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C.O.P DERIVATION AND THERMODYNAMIC CALCULATION OF AMMONIA-WATER VAPOR ABSORPTION REFRIGERATION SYSTEM

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ABSTRACT

In the current trends globally, the excessive utilization of the energy and overconsumption of fuel has resulted in the global warming and environmental pollution. The Absorption cooling offers the possibility of using heat to provide cooling. For cooling purpose the required heat input is obtained from the excessive heat of the boiler or from non conventional power sources like solar energy. NH3-H2O system ammonia used as a refrigerant and water is used as an absorbent, these two liquids served as standard and a refrigerant cycle is produced. The system VARS in environment friendly and does not deplete the atmosphere. Thus it is essential to create awareness in the world for this system for it is an alternative system which is more environmental friendly. The objective of this paper is to present empirical relations for evaluating of the performance of a single stage vapor absorption system.

Keywords: Refrigeration, COP, VARS, Ammonia-Water.

I.INTRODUCTION

In recent trends of shortage of energy production and fast increasing non-reusable energy consumption, there is a need to minimize the overall energy consumption. Recovering the lost heat energy from various heat production units like generators, boiler and thermal plants and then utilizing the waste heat energy from the system is rapidly becoming a common scientific ideology and industrial practice in recent times. The present energy crisis has forced the scientists all over the world to adopt new methods of energy conservation in various sectors of industries areas. But the sudden reduction of the different types of power and energy like electrical, thermal, and chemical are unavoidable in the competitive industrial growth throughout the world. Refrigeration systems form a vital component for the industrial growth. Therefore, it is desirable to provide a solution for the conservation of energy by adopting the Vapor Absorption System Refrigeration System.

The Refrigeration System which operates nowadays is VCRS which requires high grade energy for their operation. Apart from this, the analysis and the studies have shown that the conventional working fluids of vapor compression system are causing ozone layer depletion and green house effects. [1]

However, the VARS is operational by harnessing the harmless inexpensive waste heat, solar, biomass or geothermal energy sources for which the cost is negligible. Moreover, the working fluids of these systems are envoi mentally friendly [2]. 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 (NH3/H20) systems are widely used where lower temperature is required. [3-5].

The objective of this paper is to evaluate thermodynamic properties. And the coefficient of performance (COP) of the system is determining for various temperatures ranges. The result of this study can be used for designing a new refrigeration system which is efficient as well as harmless to the environment.

II. SYSTEM DESCRIPTION

The Vapor absorption refrigeration systems use a heat source instead of electricity to provide the energy needed to produce cooling. The most basic components of a vapor absorption cycle are the evaporator, absorber, pump(s), generator (or desorber).a condenser and throttle valves. [6-7]. Two major types of absorption refrigeration system design exist: the two fluid and the three fluid absorption system. The majority of both designs are generally the same; the differences between them lie in the way the liquid refrigerant is caused to evaporate.

In this system the NH3 is used as a refrigerant and the water is used as an absorbent. In two working fluid system the ammonia vapor is produced in the generator at high pressure from the heating of the strong aqua-ammonia solution by an external source. The ammonia vapors flow to a condenser, where heat is rejected and condensed to a high-pressure liquid form. The liquid is then throttled though an expansion valve to the lower pressure in the evaporator where it evaporates by absorbing heat and provides useful cooling. The remaining liquid absorbent, in the generator passes through a valve, where its pressure is reduced, and then is recombined with the low-pressure refrigerant vapors returning from the evaporator, so the cycle gets completed and can be repeated.

Whereas in three working fluid the expansion valve is removed and a third fluid is introduced Hydrogen gas which has the properties including lightness, high reactiveness and low partial pressure. So when the ammonia vapors comes in contact with hydrogen gas which has low partial pressure the pressure of the complete system comes down rapidly causing flash evaporation which causes cooling.

