



Research Paper

THERMODYNAMIC STUDY OF DIFFUSION ABSORPTION REFRIGERATION SYSTEM WITH ORGANIC FLUID

Mukul Kumar^{1*} and R K Das¹

*Corresponding Author: **Mukul Kumar**, ✉ mukul_2577@yahoo.co.in

In the recent years, the research interest on Diffusion Absorption Refrigeration (DAR) technology has increased significantly due to its ability to utilize exclusively low-grade heat to produce cooling effect. The operation of diffusion absorption refrigeration system is quiet and reliable therefore often used in hotel rooms and offices. The diffusion-absorption cycle utilizes ammonia-water-hydrogen as working fluid. In this paper, a mathematical model has been established and solved numerically. The model is based on the mass and energy conservation principles applied for every components of the DAR system, through which the working fluids flow. Equations have been developed to estimate mass flow rate, mass concentration and enthalpy of different fluids at various state points of the cycle by considering the mass balance and heat balance equations. Suitable thermodynamic relations have been used for estimating enthalpies at various points corresponding to their state properties of pressure, temperature and dryness fraction. The study showed that the COP of this refrigeration system, although not comparable with the COP of a vapour compression cycle, is encouraging, considering the fact that waste heat can be utilized for running the cycle and COP of the DAR system depends on different parameters like generator temperature, concentration of ammonia in rich solution, evaporator temperature and condenser temperature.

Keywords: Ammonia-water, Bubble pump, COP, Circulation ratio, Diffusion absorption refrigeration

INTRODUCTION

Diffusion Absorption Refrigeration (DAR) system is one of the most fascinating field of research interest during the last few decades, especially in developing countries like India.

There are no moving parts in DAR System, therefore this refrigeration system has quiet, reliable and maintenance free operation. DAR system was pioneer in 1920 by Von Platen and Munters (Pongsid Sriksirin *et al.*, 2001). The

¹ Department of Mechanical Engineering, Indian School of Mines, Dhanbad 826004, India.

huge advantage of DAR system is that it can operate without electricity and thus reduces the demand of electricity. Due to lack of moving parts DAR system has low maintenance cost and because of environment-friendly refrigerant, it does not contribute to ozone depletion or global-warming.

DAR cycle utilizes triple fluids namely ammonia, water and an auxiliary inert gas usually hydrogen, where ammonia is used as refrigerant and water as absorbent. The unique feature of this cycle, as compared to a conventional ammonia-water absorption cycle, is that introduction of the auxiliary inert gas plays its role to reduce the partial pressure of the refrigerant in the evaporator and allows the refrigerant to evaporate at low temperatures producing the cooling effect (Zohar and Jelinek, 2007). This refrigeration system is totally heat operated and there is no need of electrical or mechanical energy. Generally ammonia/water mixture provides cooling at quite low temperatures, -10 to -30 °C, depending on the diffusion absorption cycle configuration but requires moderately high driving temperatures which is higher than 150 °C. Although ammonia has excellent thermo-physical properties, it is toxic, explosive, and corrosive to copper and other non-ferrous metals.

Zohar *et al.* (2005) developed a complex thermodynamic model that explored the DAR cycle performance. They found that the maximum COP values reachable with a DAR cycle can be obtained when the ammonia concentrations in rich and weak solutions are 0.25 to 0.30 and 0.10, respectively and that the generator temperature is approximately 200 °C. They assumed that the vapor exiting the rectifier was pure ammonia with no traces

of water. This is rarely true, due to the fact that rectifier is not 100% efficient in separating water from ammonia.

In this paper, we investigate, by numerical simulation, the performance of a single stage diffusion-absorption cycle operating with $\text{NH}_3/\text{H}_2\text{O}$ mixture as working fluids and hydrogen as auxiliary inert gas. A parametric study of the effect of different system parameters on the COP is also presented by using the developed model. The performance of this mixture is simulated with various generator and evaporator temperatures.

