Thermal analysis of water-ammonia diffusion absorption refrigeration system

A complete thermal analysis of aqua ammonia.

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***Abstract*: - This paper provides a literature review on absorption refrigeration technology. A number
of research options such as various types of absorption refrigeration systems, research on
working fluids, and improvement of absorption processes**

Introduction:

The diffusion absorption technique was invented by Swedish engineer Von Platen and Munters in 1920[1.] The ammonia concentration in rich and weak solution could be obtained by increasing the COP values. They even found that the liquid ammonia leaves the condenser results a very low rectification process. To circulate a thermally driven bubble pump with the liquid solution would be generated through the waste heat or solar thermal energy. The DAR manufactured the most used working fluid as ammonia water where ammonia as refrigerant and water as absorbent [2]. This process includes an absorber, and a generator

Theory: -

The Diffusion absorption refrigeration system consist of seven main parts; the Generator, Bubble pump, Rectifier, Condenser, Evaporator, Absorber, RHX. Strong solution from the solar collector is heated in the solution and enters the generator. When the liquid enters the generator, bubbles of ammonia are produced from ammonia-water mixture.

combining the boiler and the bubble pump. DAR is another type of self-circulate absorption system using water/NH_3. Differential pressure between the condenser and evaporator is too large because of NH_3 as it is the most used and working fluid which would be overcome by bubble pump [5]. The most common working fluid are ammonia/water with helium or hydrogen as an auxiliary gas [4]. These are commercially used. By the boiler, the additional heat flux heated the pumped solution further. So, an additional quantity and vapor is generated [3]. An auxiliary gas is charged to the evaporator and the absorber [5]. In this the bubble pump could be used so that there is no pressure differential in this system. The density of ammonia is considerably greater than that of hydrogen[6]. The cooling capacity increases in the presence of auxiliary gas [7]. These gasses reduce the refrigeration mass flow rate in the evaporator. It cools rapidly. The rectifier that dissipates towards the ambient are non-negligible amount of supplied heat
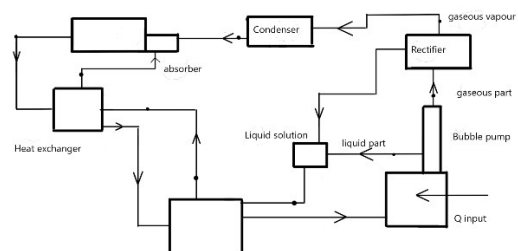

Fig-1: - Proposed figure of diffusion refrigeration absorption system

When the strong solution enters the system so the state changes from

$$\dot{m}_1 = \dot{m}_{strong\,solution}$$

When the mixture is supposed to a saturated state then,

$x_{mix1} = 0$

Therefore, the mass fraction of ammonia is

$f = ammonia_{mf}$

The temperature for ammonia

$$T_1 = T_{f_1}$$

Pressure of the system would be
$$P_1 = p_{system^{-\rho_1}} * g * z_1$$

Where g = 9.81 m/s²
z is the height
Enthalpy of superheated ammonia at point 1
$$h_1 = h_{f1}$$
And h_f is enthalpy of liquid ammonia

In heater/generator '0' is the state of atmospheric energy level or dead state, and '1' is the mix fluid entering.
z is the height of the component placed
rho is the density and 'v' is specific volume

$$\rho_1 = \frac{1}{v_{f_1}}$$

Heat is supplied by solar collector (solar energy is kept as heat input) due to which a two-phase type of solution occurs in generator. A solar collector and some sort of thermal storage device capture and store solar energy where there is a possibility of achieving 300°C or even 400°C. A thermal storage required during night time may be some sort of phase change material. It is a type of material where latent heat is utilized for thermal energy.
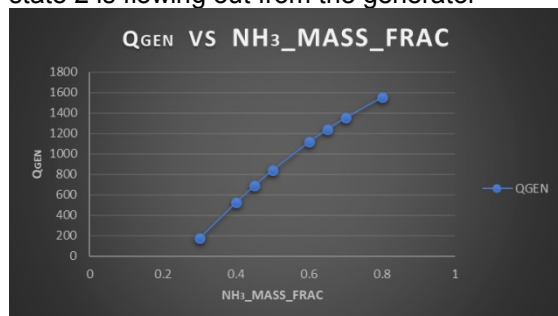state 2 is flowing out from the generator

