MECH 414 Quiz 1 November 9, 2009 **NAME**______________________________

75 minutes **ID**________________________________

Potentially useful equation for incompressible substances with constant specific heats: $\Delta s = c \ln(T_2/T_1)$

Short Answer (15 minutes). One or two sentences are fine; please do not write an essay for each question, as you will not have time to solve the problems if you do.

1) Why does the condenser in a Rankine cycle steam power plant normally increase the power output compared to a case where the turbine exhausts directly into the ambient air?
2) Why does the refrigerant cool when it passes through the expansion valve in the vapor compression cycle?
3) Can the exergy of a system be negative? Why or why not?

Problem 1 (15 minutes)

Saturated steam at a temperature of 50˚C enters the condenser of a power plant and exits as a saturated liquid. Cooling water from a nearby lake enters the tubes of the condenser at 18˚C at a rate of 140 kg/s and leaves at 27˚C. Assuming the condenser to be perfectly insulated, and operating at steady state, determine a) the flow rate of the steam, and b) the rate of exergy destruction in the condenser. Ambient temperature is the same as that of the lake water. Liquid water can be taken to have a constant specific heat *c* of 4.2 kJ/kg-K.

Problem 2 (30 minutes)

A heat pump operating on a vapor compression cycle using refrigerant-134a heats a building in Faraya in the night. At the desired steady state interior temperature, the building continuously losses heat to the outside air at a rate of 60,000 kJ/hour. The refrigerant enters the compressor at 280 kPa and 0˚C, and it leaves at 1 MPa and 60˚C. The refrigerant exits the condenser at 30˚C.

a) On the diagram on this exam sheet below, draw the expansion valve in the correct location, label the condenser and evaporator, and draw an arrow indicating the direction of the flow of refrigerant.
b) Determine the electric power input to the compressor.
c) Determine the rate of heat absorption by the heat pump from the cold outside air.
d) Determine the *increase* in electric power input if an electric resistance heater (COP=1) is used instead of the heat pump to achieve the same effect.

Short Answer (15 minutes). One or two sentences are fine; please do not write an essay for each question, as you will not have time to solve the problems if you do.

1) Why does the condenser in a Rankine cycle steam power plant normally increase the power output compared to a case where the turbine exhausts directly into the ambient air?

The condenser reduces the pressure at the exhaust of the turbine to below atmospheric pressure, resulting in a greater vdP for the turbine.

2) Why does the refrigerant cool when it passes through the expansion valve in the vapor compression cycle?

Saturated liquid enters the valve, where due to friction (viscosity) the pressure drops. When pressure of a saturated liquid suddenly drops, it responds by evaporating. Evaporation requires heat of vaporization. Since the valve is adiabatic, the only place for the fluid to obtain h_{fg} is from itself. So its temperature drops. Another way of thinking about it is that the valve forces the fluid to exchange sensible energy for latent energy.

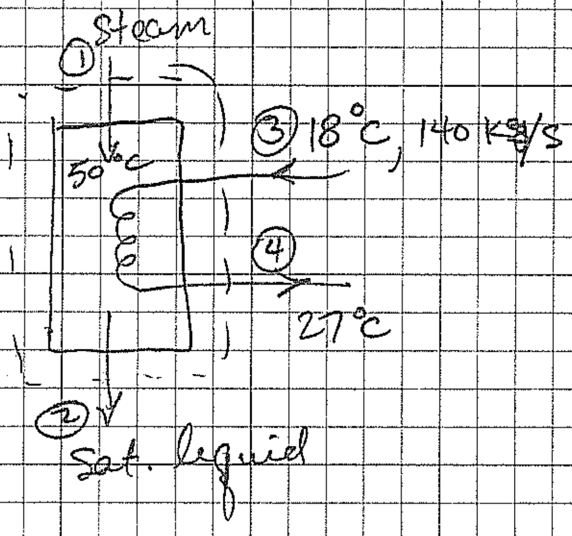
3) Can the exergy of a system be negative? Why or why not?

