

# Performance of Ammonia-water Vapour Absorption Refrigeration System

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**Abstract :** When ammonia-water absorption machines are used as heat pumps, the main problems can be found in the components operating at a high pressure (generator-condenser); the increase in temperature with respect to the exertion as refrigerator generates particular conditions that might unbalance the decomposition of ammonia into nitrogen. A decrease in the rate of the refrigerating fluid Ammonia ( $\text{NH}_3$ ) in the condenser and evaporator occurs, hence of the performance coefficient of the heat pump with an increased risk of the potential generation of explosive mixtures due to the presence of the hydrogen. Our aim is to examine the reaction of ammonia during the dissociation greenhouse gas emissions from the thermodynamic point of view. Present study deals with optimization of the parameters of ammonia-water absorption refrigeration system. Obtaining the best equations of coefficient of performance (COP) of 3TON(TR) absorption refrigeration system. Coefficient of performance (COP) is considered as an objective function and condenser, evaporator, and generator temperatures as well as solution heat exchanger and refrigerant heat exchanger effectiveness are considered as independent parameters. Results show that condenser temperature has maximum influence on COP. Maximum COP is obtained at lower condenser and higher evaporator temperature.

**Index Terms - Ammonia , absorber, generator ,rectifier, condenser and pump.**

## I. INTRODUCTION

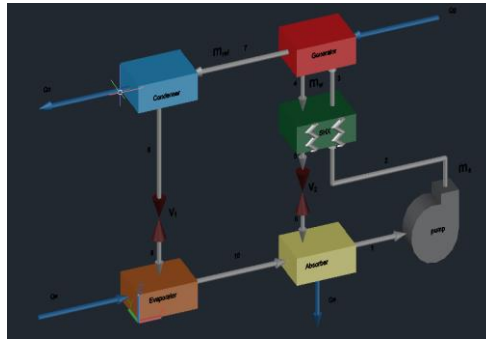
A simple absorption refrigeration system consists of an absorber, a pump, a generator and a pressure reducing valve to re-place the compressor in vapour compression refrigeration system. The other component of the system is same (condenser, evaporator and expansion valve). In this system the  $\text{NH}_3$  is used as a refrigerant and the water is used as an absorbent. In this system the low pressure ammonia vapour refrigerant leaving the evaporator enters the absorber, where it's absorbed by the cold water in the absorber. The water has an ability to absorb a very large quantity of ammonia vapour, and the solution thus formed is known as aqua ammonia solution. The absorption of ammonia vapour in water lowers the pressure in the absorber which turn draw the more ammonia vapour from the evaporator and thus raise the temperature of the solution. Some form of cooling arrangement (usually water cooling) is employed in the absorber to remove the heat of solution evolved here, this is necessary in order to increase the absorption capacity of water, because of higher temperature water absorb less ammonia vapour, the strong solution thus formed in absorber is pumped to the generator by the liquid pump. The pump increases the pressure of solution up to the 10 bar. The strong solution of ammonia in the generator is heated by some external source such as gas, steam, solar energy. During the heating process ammonia vapour is driven off from the solution at higher pressure and leaving behind the hot weak solution in the generator. The weak ammonia solution flows back to the absorber at low pressure after passing through the pressure reducing valve. The high pressure ammonia vapour from the generator is condensed in the condenser to high pressure liquid ammonia thus liquid ammonia is passed to the expansion valve through the receiver and then to the evaporator.

**Tyagi [1]** carried out the detailed study on aqua-ammonia VAR system and plotted the coefficient of performance, mass flow rates as a function of operating parameters i.e. absorber, evaporator and generator temperatures.

**Sozen [2]** studied the effect of heat exchangers on the system performance in an ammonia water absorption refrigeration system. He concluded that using refrigerant exchanger in addition to mixture heat exchanger does not increase the system performance.

