}_3 \hat{H}_3$$

$\because \hat{H}_A = \hat{H}_1 = \hat{H}_2$

$$= -\dot{M}_B (3278\ kJ/kg - \hat{H}_3) \quad -③$$

$\hat{H}_3$ is unknown

From entropy balance (o S.S., o adiabatic)

$$\frac{dS}{dt} = \dot{M}_B \hat{S}_B + \dot{M}_3 \hat{S}_3 + \frac{\dot{Q}}{T} + \dot{S}_{gen} \quad -④$$

for finding max. work $\Rightarrow$ reversible process $\Rightarrow \dot{S}_{gen} = 0$

$\Rightarrow 0 = \dot{M}_B \hat{S}_B + \dot{M}_3 \hat{S}_3 \Rightarrow \hat{S}_B = \hat{S}_3$ $\because \hat{S}_B \doteq 6.62 kJ/kg$ from steam table

$\Rightarrow \hat{S}_3 = 6.62 \text{ kJ/kg·K}$ ③

from P.921 1 bar = 0.1 MPa

$\hat{S}_3 = 6.62 \text{ kJ/kg·K} < 7.3594 \text{ kJ/kg·K}$ (Saturated temp.)

$\Rightarrow$ steam 3 consists of liquid & vapor

Let x = vapor fraction

$\hat{S}_3 = x\hat{S}_{vapor} + (1-x)\hat{S}_{liq.}$

from P.919. $\hat{S}_{vapor} = 7.3594$ $\hat{S}_{liq.} = 1.3026$

$\Rightarrow 6.62 = x \times 7.3594 + (1-x) \times 1.3026$

$\Rightarrow x \doteq 0.88$

$\Rightarrow \hat{H}_3 = 0.88\hat{H}_{vap} + 0.12\hat{H}_{liq.}$

$= 0.88(2675.5) + 0.12(417.46) \text{ kJ/kg}$

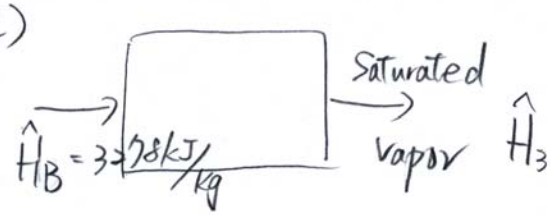
$\doteq 2405 \text{ kJ/kg}$

from eqn ③

$-\frac{\dot{W}^{rev}}{\dot{m}_k} = 3278 - 2405 \text{ kJ/kg} = 873 \text{ kJ/kg}$

(4)

c)



P.919 steam table

for saturated vapor, $\hat{H}_3 = 2675.5\ kJ/kg$

$$\Rightarrow -\frac{\dot{W}}{\dot{M}_B} = 3378 - 2675.5 = 602.5\ \frac{kJ}{kg}$$

$$\eta = \frac{-\frac{\dot{W}}{\dot{M}_B}}{-\frac{\dot{W}^{rev}}{\dot{M}_B}} = \frac{602.5}{873} = 0.69\ \%$$

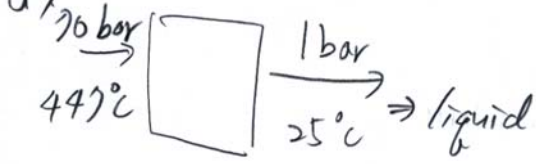
from eq'n (4)

$$\dot{M}_B \hat{S}_B + \dot{M}_3 \hat{S}_3 + \dot{S}_{gen} = 0$$

$$\Rightarrow \dot{S}_{gen} = -\dot{M}_B \hat{S}_B - \dot{M}_3 \hat{S}_3$$

$$\Rightarrow \frac{\dot{S}_{gen}}{\dot{M}_B} = -\hat{S}_B + \hat{S}_3 = -6.62 + 7.3594 \doteq 0.74\ \frac{kJ}{kg}$$

(5)

d) 

From energy balance

$$\frac{dU}{dt}^{S.S=0} = \dot{M}_B \hat{H}_B + \dot{M}_3 \hat{H}_3 + \dot{Q} + \dot{W}$$

$$\Rightarrow -\frac{\dot{W}}{\dot{M}_B} = \hat{H}_B - \hat{H}_3 + \frac{\dot{Q}}{\dot{M}_B} \quad - (5)$$

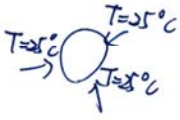
From entropy balance

$$\frac{dS}{dt}^{S.S=0} = \dot{M}_B \hat{S}_B + \dot{M}_3 \hat{S}_3 + \frac{\dot{Q}}{T} + \dot{S}_{gen}^{=0}$$

for max work system operates reversible

$$\Rightarrow \frac{\dot{Q}}{\dot{M}_B} = (\hat{S}_3 - \hat{S}_B)(T^{=25^\circ C}) \quad - (6)$$

∵ all heat transfer at ambient temp.



(6) substitute into (5)

$$\Rightarrow \frac{\dot{W}}{-\dot{M}_B} = (\hat{H}_B - T\hat{S}_B) - (\hat{H}_3 - T\hat{S}_3)$$

↙ P.917

$$= (3278 - 298 \times 6.162) - (104.89 - 298 \times 0.3674) \approx 1309.4 \ \text{kJ/kg}$$