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Analysis of Ammonia –Water (NH3-H2O) Vapor Absorption Refrigeration System based on First Law of Thermodynamics

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Abstract— The continuous increase in the cost and demand for energy has led to more research and development to utilize available energy resources efficiently by minimizing waste energy. Absorption refrigeration systems increasingly attract research interests. Absorption cooling offers the possibility of using heat to provide cooling. For this purpose heat from conventional boiler can be used or waste heat and solar energy. Absorption system falls into two categories depending upon the working fluid. These are the LiBr-H_2O and NH_3-H_2O Absorption Refrigeration system. In LiBr-H_2O system water is used as a refrigerant and LiBr is used as an absorbent, while in NH_3-H_2O system ammonia used as an refrigerant and water is used as an absorbent, which served as standard for comparison in studying and developing new cycles and new absorbent/refrigerant pairs. The objective of this paper is to present empirical relations for evaluating the characteristics and performance of a single stage Ammonia water (NH_3-H_2O) vapour absorption system. The necessary heat and mass transfer equations and appropriate equations describing the thermodynamic properties of the working fluid at all thermodynamic states are evaluated. An energy analysis of each component has been carried out and numerical results for the cycle are tabulated. Finally the variations of various thermodynamic parameters are simulated and examined.

Index Terms— Energy, Energy Rate, Coefficient of Performance

1 Introduction

In view of shortage of energy production and fast increasing energy consumption, there is a need to minimize the use of energy and conserve it in all possible ways. Energy conservation (i.e., energy saved is more desirable than energy produced) is becoming a slogan of the present decade and new methods to save energy, otherwise being wasted, are being explored. Recovering energy from waste heat and/or utilizing it for system efficiency improvement is fast becoming a common scientific temper and industrial practice now days. The present energy crisis has forced the scientists and engineers all over the world to adopt energy conservation measures in various industries. Reduction of the electric power and thermal energy consumption are not only desirable but unavoidable in view of fast and competitive industrial growth throughout the world. Refrigeration systems form a vital component for the industrial growth and affect the energy problems of the country at large. Therefore, it is desirable to provide a base for energy conservation and energy recovery from Vapour Absorption System. Although, the investigations undertaken in this work are of applied research nature but certainly can create a base for further R & D activities in the direction of energy conservation and heat recovery options for refrigeration systems and the analysis can be extended further to other Refrigeration and Air Conditioning Systems. In recent years, research has been devoted to improvement of Absorption Refrigeration Systems (ARSs). Mechanical Vapour Compression Refrigeration requires high grade energy for their operation. Apart from this, recent studies have shown that the conventional working fluids of vapour compression system are causing ozone layer depletion and green house effects.

However, ARS's harmless inexpensive waste heat, solar, biomass or geothermal energy sources for which the cost of supply is negligible in many cases. Moreover, the working fluids of these systems are envoi mentally friendly [1-3]. The overall performance of the absorption cycle in terms of refrigerating effect per unit of energy input generally poor, however, waste heat such as that rejected from a power can be used to achieve better overall energy utilization. Ammonia/water (NH_3/H_20) systems are widely used where lower temperature is required. However, water/lithium bromide (H_20/LiBr) system are also widely used where moderate temperatures are required (e.g. air conditioning), and the latter system is more efficient than the former [4-6].

The objective of this paper is to evaluate thermodynamic properties and tabulated also energy transfer rate in each components are calculated and tabulated with the help of empirical relation. Mass flow rate and heat rate in each components of the system are evaluated and tabulated. The coefficient of performance of the system is determining for various temperatures ranges. The result of this study can be used either for sizing a new refrigeration cycle or rating an existing system.

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SYSTEM DESCRIPTION

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-

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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 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 week 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. This is the complete working of simple vapour absorption refrigeration cycle.