**Fernande z-Searaand Vazquez [3]** studied the optimal generator temperature in single stage ammonia – water absorption refrigeration system based on parametric analysis by developing a computer program and based on the results designed a control system. The control system developed maintains a constant temperature for the space to be refrigerated and also control the optimal temperature in the system generator.

## II. DESCRIPTION AND WORKING OF VAPOUR ABSORPTION REFRIGERATION SYSTEM



**Fig 1: Schematic Diagram of Simple Vapour Absorption Refrigeration System**

Figure 1 shows the schematic block diagram of a simple absorption refrigeration system it consist of an absorber, a pump, a generator and a pressure reducing valve to re-pace the compressor in vapour compression refrigeration system. The other component of the system is same (condenser, evaporator and expansion valve). In this system the  $\text{NH}_3$  is used as a refrigerant and the water is used as an absorbent.

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The weak ammonia solution flows back to the absorber at low pressure after passing through the pressure reducing valve. The high pressure ammonia vapour from the generator is condensed in the condenser to high pressure liquid ammonia thus liquid ammonia is passed to the expansion valve through the receiver and then to the evaporator. This is the complete working of simple vapour absorption refrigeration cycle.

## III. ANALYSIS OF VAPOUR ABSORPTION REFRIGERATION SYSTEM

The dissociation reaction of the ammonia into nitrogen and hydrogen is



If there is an equilibrium, that is pressure and temperature are constant, the variation in the free energy of reaction is provided by:

$$\Delta G_r = RT \ln K_a$$

where  $K_a$  is the constant of the equilibrium which depends on the activities. Assuming that the three gases behave as the ideal gas, that can be written according to the partial pressures:

$$\Delta G_r = - RT \ln K_a$$

$\Delta G_r$  is related to the free energy of formation  $\Delta G_f$  by the relation

$$\Delta G_r = - 2\Delta G_f$$

While taking into consideration the (4.16) and knowing some measured values of the  $\Delta G_f$  [26], it is possible to determine, through the method of the least squares, a formula of linear interpolation providing  $\Delta G_r$  values with respect to a changing temperature:

$$K_p = 9080 - 50T$$

where  $\Delta G_r$  is expressed in cal/mol and T in °C. Through it is then possible to determine:

$$K_p = e^{\frac{50T-9080}{1.98(T+273)}}$$

In (4.3.1.6)  $K_p$  can be expressed according to the partial pressures of the components:

$$K_p = \frac{P(N_2) \cdot [P(N_2)]^3}{[P(NH_3)]^2}$$

keeping in mind that in the hypothesis of an ideal gas, partial pressures are proportional to molar fractions:

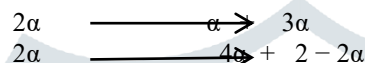
$$K_p = \frac{P^2 X(N_2) \cdot [X(N_2)]^3}{[X(NH_3)]^2}$$

where P is the total pressure in which the chemical equilibrium occurs.

#### Dissociation degree :

Dissociation defined as fraction of original solute molecules that have dissociated into respective gasses

If  $2\alpha$  moles of  $NH_3$  are examined, at equilibrium the result will be  $\alpha$  moles of  $N_2$  and  $3\alpha$  moles of  $H_2$  with  $2(1-\alpha)$  undissociated moles of  $NH_3$ .



Therefore

$$\alpha + \bar{\alpha} = 1, \alpha = (1 - \bar{\alpha})$$

Since two molecules of ammonia is dissociated

Therefore fraction of molecules will be  $2 - 2\alpha$

$$N_t = 2\alpha + 2 = 2(\alpha + 1)$$

where  $\alpha$  is the dissociation degree and it is defined as the ratio between the number of moles of  $NH_3$  dissociated and the one initially present. The molar fractions of the components at equilibrium can be expressed in reference to the dissociation degree, hence:

$$\begin{aligned} X(NH_3) &= \frac{(1-\alpha)}{(1-\alpha)} \\ X(N_2) &= \frac{\alpha}{2(1+\alpha)} \\ X(H_2) &= \frac{3\alpha}{2(1+\alpha)} \\ K_p &= \frac{P^2 X(N_2) [X(H_2)]^3}{[X(NH_3)]^2} \end{aligned}$$