SYSTEM DESCRIPTIONS

A simplified schematic diagram of the DAR cycle is depicted in Figure 1. The DAR system is similar to conventional ammonia water absorption refrigeration system with an inert gas usually hydrogen, diffused through the system to maintain a uniform system pressure throughout the cycle. The DAR system includes: (i) a generator which is basically a combination of a boiler and a bubble pump, (ii) a rectifier, (iii) a condenser, (iv) an evaporator containing gas heat exchanger, (v) an absorber, and (vi) a solution heat exchanger. Geometry of the bubble pump is very simple and it contains a cylindrical hollow tube. Application of bubble pump is to raise the solution from the lower level to the higher one. Different operations of a DAR system are as follows:

- A generator where the rich solution of ammonia is heated increasing the temperature of the solution,
- A bubble pump through which bubbles or vapours formed during heating of solution rise to the separator,

- A rectifier for condensing out the water vapour, if any, in the ammonia vapour, leaving the generator.
- A condenser for de-superheating and condensing ammonia vapour,
- An evaporator where liquid ammonia and hydrogen gas mix and liquid ammonia evaporates at partial pressure absorbing heat from the region to be cooled,
- An absorber where ammonia vapour is absorbed in the weak solution of ammonia and water, and
- A solution heat exchanger for exchanging heat between the hot weak solution returning from the generator and the cold rich solution going toward the generator.

Rich solution from the reservoir at 14 is heated in the solution heat exchanger by the return weak solution and enters the generator at 15. When heat is supplied to the generator at 1, bubbles of ammonia gas are produced from the ammonia-water mixture. The ammonia bubbles rise through the bubble pump lift tube to the separator where ammonia vapour is separated and the remaining weak ammonia-water solution (weak in ammonia) is sent to the absorber at 16 through the liquid-liquid solution heat exchanger. The ammonia vapor along with some amount of water vapour from the separator flows through the rectifier, where ammonia and water vapour mixture is cooled and water vapour is condensed to join the weak solution at 2. Almost pure ammonia refrigerant produced by rectification at 6 enters into the condenser and condenses to liquid at 7 the total pressure of the system. The condensed ammonia flows to the

evaporator through a heat exchanger where the liquid ammonia is sub cooled at 9 by the cold ammonia and hydrogen mixture returning from the evaporator, which is mixed with the uncondensed ammonia 8 and the mixture flows into the reservoir.

The ammonia and hydrogen gas mixture enters the absorber coil from the bottom and flows upward while the weak solution of ammonia enters the absorber coil from the top 16 and flows downward in a counter-current arrangement. The ammonia vapor is readily absorbed in the weak solution and the resulting rich solution flows to the reservoir. The auxiliary gas hydrogen is not absorbed and continues to flow to the evaporator with ammonia residuals at 10. The strong solution leaves the reservoir at 14 towards the generator. Hydrogen leaving the absorber is at higher temperature since it absorbs some part of heat liberated during absorption of ammonia in weak solution.

Hydrogen gas with traces of ammonia after leaving the absorber at 10 enters the evaporator and passes through the heat exchanger. When hydrogen is allowed to mix with the liquid ammonia at 12, the partial pressure of ammonia is reduced and this allows the liquid ammonia to evaporate at a lower temperature. The evaporation of ammonia extracts heat from the evaporator, providing refrigeration to the region to be cooled. From the evaporator, the mixture of ammonia and hydrogen at 13 returns to the reservoir. In the passage this mixture absorbs some amount of heat separately from the liquid ammonia coming from the condenser and hydrogen gas coming from the absorber and moving towards the evaporator.

One of the advantages of DAR system is that it is self circulating system due to the gravity and density differences of the working fluid.

It is necessary to have the following external services for the functioning of the cycle.

