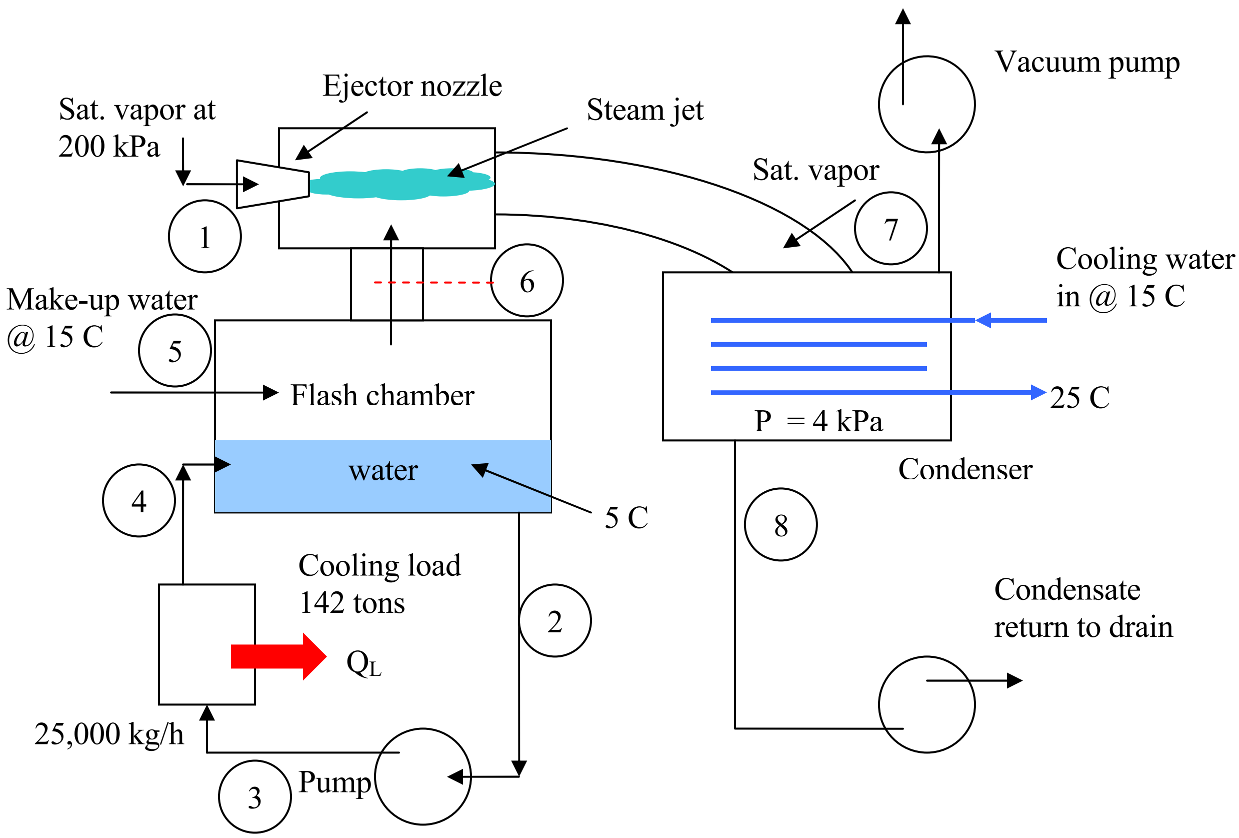
MECH 461

Assignment #3 (Refrigeration)

Assignment date: Tuesday Jan 29, 2011

Problem 1:

Figure below shows a steam jet refrigeration system that produces chilled water in a flash chamber. The chamber is maintained at a vacuum pressure by the steam ejector, which removes the vapor generated by entraining it in the low-pressure jet and discharging into the condenser. The vacuum pump removes air and other non-condensable gases from the condenser shell. For the conditions shown on the figure, determine the make-up water and cooling water flow rates in kg/h.



Note: 1 ton (of refrigeration) = 211 kJ/min.