By substituting in the relation the result is:

$$K_p = P^2 \frac{\left[\frac{\alpha}{2(1+\alpha)}\right] \left[\frac{3\alpha}{2(1+\alpha)}\right]^3}{\left[\frac{(1-\alpha)}{(1+\alpha)}\right]^2}$$

$$K_p = P^2 \frac{\frac{\alpha}{2(1+\alpha)} \times \frac{27\alpha^3}{2^3(1+\alpha)^3}}{\frac{(1-\alpha)^2}{(1+\alpha)^2}}$$

$$K_p = \frac{27}{16} P^2 \frac{\frac{\alpha}{(1+\alpha)} \frac{\alpha^3}{(1+\alpha)^3}}{\left[\frac{(1-\alpha)}{(1+\alpha)}\right]^2}$$

$$K_p = \frac{27}{16} P^2 \frac{\frac{\alpha^4}{(1+\alpha)^4}}{\left[\frac{(1-\alpha)}{(1+\alpha)}\right]^2}$$

$$K_p = \frac{27}{16} P^2 \left[ \frac{\alpha^4}{(1+\alpha)^2 (1-\alpha)^2} \right]$$

$$K_p = \frac{27}{16} P^2 \left[ \frac{\alpha^4}{(1-\alpha^2)^2} \right]$$

$$K_p = \frac{27}{16} P^2 \left[ \frac{\alpha^4}{1+\alpha^4-2\alpha^2} \right]$$

By equating these two equations represents  $\alpha$  is a function of temperature and pressure of equilibrium.

### Analysis of coefficient of performance of vapour absorption refrigeration system:

#### Governing equations:

Major equations used to evaluate COP of the system are as follows. Various properties at salient points are denoted as suffice as per numbers given in Fig-3.1

The mass balance of strong solution, weak solution and refrigerant can be written as

$$\dot{m}_r + \dot{m}_w - \dot{m}_s = 0$$

The specific rich solution circulation can be written as

$$f = \frac{x_9 - x_4}{x_3 - x_4}$$

The strong and weak solution flow rates are given by equations (4.29) and (4.30) respectively

$$\dot{m}_s = \dot{m}_r \times f$$

$$\dot{m}_w = \dot{m}_r \times (f - 1)$$

Energy balance of different components of absorption refrigeration system can be written by equations (4.26) to (4.38)

