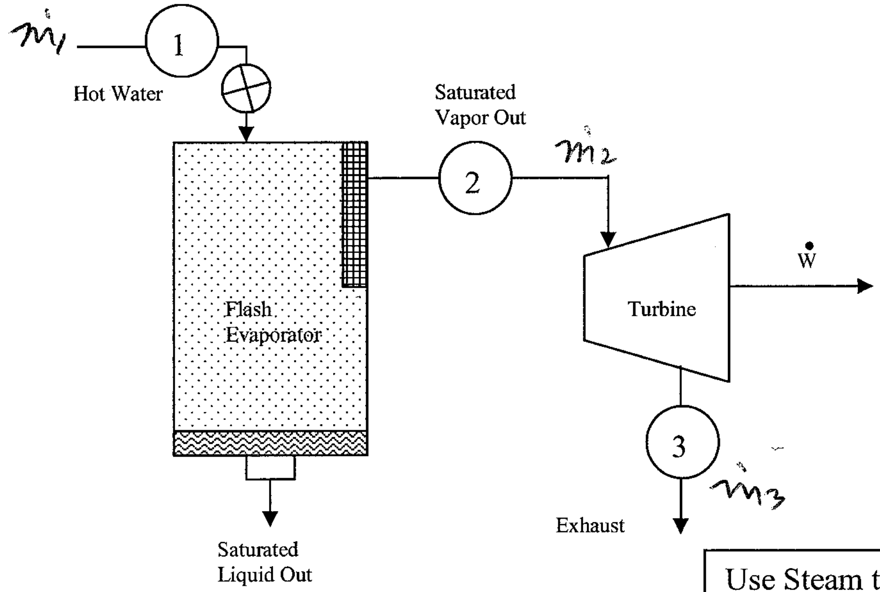
MAE3310-001
Spring 2009
April 28, 2009

Name: ______________________

ID: ______________________

a. Refer book for tables.
b. Duration of test is 75 minutes.
c. Show all steps and equations in your calculations for partial credits.
d. Use data provided in the problems where given.

1. It is proposed to use a geothermal supply of hot water to operate a steam turbine as shown in the figure. The high-pressure water at 1500 kPa, .195 °C is throttled into an insulated flash evaporator forming liquid and vapor at a lower pressure, 400 kPa. The liquid exits at the bottom, while the vapor is drawn off and fed to turbine, as shown. Steam exits from the turbine at 10 kPa, 90% quality. If the turbine produces a power output of 750 kW, how much hot water is required from the geothermal source per hour?



Use Steam table for Steam properties

Flash Evaporator $\dot{m}_e$

$\dot{m}_1 = \dot{m}_2 + \dot{m}_e$

$\dot{m}_1 h_1 = \dot{m}_2 h_2 + \dot{m}_e h_e$

$\dot{m}_1 h_1 = \dot{m}_2 h_2 + (\dot{m}_1 - \dot{m}_2) h_e$

Turbine $\dot{m}_2 = \dot{m}_3$

$\dot{Q} + (-)\dot{W} + \dot{m}_2 (h_2 - h_3) = 0$

$\dot{W} = \dot{m}_2 (h_2 - h_3)$

P = 400 kPa @ Flash Evaporator

$h_1 = u_f + v_f (1100) \Big|_{195°C}$

$= 828.18 + (0.00149)(1100)$

$= 829.4$ KJ/kg

$h_e = h_f \Big)_{\cancel{400kPa}} 143.61$

$= 604.2$ KJ/kg

$$h_2 = h_g\Big)_{\substack{400\,kPa \\ 143^\circ C}} = 2738.1 \text{ kJ/kg}$$

$$h_3 = h_f + x\,h_{fg}\Big)_{10\,kPa} = 191.81 + (.9)(2392.1) = 2344.7 \text{ kJ/kg}$$

$$750 = \dot{m}_2\,(2738.1 - 2344.7)$$

$$\dot{m}_2 = 1.91 \text{ kg/sec}$$

$$= 6864 \text{ kg/h}$$

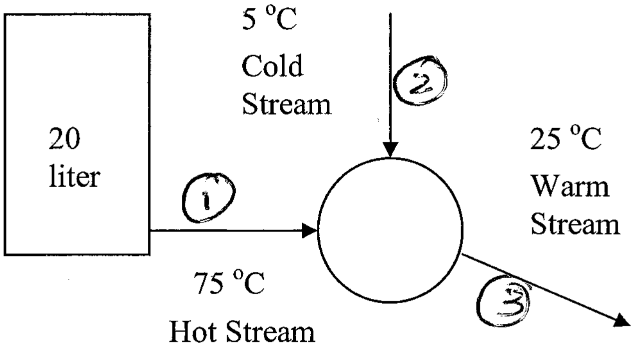
$$\dot{m}_1 = \frac{\dot{m}_2\,(h_2 - h_e)}{(h_1 - h_e)} = (1.91)\frac{(2738.1 - 604.22)}{(829.4 - 604.22)}$$