The cycle can be broken into different flows, one comprising of the ammonia-water mixture and the other comprising of the ammonia vapor alone. Points (1-6) are the cycle of the ammonium hydroxide solution, and the rest of the points constitute the ammonia vapor cycle. The solution rich in refrigerant at point (1) is pumped to higher pressure through the solution heat exchanger (2) into the generator (3) where heat is added and an ammonia-water vapor mixture is sent to the rectifier (13), and the solution poor refrigerant (4) is sent back through the solution heat exchanger to the absorber.

The ammonia-water vapor is purified in the rectifier by condensing the water vapor in the mixture into liquid. The pure ammonia vapor is sent to the condenser (7) and the water liquid is sent back to the generator (14). The ammonia vapor loses heat to the surrounding by convection as it goes through the condenser and is cooled into liquid ammonia (8). The ammonia liquid is passed through the refrigerant heat exchanger (9) for further cooling, and then passed through a flow restrictor (10) where it experiences a sudden drop in pressure and evaporates because this new pressure is less than its saturation pressure.

The ammonia is now a saturated vapor at a temperature that corresponds to this new pressure. This temperature is always lower than the desired compartment temperature. The saturated ammonia vapor is sent to the evaporator where heat from the refrigerator is absorbed. The ammonia vapor (11) goes through the heat exchanger once again, but this time to absorb heat, before returning to the absorber (12) where it is absorbed into the water and the process repeats again.

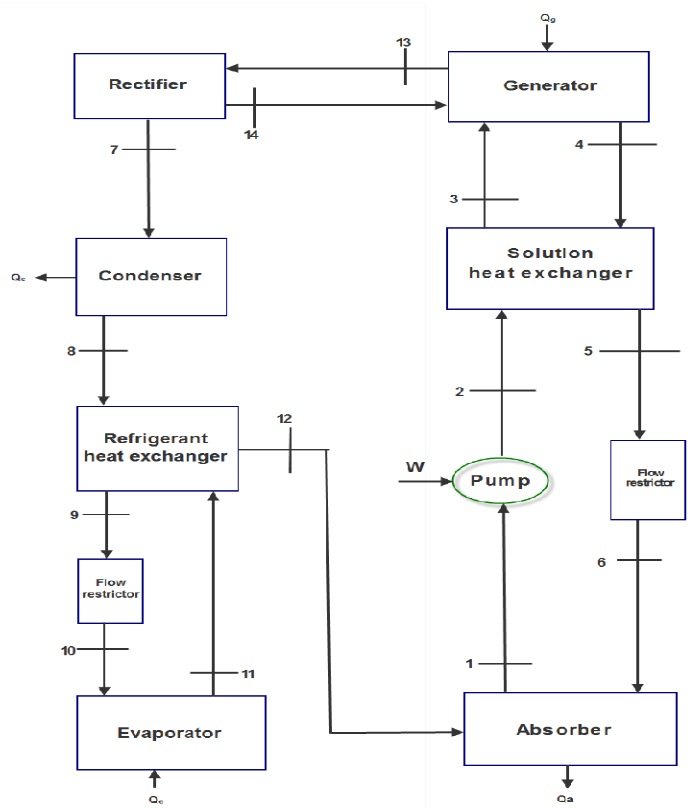

Fig - 1 Ammonia-water absorption refrigeration system flow diagram [12]

III.THERMODYNAMIC ANALYSIS

For carrying out the thermodynamic analysis of the proposed Vapor Absorption Refrigeration system, following assumption are made: [8]

1. No pressure changes except through the flow pump.
2. At point1, 4 and 8, there is only Saturated Liquid.
3. At point10, there is only Saturated Vapor.
4. Pumping is isentropic.
5. 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.
6. Percentage of weak solution at state 1, 2 and 3 and Percentage of strong solution at state 4, 5 and 6 will remain same.
7. 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.

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}).