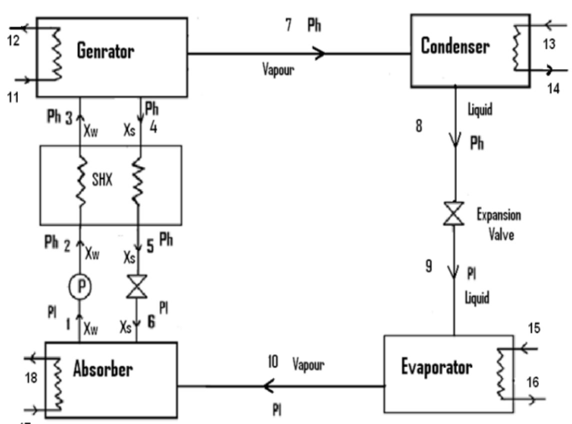

Figure 1: Schematic Diagram of Simple Vapour Absorption Refrigeration System

THERMODYNAMIC ANALYSIS

For carrying out thermodynamic analysis of the proposed Vapour Absorption Refrigeration system, following assumption are made: [5]

No pressure changes except through the flow pump.

1. At point1, 4 and 8, there is only Saturated Liquid.

2. At point10, there is only Saturated Vapour.

3. Pumping is isentropic.

4. Assume weak solution contain more percentage of refrigerant and less percentage of absorbent and strong solution contain more percentage of absorbent and less percentage of refrigerant.

5. Percentage of weak solution at state 1, 2 and 3 and Percentage of strong solution at state 4, 5 and 6 will remain same.

6. The Temperatures at Thermodynamic state 11,12,13,14,15,16,17 and 18 are the external circuit for water which is use to input heat for the components of system. As Shown in fig 1

For Generator,
Inlet Temperature of Water = 100°C
Outlet Temperature of Water = 90°C
For condenser,
Inlet Temperature of Water = 20°C
Outlet Temperature of Water = 24°C

For Absorber,
Inlet Temperature of Water = 20°C
Outlet Temperature of Water = 24°C

For Evaporator,
Inlet Temperature of Water = 20°C
Outlet Temperature of Water = 12°C

8. We have divided our system into two pressure limits, one is high pressure limit and other is low pressure limit, in the following system we are taking high pressure from the table corresponds to generator temperature (T_7) and low pressure corresponds to evaporator temperature (T_{10})

$P_1 = P_6 = P_9 = P_{10} =$ Low pressure
$P_2 = P_3 = P_4 = P_5 = P_7 = P_8 =$ High pressure

Following are the input parameters made during the analysis [5]

- Mass flow rate of Refrigerant = 0.05 kg/s
- Effectiveness of heat exchanger (ε) =0.7
- Generator Temperature =T_G=T_4=T_7 = 50°C

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- Condenser Temperature=T_C=T_8= 50°C
- Absorber Temperature=T_A=T_1=T_2= 20°C
- Evaporator Temperature=T_E=T_{10}=T_9= 2.5°C
- Percentage of weak solution X_w= 55.3
- Percentage of strong solution X_s= 56

A. Energy Analysis

GENERATOR

On balancing the energy across the generator, one can say;

$$Q_g + Q_3 = Q_4 + Q_7 \quad (1)$$

Since:

$$Q_3 = m_3.h_3 \quad (2)$$
$$Q_4 = m_4.h_4 \quad (3)$$
$$Q_7 = m_7.h_7 \quad (4)$$

Balancing the concentration across the Generator, one can say,

$$m_3.X_3 = m_4.X_4 \quad (5)$$

Putting the value of m_3, X_3 and X_4 in Equation 5, we will get,

$$m_1 = \frac{m_4 \cdot X_s}{X_w} \quad (6)$$

Combining Equations 5 and 6, one can say

$$m_6 = \frac{-m_{10}}{1 - \frac{X_6}{X_1}} \quad (7)$$

Using Equation 8, [5] one can estimate the enthalpy (h_3) and (h_4) at thermodynamic state 3 and 4,

$$h(T,X) = 100 \sum_{i=1}^{16} a_i \left[\frac{T}{273.16} - 1\right]^{m_i} (X)^{n_i} \quad (8)$$

i	m_i	n_i	a_i
1	0	1	- 7.6108
2	0	4	25.6935
3	0	8	-247.092
4	0	9	325.952
5	0	12	-158.854
6	0	14	61.9084
7	1	0	14.1314
8	1	1	1.18157
9	2	1	2.84179
10	3	3	7.41609
11	5	3	891.844
12	5	4	-1613.09
13	5	5	622.106
14	6	2	-207.588
15	6	4	-6.87393
16	8	0	3.50716

Coefficient of Equation Table (1)

