

# Design Analysis of One Tonne Liquid Ammonia Vapour Absorption Refrigeration System

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**ABSTRACT:** In this paper the thermodynamic investigation is applied to the 1TR aqua ammonia vapour absorption refrigeration system. The energy and environmental norms regarding the ozone layer depletion and the global warming are becoming more and more stringent in almost all countries. In this challenging scenario absorption refrigeration system using the binary mixture of ammonia and water are gaining popularity because they use zero global warming and ozone depletion fluids as refrigerants. Moreover these systems are heat operated and need very little electricity. These systems however have lower COP and are costlier than the conventional vapour compression systems and need optimization from thermodynamics as well as economic points of view. In this respect, thermodynamics concept has emerged to be a better tool as it addresses this multidisciplinary analysis by blending the energy analysis with economic analysis.

**KEYWORDS:** Coefficient of Performance (COP), Heat Transfer, Mass Transfer, Concentration

## I. INTRODUCTION

The conventional refrigeration system is of mechanical vapour compression type. In this method vapour gets compressed by a mechanical compressor. The vapour absorption system is an alternative to the compression system, where the energy requirement is reduced by eliminating the compressor [1]. The working fluid in this system is a pair of ammonia and water. The usage of chloro fluoro carbons is thus

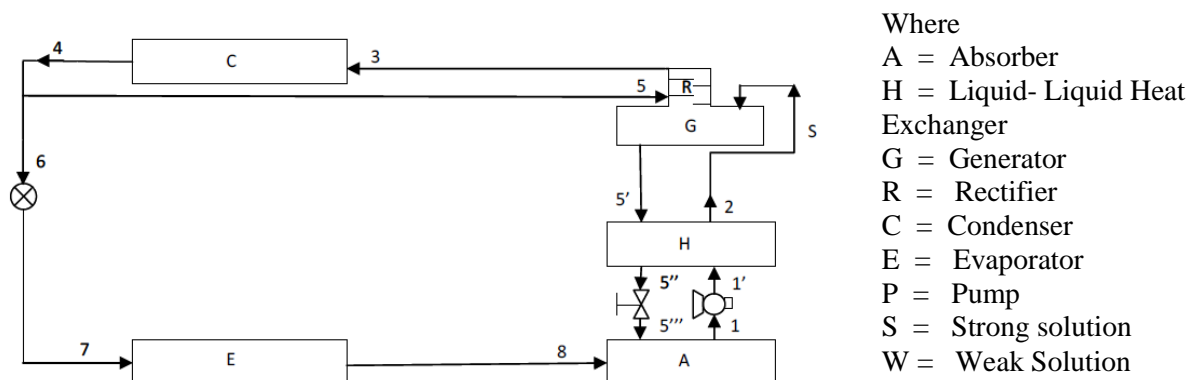


Fig. 1 Schematic Diagram of the Vapour Absorption Refrigeration Cycle

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avoided and the heat input to the system can be obtained from solar energy by flat plate or concentrating type collectors. With parabolic concentrating surface, temperatures of 150°C-300°C can be achieved while only 70°C-90°C is obtainable from flat plate collectors. The assumptions have been used in the analysis [2]:

- The system is in steady state.
- The temperatures of the condenser, evaporator, absorber, generator and rectifier are constant and uniform throughout the components.
- The condenser and the evaporator pressures are the equilibrium pressures corresponding to the temperatures and concentrations in the condenser and evaporator respectively.
- The strong solution leaving the absorber and the weak solution leaving the generator are in equilibrium at their respective temperature and pressure.
- The refrigerant vapour concentration at the rectifier exit is equal.
- The refrigerant vapour at the rectifier and the evaporator exit is equivalent vapour state at their respective temperature and pressure, while refrigerant liquid at the condenser exit is equivalent liquid state at the condenser temperature and pressure.
- The reference environmental state for the system is  $T_o=25^\circ\text{C}$  (environment temperature) and  $P_o=1$  atm (atmospheric pressure)
- The system uses high pressure steam to drive the generator.
- The cooling water first enters the absorber at  $27^\circ\text{C}$  then passes through the condenser and finally is rejected by the system.