Also P1 = P6 = P9 = P10 = Low pressure
P2 = P3 = P4 = P5 = P7 = P8 = High pressure

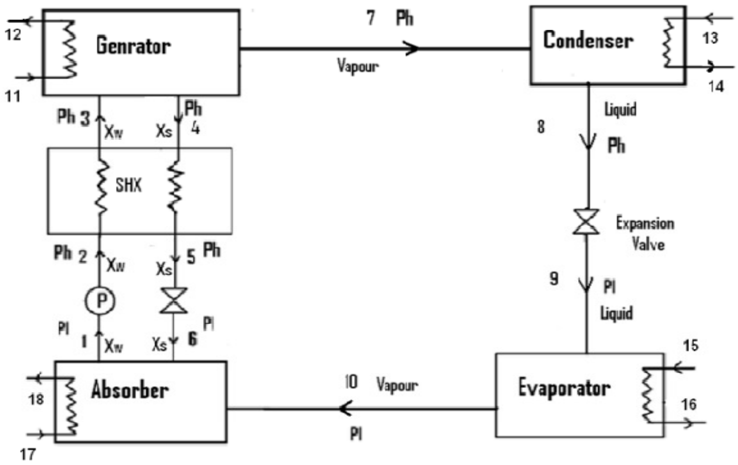

Fig - 2 Vapor Absorption Cycle [13]

IV.SELECTION OF REFRIGERANT

The Refrigerant is the most important part of the refrigeration system. The refrigerant in the system defines the working and the cycle of the refrigeration system. The working further lists out the components in the system. The components which are being used finally define the system if it is VARS or VCRS.

Aside from the afore mentioned requirements, the refrigerant must also meet standard refrigerant characteristics listed below. These characteristics are defined in other to maintain the surrounding conditions so that the refrigeration while operating should damage the atmosphere and the environment. A refrigerant must be or have the following properties –
-ozone and environmentally friendly
-low boiling temperature
-vaporization pressure lower than atmospheric
-high heat of vaporization
-nonflammable and non-explosive

In the recent times, commonly most of the manufacturers use ammonia as a refrigerant because it has a greater heat of vaporization, a lower vaporization pressure, a higher auto-ignition temperature, and is to the 100th time more soluble in water than other refrigerants. Also that ammonia (chemical formula NH_3) had all the desired properties of the refrigerant mentioned above and thus was chosen as the refrigerant for this project.

The selection of the refrigerant in turn results in the calculation which are to be determined. The total system pressure can now be obtained because it is dependent on the type of the refrigerant used. Before entering the evaporator, pure ammonia refrigerant leaves the condenser in a liquid phase at the eminent temperature of 0^oC. Here the saturation pressure of ammonia is at approximate temperature and thus the overall system pressure at the temperature of 0^oC, the saturation pressure of ammonia is 9.00 bar; but to ensure that the refrigerator works for a range of temperatures it was decided to have the operating pressure at 0 bar instead the 3 bar pressure. T his would allow the ammonia to circulate. After the flash vaporization of liquid ammonia, it was arbitrarily chosen that the difference in temperature between the cabinet compartment and the ammonia fluid that would facilitate heat transfer to the refrigerate in this case ammonia. This means that since the cabinet has a temperature of 3^oC, the vaporized ammonia gas should have a pressure that corresponds to a temperature of -5^oC. At this temperature, the saturation pressure of ammonia is approximately 3.5 bar. In order to drop the ammonia pressure to 3.5 bar, and to facilitate vaporization, the third fluid is used in a mixture with the ammonia or simply pressure valves are used to regulate the pressure in the system. Using Dalton's Law of partial pressure which states that the overall pressure of a mixture is the sum of the partial pressure of each of the gases in the mixture.[9] The desired pressure can be obtained in the system.

Physical Properties of Ammonia which is used as a refrigerant are as following -

- Ammonia is a colorless gas.
- It has a pungent odor with and an alkaline or soapy taste. When inhaled suddenly, it brings tears into the eyes.
- It is lighter than air and is therefore collected by the downward displacement of air.
- It is highly soluble in water: One volume of water dissolves about 1300 volumes of ammonia gas. It is due to its high solubility in water that the gas cannot be collected over water.
- It can be easily liquefied at room temperature by applying a pressure of about 8-10 atmosphere.
- Liquid ammonia boils at 239.6 K (- 33.5°C) under one atmosphere pressure. It has a high latent heat of vaporization (1370 J per gram) and is therefore used in refrigeration plants of ice making machines.
- Liquid ammonia freezes at 195.3 K (-77.8°C) to give a white crystalline solid.