Refrigerating effect be written as

$$Q_e = \dot{m}_r \times (h_{13} - h_{12})$$

Heat added in the generator can be written as

$$Q_g = \dot{m}_r \times (h_7 - h_4 + f \times (h_4 - h_3))$$

Pump work can be written as

$$W_p = \frac{\dot{m}_r \times f \times v_1 \times (P_2 - P_1)}{\eta_p}$$

Heat rejected in the condenser can be written as

$$Q_c = \dot{m}_r \times (h_9 - h_{10})$$

Heat rejected in the absorber can be written as

$$Q_a = \dot{m}_r \times (h_{14} - h_6 + f \times (h_6 - h_1))$$

Heat transfer in solution heat exchanger can be written as

$$Q_{SHE} = \dot{m}_r \times ((f - 1) \times (h_4 - h_5))$$

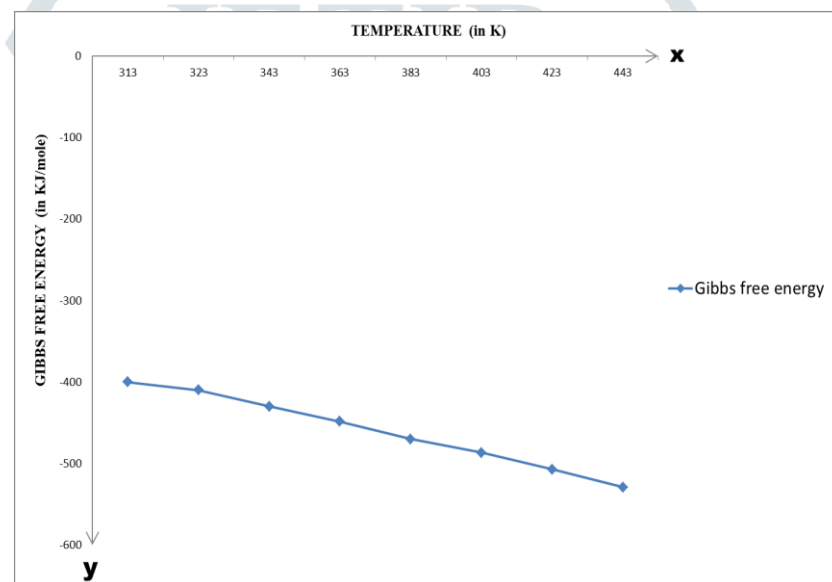
Heat transfer in refrigerant heat exchanger can be written as

$$Q_{RHE} = \dot{m}_r \times (h_{10} - h_{11})$$

Coefficient of performance of the absorption refrigeration system can be written as