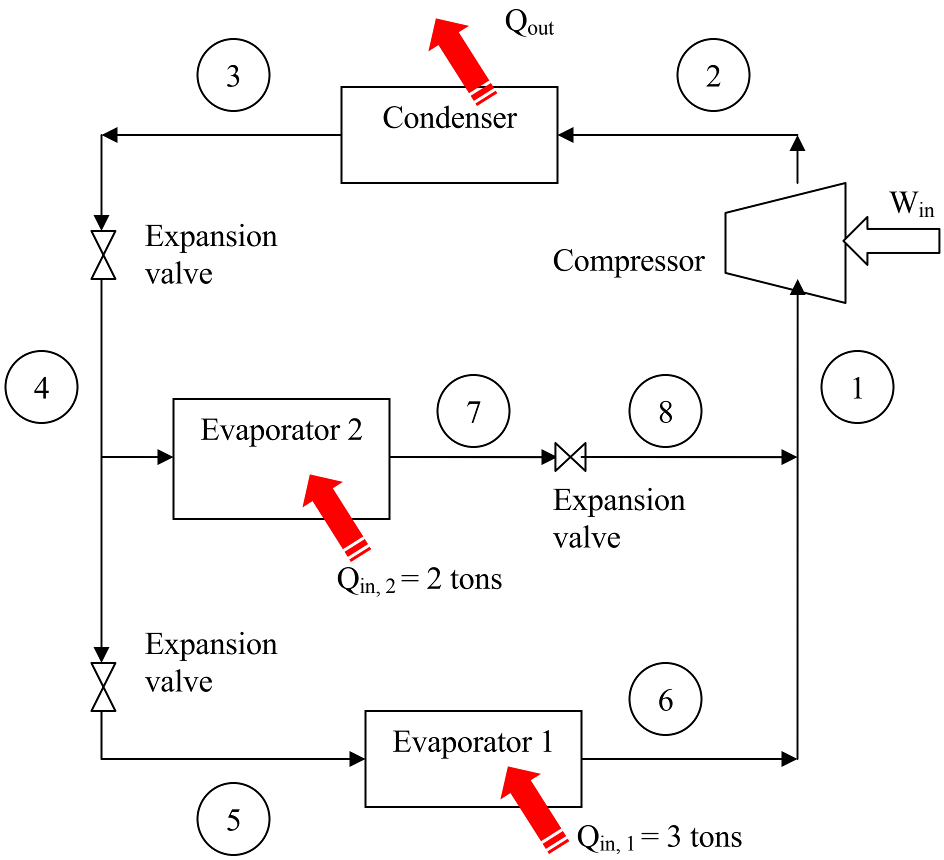
Problem 2:

The schematic diagram of a two evaporator refrigeration cycle is shown in the figure below where refrigerant R-134a is used. The arrangement is used to achieve refrigeration at two different temperatures with a single compressor and a single condenser. The low-temperature evaporator operates at -18C with saturated vapor at its exit and has a refrigerating capacity of 3 tons. The higher-temperature evaporator produces saturated vapor at 3.2 bar at its exit and has a refrigerating capacity of 2 tons. Compression is isentropic to the condenser pressure of 10 bar. There are no significant pressure drops in the flows through the condenser and the two evaporators, and the refrigerant leaves the condenser as saturated liquid at 10 bar. Calculate:

1) the mass flow rate of refrigerant through each evaporator, in kg/min

2) the compressor power input, in kW

3) the rate of heat transfer from the refrigerant passing through the condenser, in kW.



Problem 1 Solution:

Assumptions:

1) each component is analyzed as a control volume at steady-state

2) the pump work is negligible

3) kinetic and potential energies effects are negligible

4) no heat transfer with the surroundings.

Analysis:

First we fix each state of the system.

State 1: sat. vapor, 200 kPa → $h_1 = 2706.7$ kJ/kg

State 2: sat. liquid, 5°C → $h_2 = 20.98$ kJ/kg

State 3: $h_3 = h_2 + \underbrace{\dot{w}_{pump} / \dot{m}_2}_{\approx 0} \approx h_2$

State 4: $\dot{Q}_{load} = 142\ ton = 1.798 \times 10^6\ kJ/h$

$$h_4 = h_3 + \frac{\dot{Q}_{load}}{\dot{m}} = 20.98 + \left(\frac{1.798 \times 10^6}{25{,}000}\right) = 92.9 kJ/kg$$

State 5: $T_5 = 15$°C; $h_5 \approx h_f(T_5) = 62.99$ kJ/kg

State 6: sat. vapor, 5°C → $h_6 = 2510.6$ kJ/kg

State 7: sat. vapor, 4 kPa → $h_7 = 2554.4$ kJ/kg

State 8: sat. liquid, 4 kPa → $h_8 = 121.46$ kJ/kg

Now, consider a control volume enclosing the flash chamber:

$$\dot{m}_4 h_4 + \dot{m}_5 h_5 = \dot{m}_2 h_2 + \dot{m}_6 h_6$$

$$\dot{m}_4 = \dot{m}_2 \qquad \dot{m}_5 = \dot{m}_6$$

thus

$$\dot{m}_5 (h_5 - h_6) = \dot{m}_2 (h_2 - h_4)$$

$$\dot{m}_5 = 734.6\ kg/h$$

Next, consider a control volume enclosing the steam jet ejector.