V.THERMODYNAMIC ANALYSIS OF THE SYSTEM

The proper and to the point analysis of a Vapor Absorption Refrigeration system according to the thermodynamic qualities of the system involves establishing and finding important parameters that control the properties like enthalpy, mass flow rates, flow ratio, Heat and Mass Transfers for the system to calculate the Coefficient of Performance (COP). The values which were found and verified by the calculations are then used for the design of the system. The thermodynamic equations have been derived in terms of mass flow rates and enthalpy by applying mass and energy balance for each component. Then the actual system conditions like temperature, pressures, enthalpies are substituted in the equations to finally obtain the COP value for the system [10-11].The assumption for carrying out the Thermodynamic analysis of the system are as following:

A. Steady state and steady flow
B. No pressure drops due to friction
C. Only pure refrigerant boils in the generator.

To establish the symbolic representation of the calculations or understand the equations which are devised and used the following the notifications has been made in the theory.

Let m = mass flow rate of refrigerant, kg/s
mss = mass flow rate of strong solution, kg/s
mws = mass flow rate of weak solution, kg/s
Q=Heat

The analysis of each component of the system has been done by considering each system individually below, the figure explain the process:

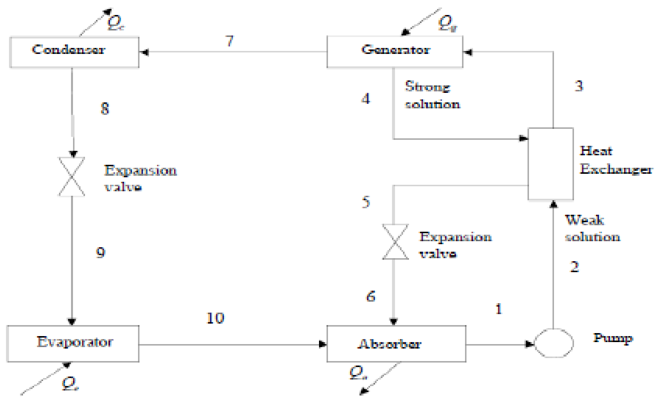

Fig 3 - The steps of the cycle

Condenser

$m_7 = m_8 = m$

$Q_c = m(h_7 - h_8)$, kJ/s

Expansion Valve

$m_8 = m_9 = m$

$h_8 = h_9$(isoenthalpic), kJ/kg

Evaporator

$m_9 = m_8 = m$

$Q_e = m(h_9 - h_8)$, kJ/s

Absorber

From total Mass balance

m+mss=mws

Solution Pump

$m_1 = m_2 = mws$

wp=(1+λ)mV sol(pc-pE) kJ/s

where *Vsol* . is specific volume of solution which can be taken as approx. 0.00055 m^3/kg.

Solution Heat Exchanger

$m_2 = m_3 = mws$

$m_4 = m_5 = mss$

$Q_{HX} = (1+\lambda)\, m(h_3 - h_2) = \lambda m(h_4 - h_5)$,kJ/s

Generator

$m_3 = m_4 + m_7$

Heat input to the Generator,

$Q_g = mh_7 + \lambda mh_4 - (1+\lambda)\, m_3$, kJ/s

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The relations have been established in the above analysis. These relations can be used to find the values of the required quantities that effect the COP of the system at hand.

Coefficient of Performance (COP):

In this system the total refrigerating effect in the system is dependent on the heat absorbed by the refrigerant (Ammonia) in the evaporator. The total energy supplied to the system is the sum total of the work done by the pump and the heat supplied in the generator. Therefore, the Coefficient of performance (COP) of the system as theoretically known is given by COP= Heat Absorbed in the Evaporator /(Work done by pump +Heat Supplied in the Generator) or $COP = Q_e/(Q_g+W_p)$.

Neglecting the Pump work, we get:

$COP=Q_e/Q_g$

Which is the expression for Coefficient of Performance (COP) of the System.