Enthalpy at thermodynamic state 7, calculated with the help of table at T_G=T_7

Using equation 2, 3 and 4, one can calculate Q_3, Q_4 and Q_7 putting the value of Q_3 Q_4 and Q_7 one can calculate Q_G

$$Q_g = (m_7 \times h_7) + (m_4 \times h_4) - (m_3 \times h_3) \quad (9)$$

We also know that heat supplied to the generator is,

$$Q_g = m_{11} \times 4.2 \times (T_{12} - T_{11}) \quad (10)$$

On comparing equation (9) with (10), one can get m_{11}

Similarly by using energy balance, one can calculate m_{11}

$$m_{11} = \frac{(m_7 \times h_7) + (m_4 \times h_4) - (m_3 \times h_3)}{4.2 \times (T_{11} - T_{12})} \quad (11)$$

CONDENSER

On balancing the energy across the condenser, one can say;

$$Q_c + Q_8 = Q_7 \quad (12)$$

Since,

$$Q_8 = m_8.h_8 \quad (13)$$
$$Q_7 = m_7.h_7 \quad (14)$$

Enthalpy at thermodynamic state 8, calculated with the help of table at T_C = T_8

With the help of equation 13, 14, one can calculate Q_7 and Q_8

On putting the value of Q_7 and Q_8 in equation 13, one can get

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$$Q_c = (m_7 \times h_7) - (m_8 \times h_8) \quad (15)$$

We also know that heat supplied to the condenser is,

$$Q_c = m_{15} \times 4.2 \times (T_{16} - T_{15}) \quad (16)$$

On comparing equation (15) with (16), one can get m_{15}
Similarly by using energy balance, one can calculate m_{15}

$$m_{15} = \frac{(m_7 \times h_7) - (m_8 \times h_8)}{4.2 \times (T_{16} - T_{15})} \quad (17)$$

EVAPORATOR

On balancing the energy across the Evaporator, one can say;

$$Q_e + Q_9 = Q_{10} \quad (18)$$

Since,

$$Q_9 = m_9 . h_9 \quad (19)$$

$$Q_{10} = m_{10} . h_{10} \quad (20)$$

Enthalpy at thermodynamic state 9, calculated with the help of table at T_9
Enthalpy at thermodynamic state 10, calculated with the help of table at T_{10}
With the help of equation 19, 20, one can calculate Q_9 and Q_{10}
On putting the value of Q_9 and Q_{10} in equation 18, one can get,

$$Q_e = (m_{10} \times h_{10}) - (m_9 \times h_9) \quad (21)$$

We also know that heat Extracted from the evaporator is,

$$Q_e = m_{17} \times 4.2 \times (T_{18} - T_{17}) \quad (22)$$

On comparing equation (21) with (22), one can get m_{17}
Similarly by using energy balance, one can calculate m_{17}

$$m_{17} = \frac{(m_{10} \times h_{10}) - (m_9 \times h_9)}{4.2 \times (T_{18} - T_{17})} \quad (23)$$

ABSORBER

On balancing the energy across the Absorber, one can say,

$$Q_a + Q_1 = Q_6 + Q_{10} \quad (24)$$

Since,

$$Q_1 = m_1 . h_1 \quad (25)$$

$$Q_6 = m_6 . h_6 \quad (26)$$

$$Q_{10} = m_{10} . h_{10} \quad (27)$$

Using Equation 8, one can estimate the enthalpy (h_1) and (h_6) at thermodynamic state 1 and 6

Enthalpy at thermodynamic state 10, calculated with the help of table at T_{10}
We have already found out m_1 and m_6 by using equation 5 and 6 for calculating T_5, one can use the relation of effectiveness of Heat Exchanger

$$T_5 = - \varepsilon - \frac{T_4}{T_4 - T_2} \times (T_4 - T_2). \quad (28)$$

With the help of equation 25, 26 and 27, one can calculate Q_1, Q_6, and Q_{10}

On putting the value of Q_1, Q_6, and Q_{10} in equation 24, one can get,

$$Q_a = (m_6 \times h_6) + (m_{10} \times h_{10}) - (m_1 \times h_1) \quad (29)$$

We also know that heat Transfer from the absorber is,

$$Q_a = m_{13} \times 4.2 \times (T_{14} - T_{13}) \quad (30)$$

On comparing equation (29) with (30), one can get m_{13}
Similarly by using energy balance, one can calculate m_{13}

$$m_{13} = \frac{(m_6 \times h_6) + (m_{10} \times h_{10}) - (m_1 \times h_1)}{4.2 \times (T_{14} - T_{13})} \quad (31)$$