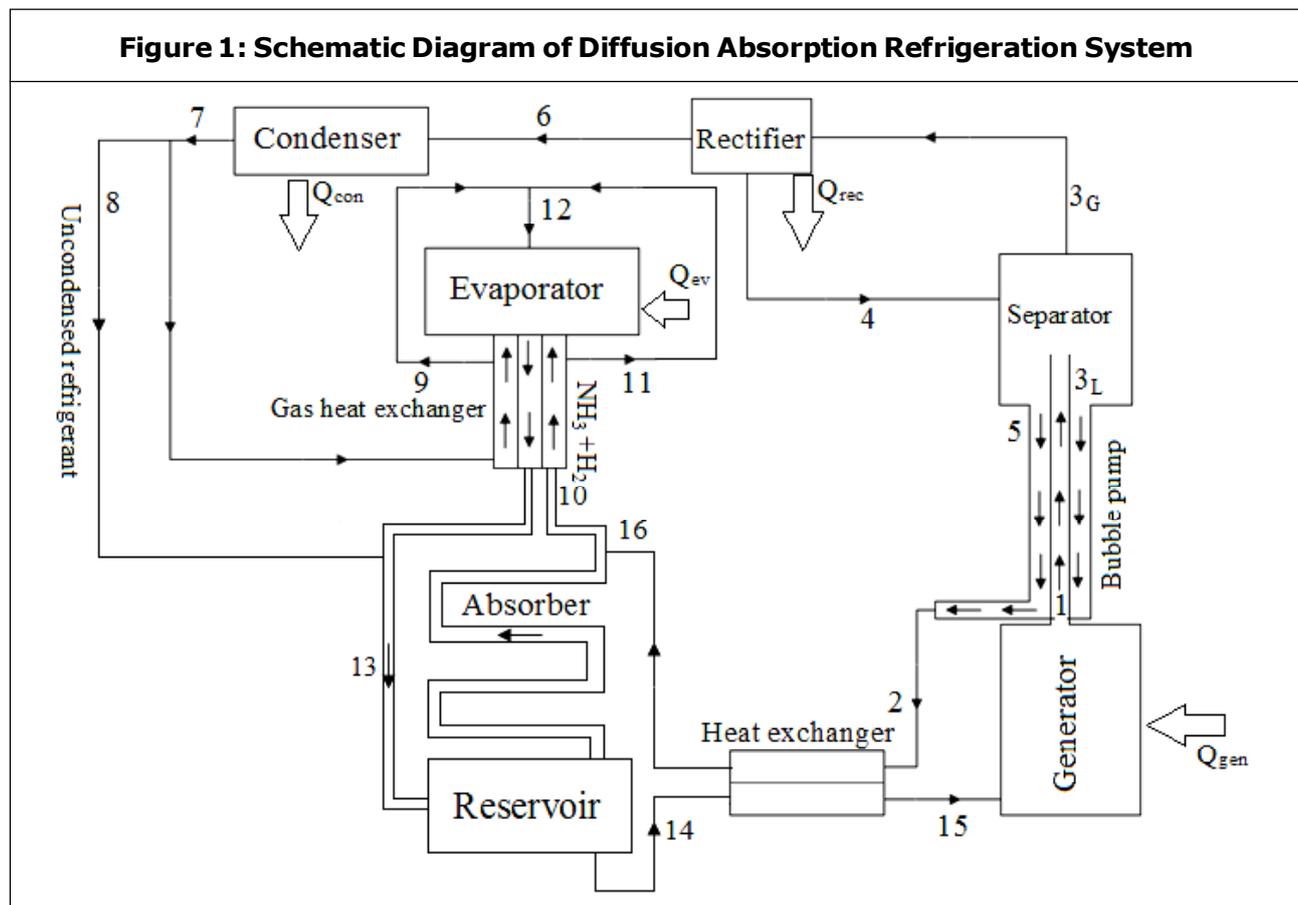
1. Supply of the heat at the generator temperature from the external sources, which may be any source of waste heat available at generator temperature, like exhaust gas from automobiles or boilers, exhaust gas from gas turbines, solar energy, etc.
2. Supply of cooling water in the condenser, in which ammonia vapour is de-superheated and condensed to liquid, liberating latent heat of liquefaction.

3. Supply of cooling water in the absorber where ammonia vapour is absorbed in the weak solution liberating latent heat of liquefaction which is to be carried away by the coolant water.

4. Supply of coolant in the rectifier. This coolant may be air or water. In the rectifier ($\text{NH}_3 + \text{H}_2\text{O}$) vapors are cooled and since water has higher saturation temperature than ammonia at any given pressure, water vapour is condensed out and almost pure ammonia proceeds to the condenser.

NUMERICAL MODELING OF DAR SYSTEM

Numerical modeling of DAR system is developed to analyze the performance of the



diffusion-absorption refrigeration cycle. The modeling proceeds by the following steps:

- To develop mass and energy balance equation at various component of DAR system.
- To specify the fundamental operating conditions like, driving heat source temperature (T_{gen}), temperature of the cold place (T_{evp}) the temperature of the surrounding (T_a).
- To characterize the heat and mass transfer processes in various heat and mass exchanging devices in DAR system.

Combined Generator, Bubble Pump, Separator and Rectifier

In the generator, the rich solution (15) is heated by external heat source. Vapours (1) produced due to heating rises through the bubble lift pump to the separator. Vapour (1) contain both gasses and liquid portion of the solution.

