Solutions to Exergy Exercise Sheet 1

Introduction to Exergy Analysis

a) At environmental state assume water is a liquid.

$h_0 = 62.9$ kJ/kg

$s_0 = 0.224$ kJ/kg K

At 400°C, 40 bar $h = 3214$ kJ/kg

$s = 6.769$ kJ/kg K

$$\varepsilon = h - h_0 - T_0(s - s_0)$$

$$= 3214 - 62.9 - 288(6.769 - 0.224)$$

$$\varepsilon = 1266 \text{ kJ/kg}$$

Flow exergy $= \dot{E} = \dot{m}\varepsilon = 25 \times 1266 = \underline{31.65 \text{ MW}}$

b) For air entropy $s - s_0 = c_p \log_e\left(\frac{T_1}{T_0}\right) - R \log_e\left(\frac{P_1}{P_0}\right)$

(from Tables)

$$s - s_0 = 1.005 \log_e \frac{(273+25)}{(273+15)} - 0.2871 \log_e \left(\frac{7}{1}\right)$$

$$= 0.03430 - 0.55867$$

$$s - s_0 = -0.5243 \text{ kJ/kg K}$$

(The air has higher entropy at T_0, p_0)

$$\varepsilon = c_p(T - T_0) - T_0(s - s_0)$$

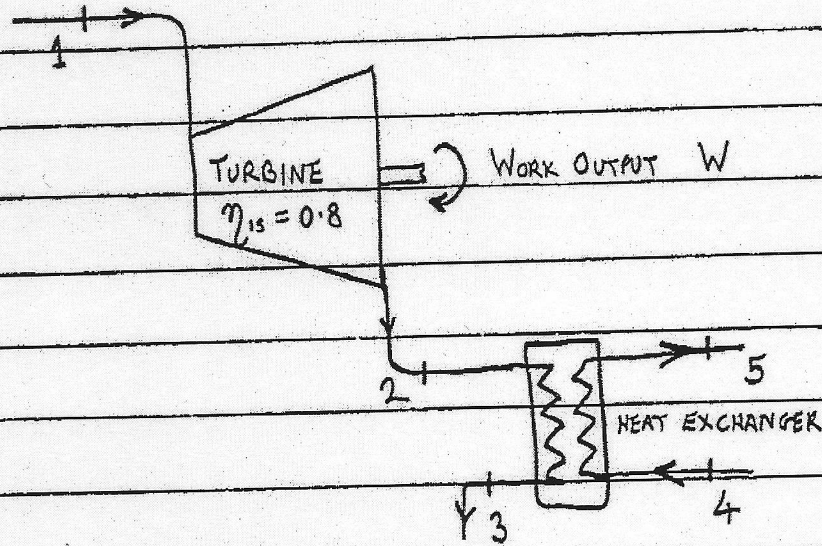
$$= 1.005(25 - 15) - (273+15)(-0.5243)$$

$$\varepsilon = 161.05 \text{ kJ/kg}$$

$\dot{E} = \dot{m}\varepsilon = 0.5 \times 161.05 = \underline{80.5 \text{ kW}}$

(1)

a)



	p (bar)	T (°C)	h (kJ/kg)	s (kJ/kg)	x (Dryness)
1	30	350	3114	6.744	
2′	2	120.2	2555	6.744	
2	2	120.2	2667	7.035	0.98
3	2	120.2	505	1.53	0
4	–	60	251.1	0.831	
5	–	80	334.9	1.075	

$T_o = 20°C$ (293 K)

$h_o = 83.9$ kJ/kgK

$s_o = 0.296$ kJ/kgK

$\Delta h'_{1-2} = 559$

$\Delta h_{1-2} = 559 \times 0.8 = 447.2$

Turbine work output $= 447.2 \times 5 =$ **2236 kW**

Rate of heat transfer in heat exchanger $= \dot{m}_s (h_2 - h_3) =$ **10810 kW**

b) Exergy in steam at inlet to turbine

$$\dot{E}_1 = \dot{m}\left((h_1 - h_o) - T_o(s_1 - s_o)\right)$$

$$= 5\left(3030.1 - 293(6.448)\right)$$

$$\dot{E}_1 = 5704.2 \text{ kW}$$

Exergy at steam at turbine outlet.

$\dot{E}_2 = 5(2583.1 - 293(6.739))$

$\dot{E}_2 = 3043$ kW

Exergy Balance of Turbine

Exergy input − Exergy output = Loss of Exergy $\dot{I}$ (Irreversibility)

$\dot{E}_1 - \dot{E}_2 - W = \dot{I}$

$5704.2 - 3043 - 2236 = 425.2$ kW

$\dot{I}_{TURBINE} = 425.2$ kW

Exergy flows in heat exchanger

$\dot{E}_3 = 5(421.1 - 293(1.234))$

$\dot{E}_3 = 297.7$ kW

Determine mass flow of water through heat exchanger by an energy balance.

$\dot{m}_s(h_2 - h_3) = \dot{m}_w(h_5 - h_4)$

$\dot{m}_w = 2162 \times 5 / 83.8$

$\dot{m}_w = 129$ kg/s

$\dot{E}_4 = 129(167.2 - 293(0.535))$

$\dot{E}_4 = 1347.4$ kW

$\dot{E}_5 = 129(251 - 293(0.779))$

$\dot{E}_5 = 2935.1$ kW

Exergy balance on heat exchanger

$$\dot{E}_2 + \dot{E}_4 - \dot{E}_5 - \dot{E}_3 = \dot{I}_{HE}$$

$$3043 + 1347.4 - 2935.1 - 297.7 = 1157.6 \text{ kW}$$

$$\dot{I}_{HE} = 1157.6 \text{ kW}$$

Loss of exergy in turbine is due to frictional losses (throttling) etc

Loss of exergy in heat exchanger is due primarily to temperature difference between the steam and water.

Reducing the exhaust pressure of the steam turbine would increase its output. The exhaust steam would be at a lower temperature and so the mean temperature difference in the heat exchanger would reduce, reducing the loss in exergy.

As a result of the lower temperature difference, a larger surface area would be needed in the heat exchanger (assuming constant heat transfer coefficient)

The reduced exergy loss in the heat exchanger has resulted in greater exergy output (power) from the turbine.