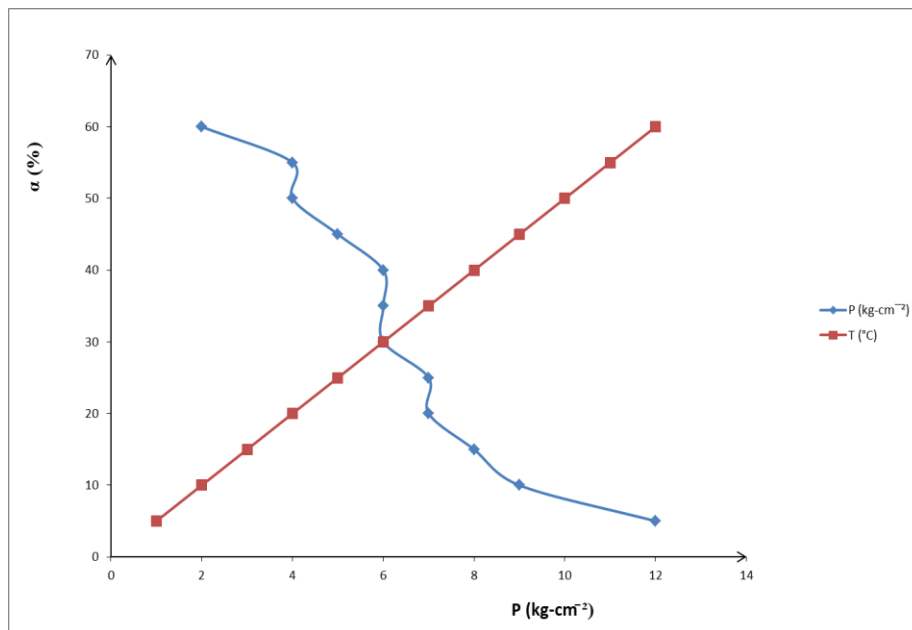
$$COP = \frac{Q_e}{Q_g + W_p}$$

#### IV. RESULTS AND DISCUSSIONS



**Fig 2 :Variation of Gibbs energy with respect to temperature**

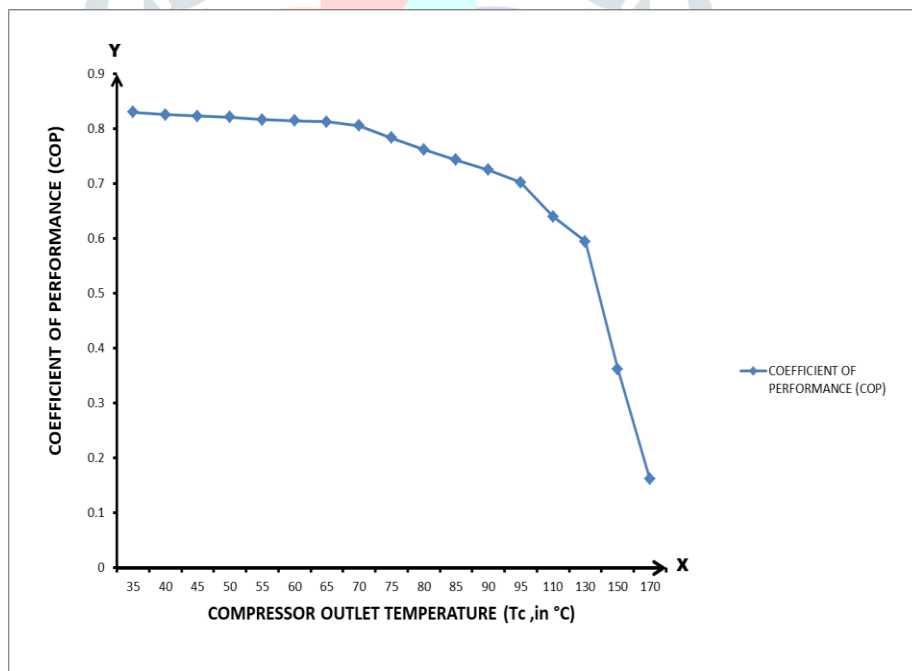
Both  $\text{NH}_3\text{-H}_2\text{O}$  presents problems in terms of high pressure (generator-condenser) the increase in temperature, for what concerns the exertion as refrigerator, provokes a higher fluid pressure thus causing the necessity of a proper mechanical dimensioning of the components, hence higher costs. Due to a higher temperature, an abundant amount of vaporous absorbent is moved to the generator with rectification difficulties. Moreover, the particular conditions in terms of temperature and pressure might unbalance the equilibrium of the decomposition reaction of the ammonia into nitrogen and hydrogen to high values of the dissociation degree. Hence it occurs a decrease in the rate of the refrigerant fluid  $\text{NH}_3$  in the condenser and evaporator, and of the coefficient of performance of the heat pump. There is also a higher probability that explosive substances (due to the presence of hydrogen) might generate.



**Fig 3: Variation of  $\alpha$  concentration with pressure**

$\alpha'$  can be expressed in function of temperature and pressure of equilibrium. (with pressures ranging between 1 and 12 kg-cm<sup>-2</sup> and temperatures between 0°C and 170°C) and (with temperatures ranging between 0 and 170°C and pressures reaching 12 kg-cm<sup>-2</sup>) show the results.

It can be noticed a remarkable decrease of  $\alpha$  with the pressure and an increase of  $\alpha$  with the temperature. In the conditions where a heat pump presents a higher probability that it might function, that is where pressure can vary from 1 and 12 kg-cm<sup>-2</sup> and temperatures between 90°C and 170°C,  $\alpha$  is characterized by high values ranging between 5% and 15%.



**Fig 4: Estimation of COP with temperature (T<sub>c</sub>°C)**

For maximum COP, lower condenser and higher evaporator temperatures are desirable. From the above plotted graph(6.3), we can conclude that there is a sudden decrease in COP of the vapor absorption refrigeration at 90°C-95°C compressor outlet temperature. The COP drops by 12.11% and thus the heat input increases by 12.11% for the same cooling effect. We can conclude that the limited maximum temperature for COP of 3TR refrigeration system is below 95°C.