RESULTS AND DISCCUSSION

Thermodynamic properties at the various states, energy flow rate at the various components of the system, Coefficient of performance of the system by using input parameters being calculated through the mathematical model on MATLAB. Summary of the same has been given in tables

Effect of Generator Temperature on Coefficient of Performance:-

It can be seen from the Figure 2, as the Generator temperature increases, Coefficient of Performance of the system decreases. This is due to the increase in the enthalpy of refrigerant which thereby increases in the generator load. This system can be operated with a relative low generator temperature to reach low evaporator temperature with an acceptable system COP, which is main advantage of this refrigeration system, as it could then utilize industry or civil waste heat and solar energy since fluid temperatures of this kind of heat source are generally low.

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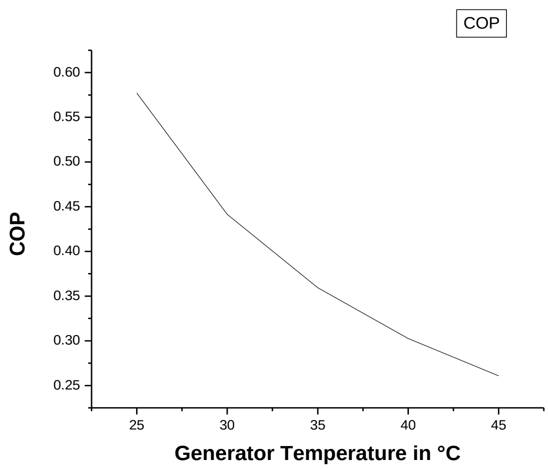

Figure 2: Variations of COP with Generator Temperature

Effect of Inlet water Temperature to Generator on Coefficient of Performance:-

It can be seen from the Figure 3, as the Temperature of inlet water to Generator increases, Coefficient of Performance of the system decreases. This is due to the increase in the temperature difference of inlet and outlet water which thereby increases the generator load.

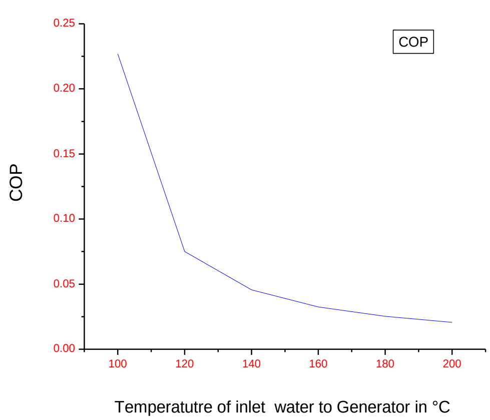

Figure 3: Variations of COP with inlet water temperature to Generator (T_{11})

Effect of Absorber Temperature on Coefficient of Performance:-

It can be seen from the Figure 4, as Absorber Temperature decreases, Coefficient of Performance of the system increases. This is due to decrease in the generator load.

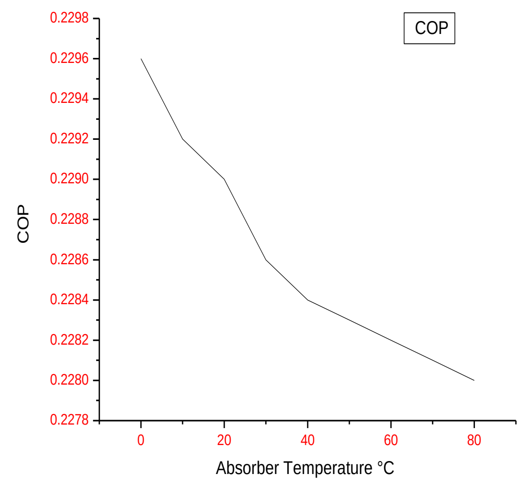

Figure 4: Variations of COP with Absorber Temperature

Effect of Evaporator Temperature on Coefficient of Performance:-

It can be seen from the Figure 5, as Evaporator Temperature decreases, Coefficient of Performance of the system increases. This is due to increase in the Evaporator load.