$$\dot{m}_1 h_1 + \dot{m}_6 h_6 = \dot{m}_7 h_7$$

$$\dot{m}_7 = \dot{m}_1 + \dot{m}_6 \qquad \text{or,}$$

$$\left(1-\frac{\dot{m}_6}{\dot{m}_7}\right)h_1+\frac{\dot{m}_6}{\dot{m}_7}h_6=h_7 \rightarrow \frac{\dot{m}_6}{\dot{m}_7}=0.7766$$

$$\dot{m}_7=945.9\ kg/h$$

Finally, for the condenser

$$\dot{m}_7\left(h_7-h_8\right)=\dot{m}_{cw}\left(h_{cw,out}-h_{cw,in}\right)$$

$h_{cw,in} = h_f(15°C) = 62.99$ kJ/kg and $h_{cw,out} = 104.89$ kJ/kg

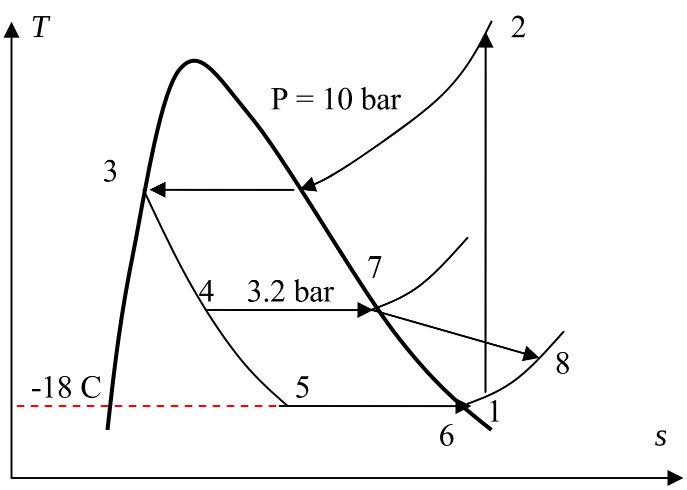
Thus,

$$\dot{m}_{cw}=54{,}920\ kg/h$$

Problem 2 Solution:

Assumptions:

1) each component is analyzed as a control volume at steady-state
2) all processes are internally reversible, except for throttling through expansion valves
3) the compressor and exp. valves are adiabatic
4) potential and kinetic energies effects are negligible.



Analysis:

Fix each of the principal states:

State 3: P_3 =10 bar, sat. liquid → h_3 = 105.29 kJ/kg

State 4: Throttling process → $h_4 = h_3$ = 105.29 kJ/kg

State 5: Throttling process → $h_5 = h_4$ = 105.29 kJ/kg

State 6: T_6 = -18 °C, sat. vapor → h_6 = 236.53 kJ/kg

State 7: P_7 = 3.2 bar, sat. vapor → h_7 = 248.66 kJ/kg

State 8: Throttling process → $h_8 = h_7$ = 248.66 kJ/kg

Fixing state 1 and 2 requires the mass flow rates through the evaporators. Thus:

$$\dot{Q}_{in,1} = \dot{m}_6 (h_6 - h_5)$$

$$\dot{m}_6 = \frac{\dot{Q}_{in,1}}{(h_6 - h_5)} = \frac{3tons}{(236.53 - 105.29)kJ/kg} \frac{211kJ/\min}{1ton} = 4.823kg/\min$$

and

$$\dot{m}_8 = \frac{\dot{Q}_{in,2}}{(h_7 - h_4)} = \frac{2tons}{(248.66 - 105.29)kJ/kg} \frac{211kJ/\min}{1ton} = 2.943kg/\min$$

State 1: Now, for adiabatic mixing streams 6 and 8 to form stream 1:

$$\dot{m}_6 h_6 + \dot{m}_8 h_8 - \left(\dot{m}_6 + \dot{m}_8 \right) h_1 = 0$$

$$h_1 = \frac{\dot{m}_6 h_6 + \dot{m}_8 h_8}{\dot{m}_6 + \dot{m}_8} = 241.13kJ/kg$$

Having the enthalpy and pressure of state 1, the specific entropy is found s_1 = 0.9493 kJ/kg.K.

State 2: P_2 = 10 bar, $s_2 = s_1$ → h_2 = 282.3 kJ/kg

b) the compressor power is:

$$\dot{w}_c = \left(\dot{m}_6 + \dot{m}_8 \right)(h_2 - h_1) = 5.329\,kW$$

For the condenser

$$\dot{Q}_{out} = \left(\dot{m}_6 + \dot{m}_8 \right)(h_2 - h_3) = 22.91\,kW$$