Fig-2: - Q_{gen} vs NH_3 Mass fraction graph

The mass flow rate remains same at state 1 and state 2 as there is no mass split for the mixture going from state 1 to state 2
$$\dot{m}_2 = \dot{m}_1$$
In the mixture of working fluid at the state, following is the fraction of ammonia
$$f_2 = f_1$$

$$T_2 = T_{gen}$$
$$P_2 = P_{system} - \rho_1 * g * (z_2 - z_1)$$
The following value can be from the inbuilt function of ees when we input the values which is enthalpy
$$h_2 = h_{f_2}$$
$$z_2 = 2.7$$
The following value can be from the inbuilt function of the ees when we input the values which is density

$$\rho_2 = \frac{1}{v_{f_2}}$$

As gest is added to the generator/heater the following energy conservation equation can be applied
$$Q_{g_{en}} + h_{1_i} \dot{m}_1 = h_{2_i} \dot{m}_2$$
The ammonia bubbles are separated in the bubble pump and are sent to the absorber through liquid solutions and the gaseous part is separated at the outlet of the bubble pump.

Now state 3 is the outlet of the bubble pump
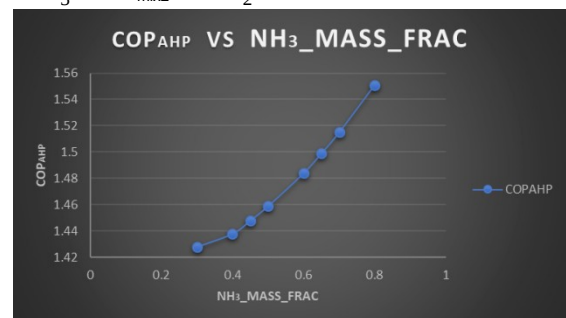$$\dot{m}_3 = x_{mix2} * \dot{m}_2$$

Fig-3: - Mass fraction of the temperature

Since only gaseous phase of the working fluid comes out of the bubble pump hence the following value is applied at state 3 which is exit of bubble pump

$$x_{mix.3} = 1$$
$$f_3 = C_{f_3}$$
In bubble pump let us assume that the temperature remains same
$$T_3 = T_2$$
$$P_3 = P_{system} - \rho_{2_i} g * (z_3 - z_2)$$
$$h_{0 \cdot 3} = h_{f_3}$$
$$z_3 = 5.5$$

$$\rho_3 = \frac{1}{v f_3}$$

Ammonia vapor along with some water vapor from the bubble pump travels through the rectifier, where ammonia

and water vapor mixture is cooled and water vapor mixture is cooled.

Solution returns to heat exchanger after mixing with solution coming from rectifier

$x_{mix4} = x_{f.4}$

$T_4 = T_{f_4}$

$P_4 = P_{system} - \rho_{2^i} g * (z_4 - z_2)$

$z_4 = 2.8$

$\rho_4 = \dfrac{1}{v_{f_4}}$

When the solution coming from rectifier, the mass balance of the solution is

$\dot{m}_2 = \dot{m}_3 + \dot{m}_4$

$f_{bp} = \dfrac{\dot{m}_3}{\dot{m}_1}$

Mass balance of ammonia pert in mixture applied of bubble pump

$f_{2^i} \dot{m}_2 = h_{3^i} \dot{m}_3 + h_4 * \dot{m}_4$

Energy equation applied to bubble pump

$h_{2^i} \dot{m}_2 = h_{3^i} \dot{m}_3 + h_{0.4^i} \dot{m}_4$

Almost pure ammonia refrigerant produced by rectification at state 5 enters into the condenser and condenses to liquid and condensed ammonia flows to the evaporator through a heat exchanger where the liquid ammonia is subcooled.

$x_{mix.5} = x_{f.5}$

$\tau 4 = 0.995$

Let us assume that the temperature of mixture or working fluid at the state 5 is equal to heater\generator temperature

$T_{0.5} = T_{gen}$

$p_5 = p_3 - \rho_{3^i} g * (z_5 - z_3)$

$h_5 = h_{f_5}$

$z_5 = 6$

$\rho_5 = \dfrac{1}{v_{f_5}}$

Since some sort of water particles still remain at state 4 rectifier separates them and as a result state 6 and state 2 mixes in liquid

solution which is used to preheat the solution coming from absorber in the heat exchanger.

