BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE, Pilani

APPLIED THERMODYNAMICS
TUTORIAL 12 (26/10/2016)

Dated 26.10.2016 **Time: 50 Mins**

Q. 1 A single stage vapour absorption refrigeration system based on H_2O-LiBr has a refrigeration capacity of 300 kW. The system operates at an evaporator temperature of $5^{o}C$ (P_{sat}=8.72 mbar) and a condensing temperature of $50^{o}C$ (P_{sat}=123.3 mbar). The exit temperatures of absorber and generator are $40^{o}C$ and $110^{o}C$ respectively. The concentration of solution at the exit of absorber and generator are 0.578 and 0.66, respectively. Assume 100 percent effectiveness for the solution heat exchanger, exit condition of refrigerant at evaporator and condenser to be saturated and the condition of the solution at the exit of absorber and generator to be at equilibrium. Enthalpy of strong solution at the inlet to the absorber may be obtained from the equilibrium solution data.

Find:

a) The mass flow rates of refrigerant, weak and strong solutions

b) Heat transfer rates at the absorber, evaporator, condenser, generator and solution heat exchanger

c) System COP and second law efficiency, and

d) Solution pump work (density of solution = 1200 kg/m^3).

Q. 2 A refrigerant R12 vapor compression system includes a liquid to vapor heat exchanger in the system. The heat exchanger cools, saturated liquid coming out from the condenser from **32°C** to **22°C** with the help of vapor coming out from evaporator at **-12°C** saturated. The compression is isentropic. Assume constant specific heats. C_{pf}=0.97 **kJ/kg K** and C_{pg}= 0.62 **kJ/kg K**. Draw the line diagram of the components and find the following:

(i) C.O.P of the system

(ii) If the compressor displacement is 1.2 m^3/min, what is the refrigeration capacity of the system

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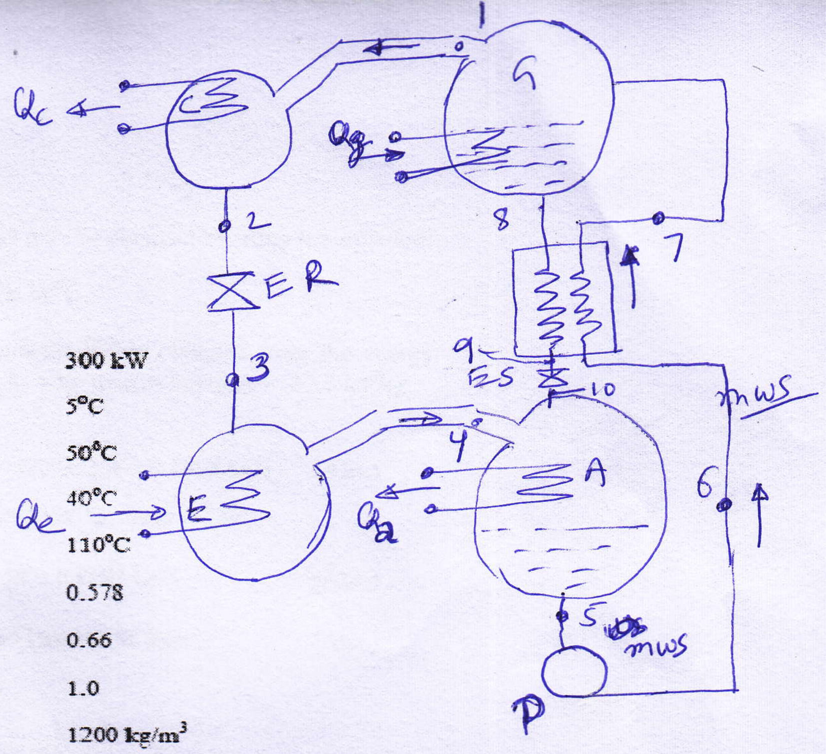
Q. 1



Solution:

Refrigeration capacity	:	300 kW
Evaporator temperature	:	5°C
Condenser temperature	:	50°C
Absorber temperature	:	40°C
Generator temperature	:	110°C
Weak solution concentration, ξ_{WS}	:	0.578
Strong solution concentration, ξ_{SS}	:	0.66
Effectiveness of solution HX, ε_{HX}	:	1.0
Density of solution, ρ_{sol}	:	1200 kg/m³
Refrigerant exit at evaporator & condenser	:	Saturated
Solution at the exit of absorber & generator	:	Equilibrium

Referring to Fig.15.5;