Energy Equations: Generator energy balance: In the generator, strong solution (15) is heated by external heat source (Q_{gen}) and saturated mixture of ammonia water (1) passes through the bubble pump. Therefore energy balance equation for generator can be written as:

$$\dot{Q}_{gen} = \dot{m}_{1L}h_{1L} + \dot{m}_{1G}h_{1G} - (\dot{m}_{15}h_{15}) \quad \dots(1)$$

Bubble Pump energy balance: The bubble pump acts as a heat exchanger, in which the returning weak solution (5) absorbs some amount of heat from the rising vapours of NH_3 and H_2O . Therefore,

Heat balance in the bubble pump:

$$(\dot{m}_{1L}h_{1L} + \dot{m}_{1G}h_{1G}) - (\dot{m}_{3L}h_{3L} + \dot{m}_{3G}h_{3G}) = \dot{m}_2h_2 - \dot{m}_5h_5 \quad \dots(2)$$

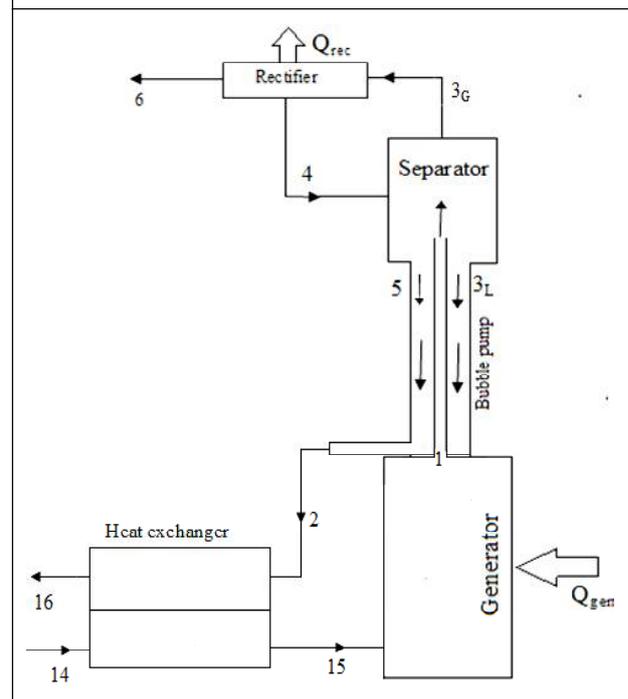
Rectifier Energy balance: In the rectifier, gaseous ammonia-water solution (at 3G) is cooled to produce almost pure ammonia refrigerant (6) and condensed solution (4), which returns into separator to form weak solution at 5. Thus energy balance equation for rectifier gives the heat rejection from the rectifier as:

$$\dot{Q}_{rec} = \dot{m}_{3G}h_{3G} - \dot{m}_6h_6 - \dot{m}_4h_4 \quad \dots(3)$$

Also, heat balance for the mixing of condensate from the rectifier (4) and weak solution (3_L) gives:

$$\dot{m}_5h_5 = \dot{m}_{3L}h_{3L} + \dot{m}_4h_4 \quad \dots(4)$$

Figure 2: Combined Block Diagram of Generator Bubble Pump Separator, Rectifier and Heat Exchanger



Condenser

Refrigerant ammonia vapour after leaving the rectifier (6) condenses in the condenser by rejecting heat into the atmosphere thus mass balance equation in the condenser.

Energy balance equation: Ammonia refrigerant is condensed at constant pressure in the condenser. Thus

Heat rejected in the condenser can be written as:

$$\dot{Q}_{con} = \dot{m}_7 X_7 h_{7G} = \dot{m}_7 (1 - X_7) h_{7L} - \dot{m}_6 h_6 \quad \dots(5)$$

The liquid portion of the refrigerant (7) from the condenser flows through the gas heat exchanger where it is sub cooled while the vapour portion of the refrigerant by passes the heat exchanger-evaporator assembly and flows to the reservoir after mixing with the (NH₃ + H₂O) gas coming out of the gas heat exchanger.

Expansion Chamber

Sub cooled liquid ammonia 9 meets with hydrogen gas with some residual ammonia gas in the expansion chamber (11). This causes pressures of both ammonia and hydrogen to drop and mixture of NH₃ and H₂ with their respective partial pressures enters the evaporation 12. Mass balance and energy balance for expansion chamber are presented below.

