Applied Thermodynamics
Tutorial 4 (24.8.2016) Solution

Q.1

Q.1 (One)

Sol:

$h_{s_2} = h_{f_2} + x h_{fg_2}$ (At 900 kPa & $x = 0.97$)

$= 742.56 + 0.97 \times 2030.5$

$= 2712.14$ kJ/kg

$h_{f_1} = 146.64$ kJ/kg (At 35°C)

Steam generated $= \frac{5600}{700} = 8$ kg/kg of fuel

Equivalent evaporation

$= \frac{(h_{s_2} - h_{f_1}) \times M_a}{2256.4}$ [h_{fg} from at 100°C]

$= \frac{(2712.14 - 146.64) \times 8}{2256.4}$

(a) $\boxed{= 9.096 \text{ kg/kg of coal}}$

Boiler efficiency

$= \frac{\text{Heat supplied by feed water, kJ/kg of fuel}}{\text{Heat supplied by fuel, kJ/kg of fuel}}$

$= \frac{(2712.14 - 146.64) \times 8}{31380} \times 100$

(b) $\boxed{= 65.40\,\%}$

Under new condition

Boiler efficiency $= 65.40 + 5$

$= 70.4\,\%$

Heat supplied by fuel/h $= \frac{\text{Heat utilised by feed water}}{\text{Boiler efficiency}}$

$$= \frac{(2712.14 - 419.17)\,5600}{0.704}$$

$$= 18239534.09 \text{ kJ}$$

$$= 18239.53 \text{ MJ}$$

$\therefore$ Mass of fuel fired $= \dfrac{18239534.09}{31380}$

$$= 581.25 \text{ Kg/h}$$

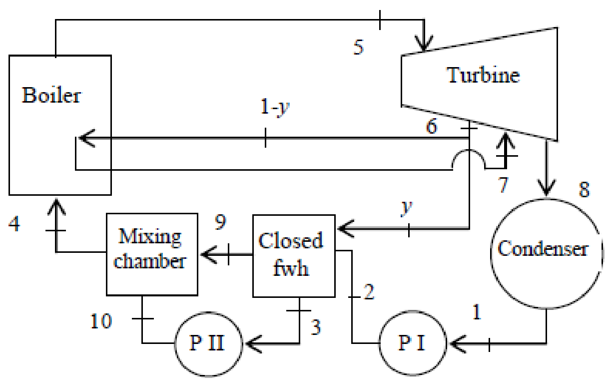
$\therefore$ Saving coal per hour $= 700 - 581.25 = 118.75$ Kg/h

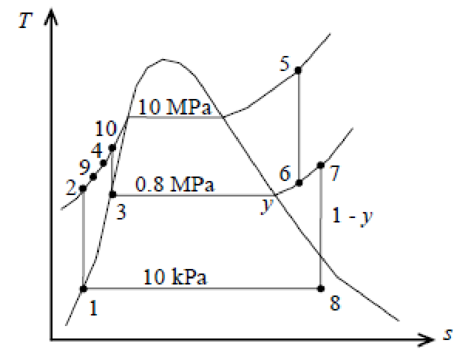
$\boxed{C \Rightarrow 118.75 \text{ Kg/h}}$

# # #

Q.2

Analysis





(*a*) From the steam tables (Tables A-4, A-5, and A-6),

$$h_1 = h_{f\,@\,10\text{kPa}} = 191.81 \text{ kJ/kg}$$

$$v_1 = v_{f\,@\,10\text{kPa}} = 0.00101 \text{ m}^3/\text{kg}$$

$$w_{pI,\text{in}} = v_1(P_2 - P_1) = \left(0.00101 \text{ m}^3/\text{kg}\right)\left(10{,}000 - 10 \text{ kPa}\right)\left(\frac{1 \text{ kJ}}{1 \text{ kPa}\cdot\text{m}^3}\right)$$
$$= 10.09 \text{ kJ/kg}$$