## II. DESIGN OF THE VAPOUR ABSORPTION REFRIGERATION SYSTEM

Before starting the design of the system, the following parameters were chosen

- Generator temperature ( $T_g^\circ\text{C}$ )
- Condenser temperature ( $T_c^\circ\text{C}$ )
- Evaporator temperature ( $T_e^\circ\text{C}$ )
- Absorber temperature ( $T_a^\circ\text{C}$ )

From condenser and evaporator temperatures, the pressures of condenser and evaporator have fixed using the aqua-ammonia enthalpy concentration diagram. The concentrations and enthalpies at various states were found out. Generally calculations for vapour absorption system are based on a unit mass of refrigerant vapour distilled from the generator. The schematic diagram of refrigeration cycle shown in Fig. 1[3,4,5].

### Mass and material balance

Considering the evaporator, the mass flow rate of the refrigerant  $M_7$  :

$$M_7 = (3.5167 * \text{tonnage of refrigeration}) / \text{Refrigeration effect} \quad \dots\dots\dots (1.1)$$

From the mass balance around the generator

$$M_2 + M_5 = M_5' + M_3 \quad \dots\dots\dots(1.2)$$

At the condenser,

$$M_3 = M_4 = M_5 + M_6 \quad \dots\dots\dots(1.3)$$

From the Eqs . (1.2) and (1.3)

$$M_2 = M_5' + M_6 \quad \dots\dots\dots (1.4)$$

Denoting 'c' as the concentration of ammonia in solution and taking a material Balance around the generator

$$M_2 \cdot c_2 + M_5 \cdot c_5 = M_5' \cdot c_5' + M_3 \cdot c_3 \quad \dots\dots\dots (1.5)$$

Taking material balance around the condenser

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$$M_3 \cdot c_3 = M_4 \cdot c_4 = M_5 \cdot c_5 + M_6 \cdot c_6 \quad \dots\dots\dots (1.6)$$

From Eqns. (1.5) and (1.6)

$$M_2 \cdot c_2 = M_5 \cdot c_5 + M_6 \cdot c_6 \quad \dots\dots\dots (1.7)$$

From Eqns (1.4) and (1.7), the values of  $M_2, M_5$  and  $M_6$  were found out .

Mass flow rate of the strong solution,

$$M_s = M_1 = M_2$$

Mass flow rate of the weak solution ,

$$M_w = M_5 = M_5' = M_5''$$

Mass flow rate of the ammonia vapour,

$$M_3 = M_4 = M_1 - M_5 + M_6$$

### Heat Balance

Generator heat load ,

$$Q_g = M_3 h_3 + M_5' h_5' - M_2 h_2 - M_5 h_5 \quad \dots\dots\dots (1.8)$$

Heat rejected by the condenser

$$Q_c = M_3 (h_3 - h_4) \quad \dots\dots\dots (1.9)$$

Heat absorbed by the evaporator,

$$Q_e = M_7 (h_8 - h_7) \quad \dots\dots\dots (1.10)$$

Heat rejected by the absorber ,

$$Q_a = M_5'' \cdot h_5'' + M_8 h_8 - M_1 h_1 \quad \dots\dots\dots(1.11)$$

### Pump work

If 'v' is the specific volume of the liquid the pump work,  $Q_p$  can be expressed as,

$$Q_p = M_3 v (p_1' - p_1) \cdot 10^2$$

Where  $p_1'$  and  $p_1$  are the pressures across the pump in bars

### Energy balance

Total heat rejected is equal to the total heat supplied.

$$Q_a + Q_c = Q_e + Q_g + Q_p$$

The coefficient of Performance.

$$C.O.P. = Q_e / (Q_g + Q_p)$$

Neglecting the pump work which extremely small compared to  $Q_g$  .