$x_{mixture.6} = x_{f.6}$

$\tau 6 = \tau 4$

$T_{0.6} = T_{0.4}$

$p_{0.6} = p_{0.3} - \rho_{3^i} g * (z_6 - z_3) - p_{0.3}$

$h_{0.6} = h_{f_6}$

$z_6 = 5.6$

$\rho_6 = \dfrac{1}{V_{f_6}}$

Law of conservation of mass and energy applied to rectifier, law of conservation of mass applied to rectifier

$\dot{m}_3 = \dot{m}_5 + \dot{m}_6$

$f_{ref} = \dfrac{\dot{m}_5}{\dot{m}_1}$

$(1 - \tau 3) * \dot{m}_3 = (1 - \tau 5) * \dot{m}_5 + (1 - \tau 6) * \dot{m}_6$

Law of conservation of energy applied to rectifier

$Q_{rec} + h_{0.3^i} \dot{m}_3 = h_{0.5^i} \dot{m}_5 + h_{0.6^i} \dot{m}_6$

The condenser exits in state 7.

Refrigerant ammonia vapor after leaving the rectifier condenses in the condenser by removing the heat. Since there is no segregate of mass flow, mass fraction of ammonia on the mixture remains the same before and after the fluid enters and leaves the condenser.

$\dot{m}_7 = \dot{m}_5$

$x_{mixture.7} = x_{f.7}$

$\tau 7 = \tau 5$

Let's assume the temperature of mixture at exit of condenser is equal to condenser temperature

$T_{0.7} = T_{C_0 nd}$

$p_{0.7} = P_{0.5} - \rho_{5^i} g * (z_7 - z_5) - \Delta p_{hx}$

$h_{0.7} = h_{f_7}$

$z_7 = 5.5$

$\rho_7 = \dfrac{1}{v_{f_7}}$

Law of conservation of mass and energy applied to condenser

Energy balance equation applied to condenser

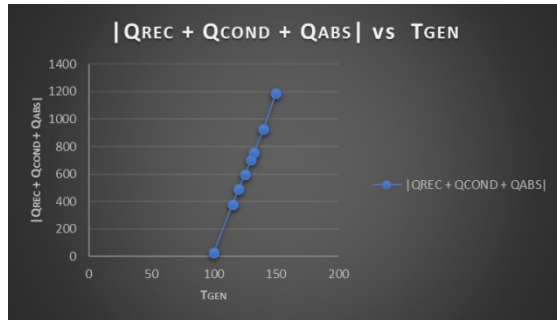$Q_{cond} + h_{0.5^i} \dot{m}_5 = h_{0.7^i} \dot{m}_7$

Fig-4: - COP vs generator temperature and evaporator exit temperature at a strong solution flow

Auxiliary gas hydrogen is not absorbed and continues to flow to the evaporator with ammonia solution using Dalton's law of partial pressure

$$P_{0,aux,8} = P_7 - P_9$$

It is assumed that there is no heat transfer from pipe

$$h_{0,aux,8} = h_{0,aux,14}$$
$$z_8 = 5.4 \quad z_9 = 5.5$$

The gaseous vapour now enters the condenser to get cooled and condensed which mixes with solution coming from absorber. There are mixed partialized components coming through therefore for water ammonia mixture evaporate at a lower temperature and ammonia extract heat from the evaporator providing the region to be cooled.

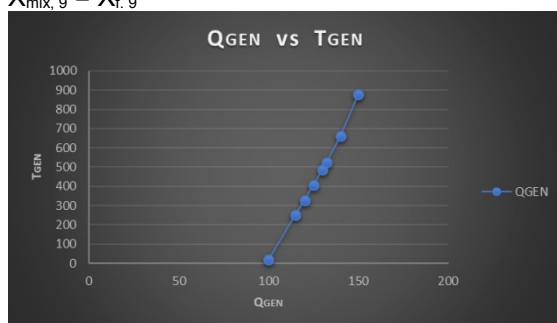$$\dot{m}_9 = \dot{m}_7$$
$X_{mix, 9} = X_{f. 9}$

Fig-5: - Q_{gen} vs T_{gen} graph

Ammonia mass fraction remains same as there is no segregation

$$f_9 = f_7$$
$$T_9 = T_{f_9}$$

$$P_9 = \frac{p_{system}}{p_{p_{artial}}} - \Delta p_{fb}$$
$$z_9 = 5.5$$
$$\rho_9 = \frac{1}{v_{f_7}}$$