Mass flow rate of ammonia vapor after expansion

$$\dot{m}_{12G} = [\dot{m}_9 + \dot{m}_v] X_{12}$$

$$\dot{m}_9 = [\dot{m}_7 (1 - X_7)]$$

X₁₂ is the dryness fraction of ammonia vapour after mixing and expansion (12)

Mass flow rate of liquid ammonia after expansion

$$\dot{m}_{12L} = [\dot{m}_9 + \dot{m}_v] (1 - X_{12}) \quad \dots(6)$$

General mass balance of ammonia at exit of expansion 12.

$$\dot{m}_{12L} + \dot{m}_{12G} = \dot{m}_{R12} \quad \dots(7)$$

$$\dot{m}_{12L} + \dot{m}_{12G} = \dot{m}_9 + \dot{m}_v \quad \dots(8)$$

Energy balance equation: Energy balance equation for sub cooled ammonia refrigerant hydrogen and ammonia residual gas leaves at expansion at 12.

$$\begin{aligned} \dot{m}_v h_{11} + \dot{m}_H h_{H,11} + \dot{m}_9 h_9 \\ = \dot{m}_H h_{H,12} + \dot{m}_{12L} h_{12f} + \dot{m}_{12G} h_{12G} \end{aligned} \quad \dots(9)$$

Evaporator Ammonia Sub Cooling and Gas Heat Exchangers

Condensed ammonia refrigerant enters into the heat exchanger portion of the coupled evaporator and gas heat exchanger where it is sub cooled up to 9, by the cold gas mixture (NH₃ + H₂) coming out from the evaporator, Hydrogen gas and residual ammonia mixture released from the absorber (10) is also cooled by the cold gas mixture from the evaporator upto 11 before mixing with the sub cooled ammonia at 9.

After mixing pressure of ammonia reduces to partial pressure in a mixture of saturated liquid ammonia, saturated vapour ammonia and hydrogen gas at 12. This mixture then enters the evaporation and absorbs heat from the evaporation, While the liquid ammonia is first evaporated to saturated vapour and then the whole mixture is heated beyond temperature at 12.

After leaving the evaporator the ammonia and hydrogen gas mixture enters the gas heat exchanger where it absorbs some amount of heat from the liquid ammonia (7L) and also from mixture of hydrogen and residual ammonia (10).

Mass flow rate of ammonia vapor leaving the evaporator at 13 is given below.

$$\dot{m}_{R,13G} = [\dot{m}_R(1 - X_7) + \dot{m}_v] X_{13} \quad \dots(10)$$

Mass flow rate of ammonia liquid refrigerant leaving the evaporator at 13 is given below.

$$\dot{m}_{R,13L} = [\dot{m}_R(1 - X_7) + \dot{m}_v](1 - X_{13}) \quad \dots(11)$$

Mass balance equation for ammonia refrigerant in evaporator gas heat exchanger. Since refrigerant at 13 may consider both saturated liquid and saturated vapour.

$$\dot{m}_{R,13L} + \dot{m}_{R,13G} = \dot{m}_{R,13} \quad \dots(12)$$

$$\begin{aligned} \dot{m}_{R,13L} + \dot{m}_{R,13G} &= [\dot{m}_{R,9} + \dot{m}_v](1 - X_{13}) \\ &+ (\dot{m}_{R,9} + \dot{m}_v) X_{13} \quad \dots(13) \end{aligned}$$

Combined energy balance equation for condense ammonia refrigerant enters at 7, residual gas mixture (ammonia and hydrogen) enters at 10 and passing through the tube meets with sub cooled ammonia at 12, ammonia and hydrogen gas mixture leaves the evaporator at 13.

$$\begin{aligned} \dot{Q}_{evap} &= \dot{m}_R(1 - X_7)(h_9 - h_{R,7f}) + \dot{m}_H C_{p,H}(T_{11} - T_{10}) \\ &+ \dot{m}_v(h_{h,11} - h_{R,10}) + (\dot{m}_{R,13,G} h_{R,13,G} + \dot{m}_{R,13,L} h_{R,13,f}) \\ &- (\dot{m}_{R,12,G} h_{R,12,G} + \dot{m}_{R,12,L} h_{R,12,f}) + \dot{m}_H C_{p,H}(T_{13} - T_{12}) \quad \dots(14) \end{aligned}$$