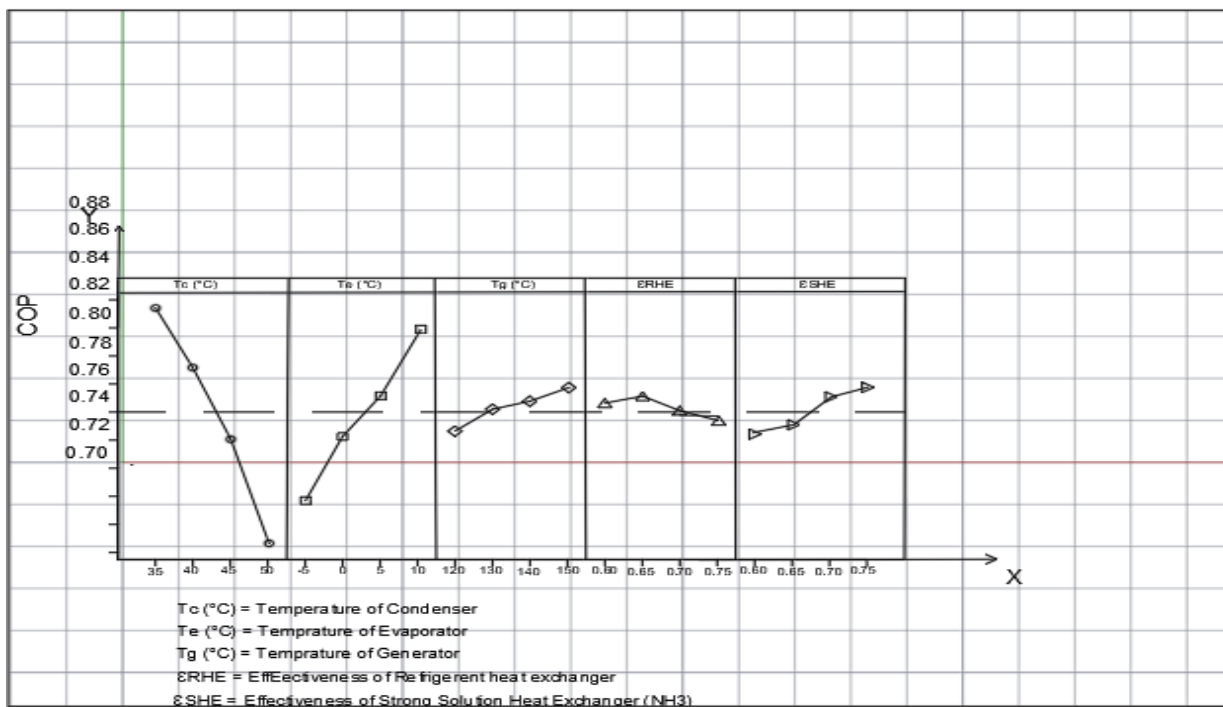


Fig 5: Variation graph of COP with respect to temperatures

From the above graph,  $T_c = 35^\circ\text{C}$ ,

$T_e = -5^\circ\text{C}$ ,  $T_g = 110^\circ\text{C}$ ,

$\epsilon_{RHE} = 0.5$ ,  $\epsilon_{SHE} = 0.5$ ,

**COP = 0.8309**

By comparing COP with various parameters like  $T_c$ ,  $T_e$ ,  $T_g$ ,  $\epsilon_{RHE}$  and  $\epsilon_{SHE}$ . The COP value for high generator temperature i.e.  $T_g = 170^\circ\text{C}$  is 0.392. Hence we can conclude that there is a change in COP of refrigerant with variations in temperatures of condenser, evaporator and generator.

The following conclusions are obtained from the Effect of Coefficient of performance of Ammonia-Water Vapour absorption refrigeration system :

1. From the Gibbs energy graph, it is observed that to maintain maximum COP the Gibbs free energy of refrigerant should not be less than that  $-448.86 \text{ kJ/mol}$ .
2. As the dissociation  $[\alpha]$  % the vapours of  $\text{N}_2$  and  $\text{H}_2$  gas formation takes place in condenser, resulting in increasing of pressure & temperature.
3. At  $95^\circ\text{C}$  the COP decreases by 12.11% therefore, the economic aspects must be evaluated carefully before any absorption refrigeration system is considered (3TR), especially when the source temperature is below  $93^\circ\text{C}$ .
4. For maximum COP, lower condenser and higher evaporator temperatures are desirable.

## V. REFERENCES

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