Assuming the refrigerant vapour at the exit of generator to be in equilibrium with the strong solution leaving the generator

$\Rightarrow$ Temperature of vapour at generator exit = 110°C

$\Rightarrow$ enthalpy of vapour = 2501+1.88 X 110 = 2708 kJ/kg

From the definition of effectiveness of solution HX:

$$\varepsilon_{HX} = [m_{SS}C_{p,SS}(T_8-T_9)]/[m_{SS}C_{p,SS}(T_8-T_6)] = 1.0 \quad (\because m_{SS} < m_{WS})$$

$$\Rightarrow T_9 = T_6 = 40°C$$

$\frac{T_7 - T_6}{T_8 - T_6} = 1$

$T_7 - T_6 = T_8 - T_6$

$T_8 - T_9 = T_8 - T_6$

From the above equation, the following property data at various points are obtained using refrigerant property charts and water – LiBr solution property charts

State point	Temperature (°C)	Pressure (mbar)	Mass fraction, ξ	Enthalpy (kJ/kg)
1	110	123.3	-	2708
2	50	123.3	-	209
3	5	8.72	-	209
4	5	8.72	-	2510
5	40	8.72	0.578	-154
6	40	123.3	0.578	-154
7	-	123.3	0.578	-37.5
8	110	123.3	0.66	-13
9	40	123.3	0.66	-146
10	40	8.72	0.66	-146

The enthalpy of superheated water vapour (h_v) may be obtained by using the equation:

$h_v = 2501 + 1.88\,t$, where h_v is in kJ/kg and t is in °C.

Enthalpy of weak solution at the exit of solution HX is obtained from the energy balance equation: $m_{WS}(h_7-h_6) = m_{SS}(h_8-h_9) \Rightarrow h_7 = h_6+m_{SS}(h_8-h_9)/m_{WS}$ = **-37.5 kJ/kg**

a) Required mass flow rate of refrigerant, $m = Q_e/(h_4-h_3)$ = **0.1304 kg/s** **(Ans.)**

$\lambda = \frac{m_{SS}}{m}$

Circulation ratio, $\lambda = m_{SS}/m = \xi_{WS}/(\xi_{SS}-\xi_{WS}) = 7.05$

$\therefore$ mass flow rate of strong solution, $m_{SS} = \lambda m$ = **0.9193 kg/s** **(Ans.)**

$m_{SS} = \lambda m$

mass flow rate of weak solution, $m_{WS} = (\lambda+1)m$ = **1.05 kg/s** **(Ans.)**

$m_{WS} = (\lambda+1)m$

b) Heat transfer rates at various components:

<u>Evaporator:</u> **Qe = 300 kW (input data)**

<u>Absorber:</u> From energy balance:

$Q_a = mh_4+m_{SS}h_{10}-m_{WS}h_5$ = 354.74 kW (Ans.)

<u>Generator:</u> From energy balance:

$Q_g = mh_1+m_{SS}h_8-m_{WS}h_7$ = 380.54 kW (Ans.)

<u>Condenser:</u> From energy balance:

$Q_c = m(h_1-h_2)$ = 325.9 kW (Ans.)

<u>Solution heat exchanger:</u> From energy balance:

$Q_{SHX} = m\lambda(h_8-h_9) = m(\lambda+1)(h_7-h_6)$ = 122.3 kW (Ans.)

c) System COP (neglecting pump work) = Q_e/Q_g = 0.7884 (Ans.)

Second law efficiency = COP/COP_{Carnot}

$COP_{Carnot} = [T_e/(T_c-T_e)][(T_g-T_a)/T_g] = 1.129$

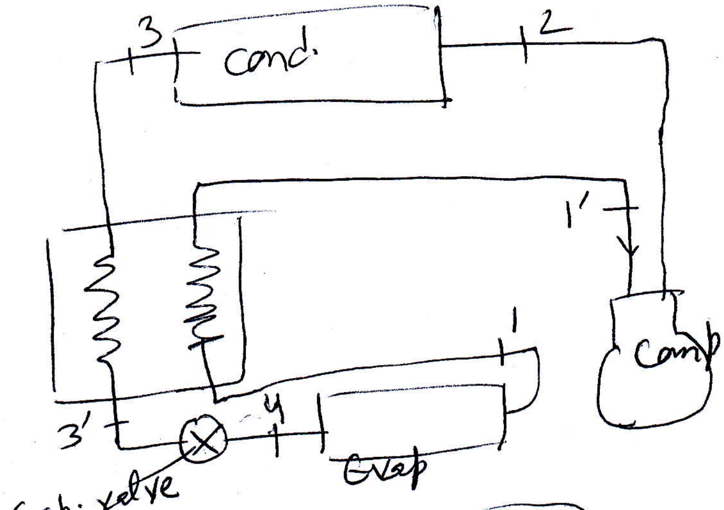
$\therefore$ Second law efficiency = 0.6983 (Ans.)