More the liquid evaporates while traversing the evaporator more the NH₃ refrigerant partial pressure in the vapor phase increases. Therefore temperature through the evaporator-gas heat exchanger increases. The evaporator-gas heat exchanger outlet temperature (T₁₃) is a model input parameter of the simulation. Many factors affect the evaporation process such as refrigerant mass flow, NH₃ partial pressure, temperature, absorber effectiveness, etc. The partial pressure of NH₃ in the gas mixture is defined as:

$$\frac{P_{part}}{P_{total}} = \frac{{}^nNH_3}{{}^nNH_3 + {}^nH_2} \quad \dots(15)$$

Absorber and Reservoir

In the Reservoir ammonia and hydrogen gas mixture leaving the evaporator at 13 and uncondensed ammonia gas from the condenser mix with the weak solution from the solution heat exchanger. Ammonia vapour is readily absorbed in the weak ammonia solution to produce strong ammonia solution (14). During the absorption processes, hydrogen gas is liberated which leaves the reservoir along with some amount of unabsorbed ammonia gas. Thus residual gas mixture (10) (hydrogen and unabsorbed ammonia) leaves the reservoir and moves towards gas heat exchanger.

Energy balance equation: Heat rejected in the absorber is given by

$$\begin{aligned} \dot{Q}_{abs} &= (\dot{m}_{14} h_{14} + \dot{m}_H h_{H,10} + \dot{m}_v h_{R,10}) \\ &- (\dot{m}_7 X_7 h_{R,8,G} + \dot{m}_{R,13,G} h_{R,13,G} + \dot{m}_{R,13,L} h_{R,13,f} \\ &+ \dot{m}_H h_{H,13} + \dot{m}_{16} h_{16}) \quad \dots(16) \end{aligned}$$

Heat of absorption is liberated when ammonia is absorbed in weak solution. Due to this temperature of leaving strong solution (14) and inside gas (10) increases. Also heat is rejected from the absorber to the atmosphere.

Solution Heat Exchanger

In the solution heat exchanger, the strong solution is heated from state 14 to state 15 by extracting heat from the weak solution returning from the bubble pump.

$$(\dot{m}_{15} h_{15} + \dot{m}_{16} h_{16}) - (\dot{m}_2 h_2 + \dot{m}_{14} h_{14}) = 0 \quad \dots(17)$$

Relation between mole fraction and mass fraction is presented below:

$$\xi = \frac{17.03x}{17.03x + (1-x)18.01} \quad \dots(18)$$

Numbers of equations developed for finding the enthalpy such that the results are obtained in terms of refrigeration capacity, coefficient of performance, heat addition in the generator, heat rejection in the condenser and absorber. Governing equation for enthalpy of ammonia-water solution in liquid phase as well as gas phase is expressed below:

$$h_L(T, x) = h_0 \sum_i a_i \left(\frac{T}{T_0} - 1 \right)^{mi} x^{ni} \quad \dots(19)$$

$$h_g(T, y) = h_0 \sum_i a_i \left(1 - \frac{T}{T_0} \right)^{mi} (1-y)^{ni/4} \quad \dots(20)$$

Temperature-pressure and mole fraction (liquid phase and gas phase) relation is presented below.

$$T(p, x) = T_0 \sum_i a_i (1-x)^{mi} \left[\ln \left(\frac{p_0}{p} \right) \right]^{ni} \quad \dots(21)$$

$$T(p, y) = T_0 \sum_i a_i (1-y)^{mi/4} \left[\ln \left(\frac{p_0}{p} \right) \right] \quad \dots(22)$$

Circulation Ratio

Circulation Ratio (CR) is defined as the ratio of the mass flow rate of the strong solution entering the generator to the mass flow rate of refrigerant.

$$f = \frac{\dot{m}_{15}}{\dot{m}_6} \quad \dots(23)$$

Cycle Performance

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 heat addition at the generator.

$$COP = \frac{\dot{Q}_{evp}}{\dot{Q}_{gen}} \quad \dots(24)$$

RESULTS AND DISCUSSION

In this section, the effects of variation of generator temperature (T_GEN), ammonia mass concentration (ZETA) in rich solution, evaporator temperature and condenser temperature on performance parameters like COP, refrigeration capacity and circulation ratio (f) are presented.

