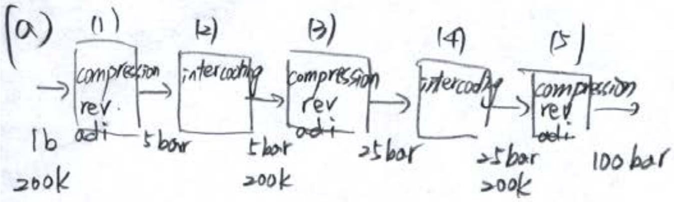
①

5.8

(a)



Take (1) as the system

Mass Balance s.s.

$$\frac{d\cancel{M}^{0}}{\cancel{dt}} = \dot{M}_{in} + \dot{M}_{out} \Rightarrow \dot{M}_{out} = -\dot{M}_{in}$$

Energy Balance

$$\frac{d\cancel{U}^{0\ s.s}}{\cancel{dt}} = \dot{M}_{in}\hat{H}_{in} + \overset{-\dot{M}_{in}}{\dot{M}_{out}}\hat{H}_{out} + \cancel{\dot{Q}}^{0\ \text{adiabatic}} + \dot{W}$$

$$\Rightarrow \dot{W} = \dot{M}_{in}(\hat{H}_{out} - \hat{H}_{in}) \Rightarrow \frac{\dot{W}}{\dot{M}_{in}} = \hat{H}_{out} - \hat{H}_{in}$$

Entropy Balance

$$\frac{d\cancel{S}^{0\ s.s}}{\cancel{dt}} = \dot{M}_{in}\hat{S}_{in} + \overset{-\dot{M}_{in}}{\dot{M}_{out}}\hat{S}_{out} + \frac{\cancel{\dot{Q}}^{\text{adi}}}{T} + \cancel{\dot{S}_{gen}}^{\text{rev.}}$$

$$\Rightarrow \hat{S}_{in} = \hat{S}_{out}$$

From Fig. 3.3-2.

$$\hat{H}_{in}(200K, 1\ bar) = 767\ kJ/kg$$

$$\hat{S}_{in}(200K, 1\ bar) = 6.5\ kJ/kg \cdot K = \hat{S}_{out}$$

$$\Rightarrow \hat{H}_{out}(S = 6.5\ kJ/kg \cdot K,\ 5\ bar) = 963\ kJ$$

$$\Rightarrow \frac{\dot{W}}{\dot{M}_{in}} = 963 - 767 = 196\ kJ/kg$$

Take (2) as the system $\quad$ ②

$$\frac{\dot{W}_{in}}{\dot{M}_{in}} = \hat{H}_{out} - \hat{H}_{in}$$ From Fig 3.3-2 $\hat{H}_{in}(200K,\ 5\,bar) = 760\ kJ/kg$

$\hat{S}_{in}(200K,\ 5\,bar) = 5.65\ kJ/kg$

$\Rightarrow \hat{H}_{out}(S = 5.65\ \frac{kJ}{kg\cdot K},\ 25\,bar) = 960\ kJ/kg$

$$\Rightarrow \frac{\dot{W}_{in}}{\dot{M}_{in}} = 960 - 760 = 200\ kJ/kg\cdot K$$

Take (3) at the system

$$\frac{\dot{W}_{in}}{\dot{M}_{in}} = \hat{H}_{out} - \hat{H}_{in}$$ From Fig 3.3.2 $\hat{H}_{in}(200K,\ 25\,bar) = 718\ kJ/kg$

$\hat{S}_{in}(200K,\ 25\,bar) = 4.65\ kJ/kg$

$\Rightarrow \hat{H}_{out}(\hat{S} = 4.65\ \frac{kJ}{kg\cdot K},\ 100\,bar) = 855\ kJ/kg$

$$\Rightarrow \frac{\dot{W}_{in}}{\dot{M}_{in}} = 855 - 718 = 137\ kJ/kg$$

The total work:

$196 + 200 + 137 = 533\ kJ/kg$

(b) Take the valve as the system. (3)

From energy balance

$$\frac{d\cancel{U}^{0\ S.S}}{dt} = \dot{M}_{in}\hat{H}_{in} + \overset{-\dot{M}_{in}}{\dot{M}_{out}}\hat{H}_{out} + \overset{adi}{\cancel{\dot{Q}}} + \overset{\text{No work.}}{\cancel{\dot{W}}}$$

$$\Rightarrow \hat{H}_{in} = \hat{H}_{out}$$

mass fraction of Liq.

Fig Fig 3.3-2 $\hat{H}_{in}(200K, 100\,bar) = (1-X)\hat{H}(sat.\,Liq,\ 1bar) + X\,\hat{H}(sat.\,vap,\ 1bar)$

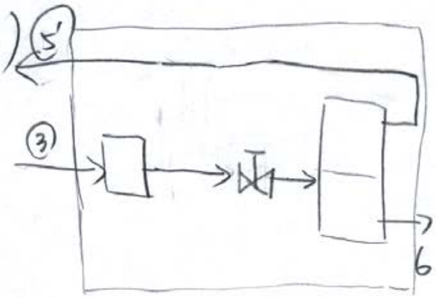
$$\Rightarrow 423 = (1-X)\cdot 21 + X \cdot 582$$

From Fig 3.3-2

$$\Rightarrow X = 0.689$$

$\Rightarrow \dfrac{533}{(1-0.689)} = 1713$ kJ of work are required for each kg. of LNG produced.

(c)



From mass balance

$$\frac{dM}{dt}^{\nearrow 0 \text{ s.s.}} = \dot{M}_3 + \dot{M}_5' + \dot{M}_6 \Rightarrow \dot{M}_6 + \dot{M}_5' = -\dot{M}_3$$

From energy balance

$$\frac{dU}{dt}^{\nearrow 0 \text{ s.s.}} = \dot{M}_3\hat{H}_3 + \dot{M}_5'\hat{H}_5' + \dot{M}_6\hat{H}_6 + \underbrace{\dot{Q}}_{\text{adiabatic}} + \underbrace{\dot{W}}_{\text{No work}}$$

$$\Rightarrow \dot{M}_3\hat{H}_3 + \dot{M}_5'\hat{H}_5' + \dot{M}_6\hat{H}_6 = 0$$

Let $\dot{M}_3 = 1$ $\quad \dot{M}_5' = -\omega$, $\dot{M}_6 = -1+\omega$.

$$\underbrace{\hat{H}_3(200K, 100bar)}_{453 \text{ kJ/kg}} - \omega \underbrace{\hat{H}_5'(\text{sat. vap}, 1bar)}_{718 \text{ kJ/kg}} + (-1+\omega)\underbrace{\hat{H}_6(\text{sat liq}, 1bar)}_{71 \text{ kJ/kg}} = 0$$

$\Rightarrow \omega = 0.544$. $\qquad 1-\omega = 0.456$

$$\frac{533}{0.456} = 1168 \text{ kJ/kg of LNG produced}$$

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