Hydrogen gas with traces of ammonia after leaving the absorber enters the evaporator.
After leaving the evaporator the ammonia and hydrogen gas mixture enters the gas heat exchanger and also from mixture of by hydrogen.
Tertiary gas equations:

$$\dot{m}_{aux_9} = \dot{m}_{aux_8}$$
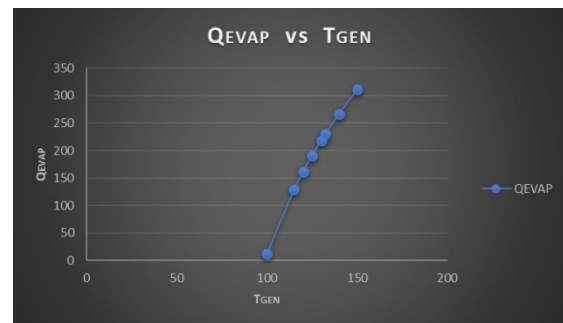$$p_{aux_9} = p_{aux\,8}$$
$$h_{aux_9} = h_{aux_8}$$

Fig-6: - Q_{evap} vs T_{gen} graph

Dalton partial pressure equilibrium gas constant for ammonia water solution which is used as a refrigerant.

$$R_7 = (4.872 - 2.7792) * 1$$

The gas constant for the tertiary gas.

$$R_8 = C_P \left(A_{ux} T = T_{aux_8} \, p = p_{aux_8} \right) - C_v \left(A_{ux} T = T_{aux} \, P = p_{aux_8} \right)$$
$$R_7 * T_7 * p_{aux} = V_{aux * R_8 \cdot Taux\,8^{\circ}} p_7$$

$$V_{aux} \, ratio = \frac{\dfrac{\dot{m}\,au\,x_8}{\rho_{aux8}}}{\dfrac{\dot{m}_9}{\rho_9}}$$

$$\dot{m}_{aux} = \dot{m}_{aux_8}$$

Thermodynamic properties of ammonia water.
After leaving the evaporator the ammonia and hydrogen gas mixture enters the gas heat exchanger and mass flow rate of ammonia liquid leaving the evaporator for refrigerant state 10 is the evaporated refrigerant outlet therefore following equations are for refrigerant leaving the evaporated refrigerant.

$$\dot{m}_{10} = \dot{m}_9$$

$$x_{mi\,x_{10}} = x_{f_{10}}$$
$$f_{10} = f_9$$
$$T_{10} = T_{evap}$$
$$h_{10} = f_{10}$$
$$z_{10} = 6$$
$$\rho_{10} = \frac{1}{v_{F_{10}}}$$

Following are equations for tertiary gas.

$$\dot{m}_{au\,x_{10}} = \dot{m}_{au\,x_9}$$
$$T_{au\,x_{10}} = T_{10}$$
$$h_{au\,x_{10}} = h\left(Aux, T = T_{au\,x_{10,}} P = p_{au\,x_{10}}\right)$$

$$x_{mi\,x_{11}} = x_{f_{11}}$$
$$f_{11} = f_{10}$$
$$T_{11} = T_{f.11}$$
$$h_{11} = f_{11}$$
$$z_{11} = 3$$
$$\rho_{11} = \frac{1}{v_{F_{11}}}$$

$$x_{mi\,x_{12}} = x_{f_{12}} \qquad f_{12} = f_{16}$$
$$T_{12} = T_{f.12}$$
$$h_{12} = h\,16$$
$$z_{12} = 3$$

$$x_{mi\,x_{13}} = x_{f_{13}}$$
$$f_{13} = f_{17}$$
$$T_{13} = T_{f.13}$$
$$z_{13} = 2.2$$
$$\rho_{13} = \frac{1}{v_{F_{13}}}$$

State 14 is the auxiliary gas returning outlet

$$\dot{m}_{au\,x_{14}} = \dot{m}_{au\,x_{11}}$$
$$Tau\,x_{14} = T\,13$$

$$z_{14} = 3$$

Conservation laws

$$\dot{m}_{11} + \dot{m}_{12} = \dot{m}_{13}$$
$$|¿| = Q_{|.|sol} + Q_{|.|aux}$$
$$Q_¿$$
$$Q_{|.|sol} + h\,11 * \dot{m}_{11} + h_{12} * \dot{m}_{12} = h_{13¿}\,\dot{m}_{13}$$
$$Q_{|.|aux}\,h_{11} + \dot{m}_{11} + h_{12*\dot{m}_{12}} = h_{13} * \dot{m}_{12}$$

$$x_{mi\,x_{16}} = x_{f_{16}}$$
$$f_{16} = f_{16}$$
$$T_{16} = T_{f.16}$$

Conservation laws

$$Q_{evap} = Q_{evap.ref} + Q_{evap.aux}$$
$$Q_{evap.ref} + h_9 * \dot{m}_9 = h_{au\,x_{10}}\,\dot{m}_{au\,x_{10}}$$
$$Q_{evap.aux} + h_{aux\,9}\,\dot{m}_{au\,x_9} = h_{au\,x_{10}}\,\dot{m}_{au\,x_{10}}$$