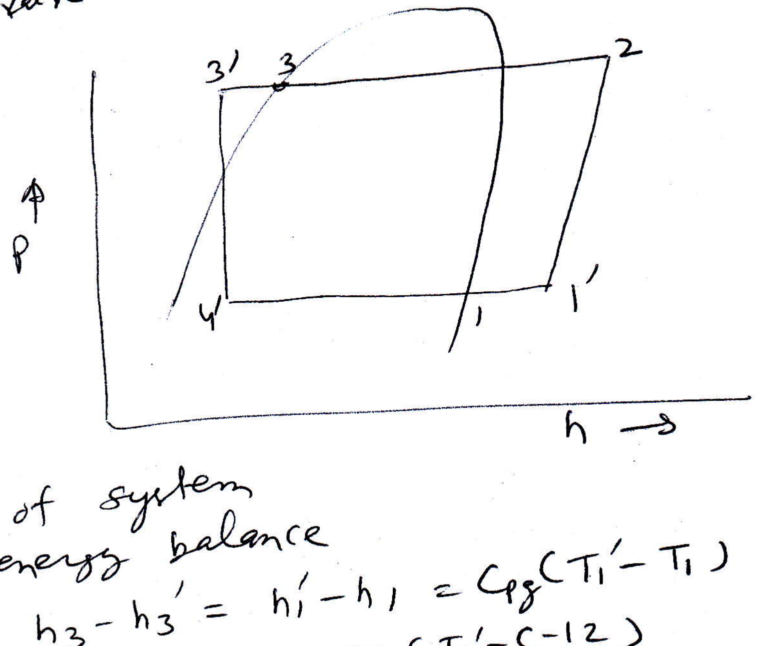
d) Solution pump work (assuming the solution to be incompressible)

$W_P = v_{sol}(P_6-P_5) = (P_6-P_5)/\rho_{sol} = (123.3-8.72)*10^{-1}/1200 = 0.0095$ kW (Ans.)

Q.2 Use Interpolation to find values (For precise ~~An~~ answer Do your own calculations)

T_s (°C)	P_s (bar)	v_g m^3/kg	h_f kJ/kg	h_{fg} kJ/kg	h_g kJ/kg	s_f kJ/kgK	s_g kJ/kgK
−12	2.04605	0.0821	25.05	157.26	182.31	0.1010	0.7032
32	7.85089	0.0225	66.57	133.79	200.36	0.2403	0.6847





(1) COP of system

By energy balance

$$h_3 - h_3' = h_1' - h_1 = C_{pg}(T_1' - T_1)$$

$$66.57 - 56.87 = 0.62(T_1' - (-12))$$

$$T_1' = 276.5\ K$$

$$h_1' = h_1 + (h_3 - h_3') = 191.61\ kJ/kg$$

Now (1'−2) (Isentropic compression)

$$s_1' = s_2 \quad (\text{we get } T_2 = 332.9\ K = 59.9°C$$

& $$h_2 = h_{g2} + C_{pg}(T_2 - T_{s2})$$

$$= 200.32 + 0.62(59.9 - 32) = 217.62\ kJ/kg$$

$$W.D = h_2 - h_1' = 217.62 - 191.61 = 26.01\ kJ/kg$$

$$R.E = h_1 - h_4' = 182.31 - 56.87 = 125.4\ kJ/kg$$

$$C.O.P = R.E/WD = \frac{125.44}{26.01} = 4.823$$

(ii) Refrigeration capacity

$$\frac{v_1'}{T_1'} = \frac{v_1}{T_1}$$

$$\therefore \quad v_1' = \frac{T_1'}{T_1} \times v_{g_1} = \frac{276.5}{261} \times 0.0821$$

$$= 0.08976 \ m^3/kg$$

Mass flow of refrigerant

$$\dot{m} = \frac{\dot{V}}{v_1'} = \frac{1.2}{0.08976} = 13.797 \ kg/min$$

$$\text{Capacity of plant in T.R} = \frac{\dot{m} \times R.E}{3.517}$$

$$= \frac{13.797}{60} \times \frac{125.44}{3.517} = 8.2 \ TR$$