$$h_2 = h_1 + w_{pI,\text{in}} = 191.81 + 10.09 = 201.90 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_3 = 0.8 \text{ MPa} \\ \text{sat.liquid} \end{array}\right\} \begin{array}{l} h_3 = h_{f\,@\,0.8\text{ MPa}} = 720.87 \text{ kJ/kg} \\ v_3 = v_{f\,@\,0.8\text{ MPa}} = 0.001115 \text{ m}^3/\text{kg} \end{array}$$

$$w_{pII,\text{in}} = v_3(P_4 - P_3) = \left(0.001115 \text{ m}^3/\text{kg}\right)\left(10{,}000 - 800 \text{ kPa}\right)\left(\frac{1 \text{ kJ}}{1 \text{ kPa}\cdot\text{m}^3}\right)$$
$$= 10.26 \text{ kJ/kg}$$

$$h_4 = h_3 + w_{pII,\text{in}} = 720.87 + 10.26 = 731.13 \text{ kJ/kg}$$

Also, $h_4 = h_9 = h_{10} = 731.12$ kJ/kg since the two fluid streams that are being mixed have the same enthalpy.

$$\left.\begin{array}{l} P_5 = 10 \text{ MPa} \\ T_5 = 550°\text{C} \end{array}\right\} \begin{array}{l} h_5 = 3502.0 \text{ kJ/kg} \\ s_5 = 6.7585 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_6 = 0.8 \text{ MPa} \\ s_6 = s_5 \end{array}\right\} h_6 = 2812.7 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_7 = 0.8 \text{ MPa} \\ T_7 = 500°\text{C} \end{array}\right\} \begin{array}{l} h_7 = 3481.3 \text{ kJ/kg} \\ s_7 = 7.8692 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_8 = 10 \text{ kPa} \\ s_8 = s_7 \end{array}\right\} \begin{array}{l} x_8 = \dfrac{s_8 - s_f}{s_{fg}} = \dfrac{7.8692 - 0.6492}{7.4996} = 0.9627 \\ h_8 = h_f + x_8 h_{fg} = 191.81 + (0.9627)(2392.1) = 2494.7 \text{ kJ/kg} \end{array}$$

The fraction of steam extracted is determined from the steady-flow energy balance equation applied to the feedwater heaters. Noting that $\dot{Q} \cong \dot{W} \cong \Delta\text{ke} \cong \Delta\text{pe} \cong 0$,

$$\dot{E}_{in} - \dot{E}_{out} = \Delta\dot{E}_{system}^{\cancel{\nearrow}0\,(steady)} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\sum \dot{m}_i h_i = \sum \dot{m}_e h_e \longrightarrow \dot{m}_2(h_9 - h_2) = \dot{m}_3(h_6 - h_3) \longrightarrow (1-y)(h_9 - h_2) = y(h_6 - h_3)$$

where y is the fraction of steam extracted from the turbine ($= \dot{m}_3 / \dot{m}_4$). Solving for y,

$$y = \frac{h_9 - h_2}{(h_6 - h_3) + (h_9 - h_2)} = \frac{731.13 - 201.90}{2812.7 - 720.87 + 731.13 - 201.90} = 0.2019$$

Then,

$$q_{in} = (h_5 - h_4) + (1-y)(h_7 - h_6) = (3502.0 - 731.13) + (1 - 0.2019)(3481.3 - 2812.7) = 3304.5 \text{ kJ/kg}$$

$$q_{out} = (1-y)(h_8 - h_1) = (1 - 0.2019)(2494.7 - 191.81) = 1837.9 \text{ kJ/kg}$$

$$w_{net} = q_{in} - q_{out} = 3304.5 - 1837.8 = 1466.6 \text{ kJ/kg}$$

and

$$\dot{m} = \frac{\dot{W}_{net}}{w_{net}} = \frac{80{,}000 \text{ kJ/s}}{1467.1 \text{ kJ/kg}} = \mathbf{54.5\ kg/s}$$

(b) $$\eta_{th} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{1837.8 \text{ kJ/kg}}{3304.5 \text{ kJ/kg}} = \mathbf{44.4\%}$$