$$c.o.p. = Q_e / Q_g$$

## III. DESIGN OF ITR AQUA-AMMONIA VAPOUR ABSORPTION SYSTEM

The vapour absorption system was designed for 1 TR capacity. The following data have been taken:

- Generator temperature : 110<sup>0</sup>C
- Condenser temperature: 40<sup>0</sup>C

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- Evaporator temperature:  $-9^{\circ}\text{C}$
- Absorber temperature :  $40^{\circ}\text{C}$

Pure ammonia is present at condenser. The saturation vapour pressure of ammonia at  $40^{\circ}\text{C}$  is 15.55 bar and at the evaporator ( $-9^{\circ}\text{C}$ ), it is 3 bar. The enthalpies and concentrations of liquid and vapour ammonia were found out from the standard aqua ammonia tables. The enthalpies and concentrations of every state were found out by locating the pressure, temperature coordinates on the chart, this is shown in table 1. From the Table the refrigeration effect was found to be 1320 KJ/Kg vapour. Mass flow rate of the refrigerant for 1 TR = 9.6 Kg/hr (from 1.1). By doing the mass and material balances around each component, following were found out.

Mass flow rate of strong solution = 115 Kg/hr (from 1.4 & 1.7)

Mass flow rate of weak solution = 105 Kg/hr (from 1.4)

Mass flow rate of vapour from rectifier = 19.2Kg/hr

The heat loads of different components were found out by doing heat balances.

Heat supplied to the Generator,

$Q_g = 8.83 \text{ KW}$  (from eqn 1.8)

Heat rejected by the condenser ,

$Q_c = 7.31 \text{ KW}$  (from eqn. 1.9)

Heat absorbed by the evaporator ,

$Q_e = 3.52 \text{ KW}$  (from eqn. 1.10)

Heat rejected by the absorber,

$Q_a = 4.5 \text{ KW}$  (from eqn. 1.11)

Energy Balance

Total heat rejected ,

$Q_a + Q_c = 11.8 \text{ KW}$

Total heat absorbed,

$Q_e + Q_g = 12.3 \text{ KW}$

Ideally ( $Q_a + Q_c$ ) should be equal to ( $Q_e + Q_g$ ) . The slight difference which is observed here is due to the association in locating the state points on Fig.1

The C.O.P of the system =  $Q_e/Q_g = 0.38$

**Table:1 Heat Balance of 1 TR Vapour Absorption Refrigeration System**

State point	Pressure (bar)	Temperature ( $^{\circ}\text{C}$ )	Concentration Of Ammonia	Enthalpy KJ/Kg
1	3.0	40	0.4	70
1'	15.5	40	0.4	70
2	15.5	97	0.4	350
3	15.5	97	0.95	1850
4	15.5	40	0.95	480
5	15.5	40	0.95	480
5'	15.5	110	0.35	400
5''	15.5	-	0.35	-
5'''	3.0	-	0.35	-
6	15.5	40	0.95	260
7	3.0	-9	0.95	260
8	3.0	-9	0.95	1580

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## IV. CONCLUSION

It is concluded that the vapour absorption refrigeration system uses the heat energy to change the condition of the refrigerant from the evaporator. The vapour absorption system can operate at reduced evaporator pressure and temperature by increasing the steam pressure to the generator with the little decrease in capacity. The load variation does not affect the performance of the system. Since in vapour absorption refrigeration system the exhaust steam from the furnaces and solar energy may also be used therefore this system can be used where the electric power is difficult to obtain or is very expensive.

## NOMENCLATURE

$T_g$	Generator Temperature
$T_c$	Condensor Temperature
$T_e$	Evaporator Temperature
$T_a$	Absorber Temperature
$C$	Concentration
$Q_g$	Condenser
$Q_c$	Heat Rejected by condenser
$Q_e$	Heat Absorbed by evaporator
$Q_a$	Heat Rejected by absorber
$Q_p$	Pump Work

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