Ammonia and hydrogen gas mixture leaving the evaporator and uncondensed ammonia gas from the condenser. Ammonia vapor during the absorption processes, hydrogen gas inlets along refrigerant and auxiliary gas.

$$\dot{m}_{11} = \dot{m}_{10}$$

.
$$\dot{m}_{au\,x_{11}} = \dot{m}_{au\,x_{10}}$$

$$h_{au\,x_{11}} = h_{au\,x_{11}}$$

State 12 is the weak solution inlet
$$\dot{m}_{12} = \dot{m}_{16}$$

$$\rho_{12} = \frac{1}{v_{F_{12}}}$$

State 13 is the strong solution outlet

Ammonia heat is liberated when ammonia is absorbed in weak solution. Due to the strong solution leaving, the weak solution in RHX is rejected from the absorber to the atmosphere

$$x_{mi\,x_{15}} = x_{f\,15}$$
$$T_{15} = T_{f_{15}}$$
$$z_{15} = 2.4$$
$$\rho_{15} = \frac{1}{v_{f_{15}}}$$
$$\dot{m}_{15} = \dot{m}_4 + \dot{m}_6$$
$$f_{15} * \dot{m}_{15} = f_4 * \dot{m}_4 + f_{6¿}\,\dot{m}_6$$
$$h_{15} * \dot{m}_{15} = h_{4¿}\,\dot{m}_4 + h_6 * \dot{m}_6$$

In the solution heat exchanger, the strong solution is heated by extracting heat from the weak solution returning the bubble pump. State 16 is the weak solution outlet.

$$\dot{m}_{16} = \dot{m}_{15}$$

$$z_{16} = 2.4$$

$$\rho_{16} = \frac{1}{v_{F_{16}}}$$

State 17 may be the strong solutions inlet means more amount of ammonia in ammonia

$$x_{mix_{17}} = x_{17} \qquad T_{17} = T_{f.17}$$
$$+ \Delta Phx$$
$$z_{17} = 0$$
$$\rho_{17} = \frac{1}{v_{F_{17}}}$$

Relation between mole fraction and mass fraction Is presented below;

$$Q_{RH\,X_{max}} = \dot{m}_{15} * (h_{15} - h_{17})$$
$$Q_{RHX} = \varepsilon_{RH\,X^{i}} Q$$
$$Q_{RHX} = \dot{m}_{17} * (h_1 - h_{17})$$
$$Q_{RHX} = \dot{m}_{15} * (h_{15} - h_{16})$$

The performance of the DAR cycle can be expressed in terms of COP. Performance of the DAR system is the amount of cooling achieved by a refrigerating machine per unit heat supplied. However, COP is also defined as the refrigeration rate over the rate of the heat addition at the generator.

$$Q_{rec} + Q_{C_0 nd} + \frac{Q_{\dot{c}}}{Q_{g_{en}}}$$
$$CP_{AHP} = \dot{c}$$
$$C_0 P_{A_R} = \frac{Q_{evap}}{Q_{gen}}$$
$$\overset{|\dot{c}|}{E_{err.}} = Q_{gen} + Q_{evap} + Q_{rec} + Q_{c_0 nd} + Q_{\dot{c}}$$

This cooled solution is now used to extract heat from the surroundings and then the cycle continues.

Conclusions: -
This paper describes a number of research options of diffusion absorption refrigeration

water mixture because more ammonia is coming from state 11

$$\dot{m}_{17} = \dot{m}_{13}$$

system. A mathematical model has been developed to predict the performance of the diffusion absorption refrigeration systems for various generator temperature and concentrations of the refrigerant in rich solution of ammonia. In this system the large amount of heat is lost during cooling process in rectifier, condenser, absorber, and heat exchangers. The additional advantage of this system is that the system can utilize heat sources as in solar.

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