Figures 3 and 4 present the variation of COP as a function of generator temperature and ammonia concentrations in rich solution (ZETA), respectively. It can be seen that for all concentrations, COP of the cycle is very low at temperatures which are closer to the bubble point for a particular concentration. COP increase quickly with increase in generator temperature, reaches the peak and then

Figure 3: Effect of Generator Temp. on COP

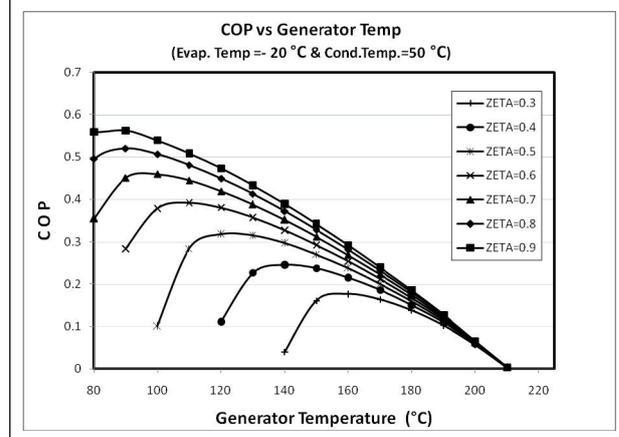
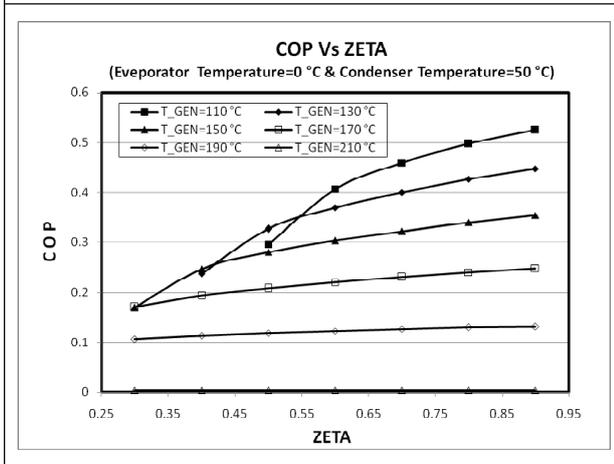


Figure 4: Effect of Ammonia Concentration on COP



decreases slowly with further increase in generator temperature.

At temperature closer to the bubble point, amount of ammonia evaporated in the generator is very low causing to lower refrigeration capacity (Figure 5). After reaching the peak, when generator temperature is increased, both ammonia and water are heated to higher temperatures and amount of heat input for the mass flow rate increases, most part of which is rejected through the rectifier and condenser without any significant increase in refrigeration capacity (Figure 5). Since COP is defined as the ratio of refrigeration capacity and the rate heat input in the generator, COP decreases with increase in generator temperature. The other revelations from these figures are as follows:

- At a particular generator temperature, COP increases with increase in ammonia concentration, but at higher temperatures, COP is less sensitive to the concentration.
- The generator temperature at which the peak COP occurs is lower for higher concentration (ZETA). For ZETA = 0.9, the

maximum COP occurs at generator temperature of 100 °C, while for ZETA= 0.3, the same occurs at 160 °C of generator temperature.

- The maximum value of COP obtained at a particular ZETA is higher at higher concentrations, which is justified by lower circulation ratio at higher concentrations. The maximum COP obtained is 0.56 for ZETA of 0.9 and while the same for ZETA = 0.3, is only 0.18.
- For ZETA = 0.9, the maximum COP occurs at generator temperature of 100 °C, while for ZETA = 0.3, the same occurs at 160 °C of generator temperature.
- Variation of COP with temperature (i.e., difference if the maximum and the minimum COP at a particular ZETA) is higher at higher concentrations.
- At temperatures higher than 220 °C, COPs for all concentrations are very low and approach towards zero.

Figure 4 exhibits the variation of COP with ammonia concentration in rich solution (ZETA) at different generator temperature. The figure reveals that COP depends significantly ZETA only at lower temperatures, while at higher temperatures, there is very little dependence of COP on the concentration.