$$=$$

Hot Water Flow Rate $\boxed{18.1 \text{ kg/sec}}$

65,159 kg/h

2. The household water heater shown in the diagram below is designed with a control to maintain the temperature at 75 °C. On a cold day, the water supply to the heater was blocked due to extreme weather. The resident is used to having shower at 25 °C. On this particular day, water coming in from the cold line at 5 °C is flowing at the rate of 5 liter/min. How long can the resident take a shower if the capacity of the water heater is 20 liter?



$$\dot{m}_1 + \dot{m}_2 = \dot{m}_3$$

$$\dot{m}_1\,(75) + \dot{m}_2\,(5) = \dot{m}_3\,(25)$$

$$\dot{m}_3 = \dot{m}_1 + 5$$

$$\dot{m}_1\,(75) + 25 = \dot{m}_1\,(25) + 125$$

$$\dot{m}_1\,(50) = 100$$

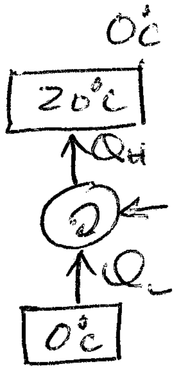
$$\dot{m}_1 = 2 \text{ l/min}$$

Shower time $\boxed{10 \text{ mins.}}$

$$\Delta t = 20/2 = 10 \text{ min}$$

3. A heat pump is to be used to heat a house in the winter and then reversed to cool the house in the summer. The interior temperature is to be maintained at 20 °C in the winter and 25 °C in the summer. Heat transfer through the walls and roof is estimated to be 2400 kJ per hour per degree temperature difference between the inside and outside. (Note: Check unit consistency).

   a. If the outside temperature in the winter is 0 °C, what is the minimum power required to drive the heat pump?



$$\dot{Q}_H = (2400)(20) = 48{,}000 \ \text{kJ/h}$$

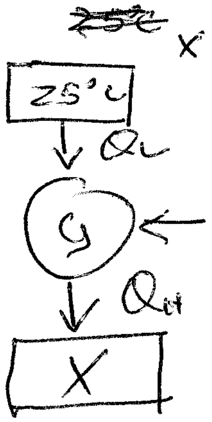
$$COP = \frac{T_H}{20} = \frac{293}{20} = 14.65$$

$$\dot{W} = \frac{\dot{Q}_H}{COP} = \frac{48{,}000}{14.65} = 3276 \ \frac{\text{kJ}}{\text{h}}$$

$$=$$

Minimum power $\boxed{0.91 \ \text{kW}}$

   b. If the power input is the same as that in part (a), what is the maximum outside summer temperature for which the inside of the house can be maintained at 25 °C?



$$2400(X-25) = \dot{Q}_L$$

$$COP_R = \frac{298}{(X-25)} = \frac{\dot{Q}_L}{0.91} = \frac{2400(X-25)}{3600 \times 0.91}$$

$$\Rightarrow (298)(0.91) = \frac{2400}{3600}(X-25)^2$$

$$(X-25) = \left(\sqrt{\frac{(298)(0.91)}{2400}}\right) 60$$

$$(X-25) = (0.33)(60)$$

$$X = 45.2\ °C$$

Maximum outside temperature $\boxed{45.2\ °C}$

4. The field of geothermal power, utilizing underground water source of hot water or steam as the energy source for a power plant is shown in problem 1.

   a. For the conditions stated in this problem, what is the maximum possible efficiency of a cyclic heat engine treating the flash evaporator as the source of energy?

$$\eta_{Carnot} = \frac{T_H - T_L}{T_H} = \frac{(143.6 - 45.81)}{(143.6+273)} = \underline{0.21}$$

Flash Evaporator treated as source

Maximum efficiency $\boxed{21\ \%}$

   b. What is the actual efficiency of this system?

$$\frac{\dot{W}}{\dot{Q}_H} = \eta_{actual} = \frac{\dot{W}}{\dot{m}_2 h_2} = \frac{750}{(1.91)(2738.1)} = \underline{0.143}$$

$\downarrow$

Flash Evaporator Source

Actual efficiency $\boxed{14.3\ \%}$