No. If a system were at any state other than the dead state, it could spontaneously change its condition toward the dead state with no external work needed. E.g. a cold or hot block of steel can both get to the dead state spontaneously with no work required. So any change in state of the system can be achieved with at least zero work being developed, and thus the maximum work (i.e. the exergy) cannot be negative. (To paraphrase Moran and Shapiro).

3

Problem 1

(+5 physical setup is OK)



a) CV: entire system

$$\frac{dE}{dt} = \sum_{in} \dot{m}h - \sum_{out} \dot{m}h + \dot{Q} - \dot{W}$$

(+3 energy balance) $\dot{m}_s(h_1 - h_2) = \dot{m}_{cw}(h_4 - h_3) = \dot{m}_{cw}\, c\,(T_4 - T_3)$

$\therefore \dot{m}_s = \dot{m}_{cw}\, c \frac{(T_4 - T_3)}{(h_1 - h_2)}$ $\quad h_1 = h_g(50°C)$, $h_2 = h_f(50°C)$ } +2 proper

b) $\dot{E}_d = T_0 \dot{S}_{gen}$

same CV: $\frac{dS}{dt} = \sum \frac{\dot{Q}}{T} + \sum_{in} \dot{m}s - \sum_{out} \dot{m}s + \dot{S}_{gen}$

$\dot{m}_s(s_2 - s_1) + \dot{m}_{cw}(s_4 - s_3) = \dot{S}_{gen}$ } +3 entropy bala

$s_2 - s_1 = s_{fg}(50°C)$

$s_4 - s_3 = c \ln\left(\frac{T_4}{T_3}\right)$ } +2 properties

$\dot{E}_d = T_0 \dot{S}_{gen}$

FACULTY OF ENGINEERING & ARCHITECURE - AMERICAN UNIVERSITY OF BEIRUT

Date : Name : Course :

ON MY HONOR, I WILL NOT GIVE OR RECEIVE ANY ASSISTANCE ON THIS QUIZ OR EXAM.

Signature: ____________________

Problem 8

a) see exam

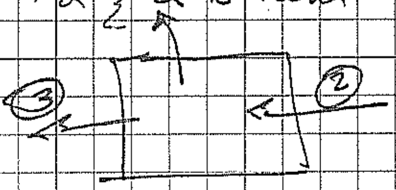
b) CV is turbine, $\dot{Q}=0$, s.s.:

+2 $\left\{ \dot{W} = \dot{m}(h_2 - h_1) \right.$ $= 3.62$ kW

+2 $\left\{ \begin{array}{l} h_2 = h(1\text{ MPa}, 60°C) = 291.36 \text{ kJ/kg} \\ h_1 = h(280\text{ kPa}, 0°C) = 247.64 \end{array} \right.$

need $\dot{m}$: CV is now the condenser

+2 $\left\{ \dot{Q} \text{ to room} = \dot{Q}_{\text{needed to keep house @ steady desired temp}} \right.$



$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \dot{m}_{ref}(h_2 - h_3)$$

+3 $\left\{ \dot{m}_{ref} = \dfrac{-\dot{Q}}{(h_2 - h_3)} = \dfrac{(-60{,}000/3600)}{(h_2 - h_3)} \right.$ $= 0.083$ kg/s

$h_2 = h(1\text{ MPa}, 60°C)$

+1 $\left\{ h_3 = h(1\text{ MPa}, 30°C) \right.$ $\cong h_f(30°C) = 91.49$ kJ/kg

c) CV: entire system

+5 $\left\{ \dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} = 0 \right.$

+5 d) it would be greater by $\dot{Q}_{in}$!

Note that the numerical answer for parts c) and d) are the same. I was hoping that you would notice this on the exam. It is precisely the fact that the vapor compression cycle, in addition to delivering the work of the compressor as heat to the room, also delivers heat it absorbed from outside to the room. It moves heat from the cold outside to the warm inside. The simple resistance heater has no mechanism to do this; it must provide all the required heat by converting an equivalent amount of electrical work. I.e. all the heat absorbed from outside "for free" in the vapor compression cycle must be "paid" for in the resistance heating system.