Figures 5 and 6 show the variation of refrigeration capacity as a function of generator temperature and ZETA, respectively. Fig. 5 reveals that the refrigeration capacity, at a particular concentration, increases initially, reaches the peak and then starts decreasing sharply with increase in generator temperature. On the other hand, increase of

Figure 5: Effect of Generator Temperature on Refrigeration Capacity

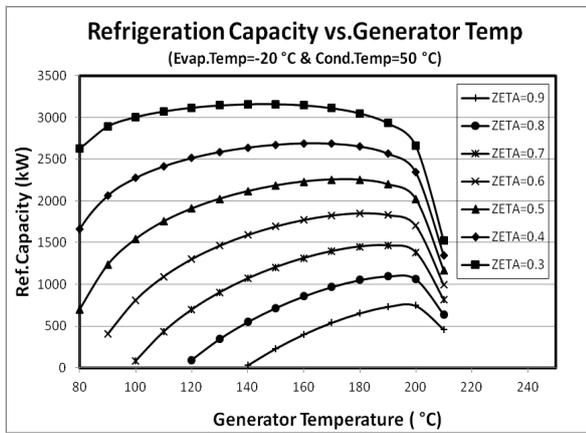
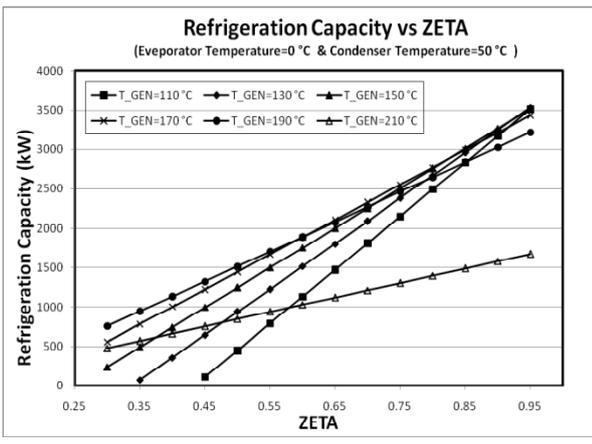


Figure 6: Effect of Ammonia Concentration on Refrigeration Capacity



ZETA at any temperature causes increase in refrigeration capacity. The other observations from these figures are as follows:

- The maximum refrigeration capacity obtained at a particular ZETA is higher for higher concentrations, which is justified by higher mass of refrigerant flow rate through the evaporator for given mass flow rate of ammonia-water solution through the generator at higher concentrations. The maximum refrigeration capacity obtained is 3160.7 kW for ZETA of 0.9 while the value

of the same is 743.8 kW for ZETA = 0.3. Here, it may be mentioned that the above performances are obtained for a mass flow rate of 5 kg/s through the generator.

- Temperature, at which the maximum refrigeration capacity occurs at a particular ZETA, is lower for higher concentration. For ZETA = 0.9, the maximum refrigeration capacity occurs at generator temperature of 150 °C, while for ZETA = 0.3, the same occurs at 200 °C of generator temperature.
- The generator temperature, at which the maximum COP occurs, is, in general, not equal to the generator temperature, at which the maximum refrigeration capacity, is obtained. ☺

CONCLUSION

A mathematical model has been developed to predict the performance of the diffusion absorption refrigeration system for various generator temperatures and concentrations of the refrigerant (ammonia) in the rich solution of ammonia-water solution.

It is found that the performance of the diffusion absorption refrigeration system, in general, is poor due to large amount of heat lost during cooling process in rectifier, condenser, absorber and gas heat exchanger. Although NH₃/H₂O diffusion absorption refrigeration system can be used for maintaining temperatures below 0 °C, NH₃/H₂O mixture may not be a good potential pair for absorption refrigeration cycles operating with lower generation temperatures. The additional advantage of this system is that the system can utilize heat sources like solar, geothermal, industrial waste or others.

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APPENDIX

Nomenclature			
\dot{Q}	Heat transfer rate (W)	x	Mole fraction of ammonia in liquid phase
T	Temperature ($^{\circ}\text{C}$)	y	Mole fraction of ammonia in vapor phase
h	Enthalpy (kJ Kg^{-1})	L	Liquid
ξ	Ammonia mass fraction in solution	G	Gas
COP	Coefficient of performance	f	Circulation ratio (CR)
\dot{m}	Mass flow rate (kg s^{-1})	X	Quality of gas
P	Pressure (bar)	C_p	Specific heat ($\text{kJ kg}^{-1} \text{K}^{-1}$)
T_g	Generator temperature	R	Refrigerant
C	Concentration	H	Hydrogen