STATES	P (bar)	h (kJ/kg)	T (°C)	m (kg/s)	X %
1	4.712	-144.6	20	4.01	55.3
2	20.33	-139.1	21	4.01	55.3
3	20.33	-26.26	41.3	4.01	55.3
4	20.33	24.25	50	3.96	56
5	20.33	-89.87	29.7	3.96	56
6	4.712	-89.87	29.7	3.96	56
7	20.33	1474.92	50	0.05	0
8	20.33	421.94	50	0.05	0
9	4.712	192.9	2.5	0.05	0
10	4.712	1447.06	2.5	0.05	0

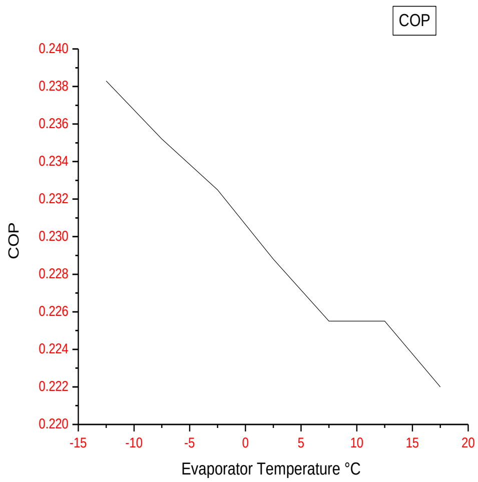

Figure 5: Variations of COP with Evaporator Temperature

Effect of Effectiveness of Heat exchanger on Coefficient of Performance:-

It can be seen from the Figure 6, as Effectiveness of Heat Exchanger increases, Coefficient of Performance increases. Heat exchanger used to increase the performance of Refrigeration system, it exchange the heat from hot fluid to cold fluid, which thereby the temperature of cold fluid increases before entering to the generator, so as in the generator there is less heat input require and hence COP of system is increases.

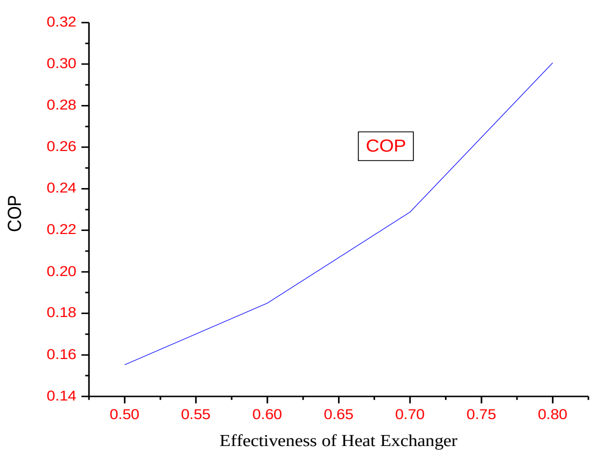

Figure 6: Variations of COP with Effectiveness of Heat Exchanger

Tabulation of the calculated Thermodynamic properties at the various, Thermodynamic States for the NH_3-H_2O Vapour Absorption System:-

Tabulation of the calculated Energy flows at the various components for the Ammonia -Water Vapour Absorption Refrigeration System:-

Table 3 Energy flows at the various components

S. No.	Description	Notations	Calculated Value (k J/s)
1	Heat load in Evaporator	Q_e	62.70
2	Heat load in Condenser	Q_c	52.643
3	Heat load in Absorber	Q_a	296.31
4	Heat load in Generator	Q_g	275.07
5	Coefficient of Performance	COP	0.227 (Dimensionless)

CONCLUSIONS

In this Paper, the first Law of Thermodynamics is applied to a single stage Ammonia-Water Vapour Absorption Refrigeration system, the performance analysis of each component is calculated through mathematical model on MATLAB 7.0.1. Followings are the conclusion made:

1. Coefficient of Performance of the system decreases with increasing inlet water Temperature to generator (T_{11}) keeping the outlet water temperature to generator (T_{12}) is constant.

2. As the generator Temperature increases, the COP of the system decreases.

3. As we increase Condenser Temperatures, the Coefficient of Performance of the system decreases.

4. As we increase Absorber Temperatures, the Coefficient of Performance of the system decreases.

5. As the effectiveness of Heat exchanger increases, COP of the system is also increases.

Finally, the results of the Energy Analysis presented in our project can be applied as a useful tool for evaluation and improvement of the absorption systems; it provides a simple and effective method to identify how losses at different devices are interdependent and where a given design should be modified for the best performance.

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