VI. MATHEMATICAL CALCULATIONS FOR EACH COMPONENT

Operating temperatures and pressures:

The most favourable working temperatures for a ammonia and water refrigeration system (for a COP value between 0.6 and 0.8) are:

Generator Temperature, T_g= 60- 99 °C
Condenser Temperature, T_c= 28- 60 °C
Absorber Temperature, T_a = 16- 32 °C
Evaporator Temperature, T_e= 2.5- 10 °C

The operating temperatures chosen are:

Generator Temperature, T_g =64°C

The generator temperature are generally choice for the calculations are the highest temperature that can be achieved in the generator.

Condenser Temperature, T_c= 30°C

The temperature which is lowest in the condenser is theoretically chosen for the calculations.

Absorber Temperature, T_a =20°C

Evaporator Temperature, T_e =4°C

The temperature which is lowest in the condenser is theoretically chosen for the calculations.

VII .OPERATING PRESSURES

The temperature is directly proportional to the pressure, that is the reason for the operating pressures to correspond to the temperatures of the system. Taking a theoretical example for the system, the saturation pressure for condensation in the Condenser at 300°C can be obtained from steam tables and is equal to 0.0425bar. Also 1bar = 750.06mm of Hg. Therefore 0.0425bar= 32mm of Hg which is also equal to Generator pressure because Condenser and Generator operate at same pressure. Now the saturation pressure for saturated vapors formed in the Evaporator at a temperature of 40°C can again be obtained from steam table which comes to be 0.0081bar or 6.1mm of Hg which will also be equal to the Absorber pressure as both operate under same pressure.

Capacity of the system or Refrigerating Effect (Q_e) = 3.788*kW* (Theoretical value)

VIII. CALCULATION OF ENTHALPY (H) AT EVERY DESIGNATED POINT OF THE SYSTEM

Enthalpy of pure water and of superheated water vapors at any temperature can be determined from steam tables. The values of the steam table can be tabulated in the following manner and can be used for calculation:

Table - Ammonia Water Value tabulates from the Theoretical values

No.	h_{sp} kJ/kg	$\dot{m}$ kg/s	p kPa	Q Fraction	T °C	x, Fraction NH3
1	-57.2	10.65	515.0	0.0	40.56	0.50094
2	-56.0	10.65	1461		40.84	0.50094
3	89.6	10.65	1461		72.81	0.50094
4	195.1	9.09	1461	0.006	55.55	0.41612
5	24.6	9.09	1461		57.52	0.41612
6	24.6	9.09	515.0	0.006	55.55	0.41612
7	1349	1.55	1461	1.000	55.00	0.99809
8	178.3	1.55	1461	0.0	37.82	0.99809
9	82.1	1.55	1461		17.80	0.99809
10	82.1	1.55	515.0	0.049	5.06	0.99809
11	1216	1.55	515.0	0.953	6.00	0.99809
12	1313	1.55	515.0	1.000	30.57	0.99809
13	1429	1.59	1461	1.000	79.15	0.98708
14	120.4	0.04	1461	0.0	79.15	0.50094

IX. OBTAINING HEAT TRANSFERS FOR EACH COMPONENT

Evaporator

Applying the Energy balance
Qe = Refrigerating effect =3.788kW = m (h_{10} - h_9)
= m×(2508.70 -125.70)
m=3.788/ (2508.70- 125.70)
or m = 1.58×10-3 kg/s = mass flow rate of refrigerant.
Now, Circulation Ratio, λ=ξWS/ (ξSS- ξWS)
λ=0.48/(0.56-0.48) = 6
therefore, mSS= λ×m=13.22×10-3kg/s
and mws=(1+ λ)m=(1+6) ×2.203×10-3 =15.42×10-3 kg/s

Absorber

Applying the Energy balance

$Qa=mh_{10}+mssh_6-mwsh_1$

$= (2.203\times10\text{-}3 \times2508.70) + (13.22\times10\text{-}3\times -195)$

$(15.42\times10\text{-}3\times\text{-}180)$

$=5724W=5.724kW$

Solution Heat Exchanger (HX)

Writing the Energy balance for Heat Exchanger,

$mws\times(h_3\times\text{-}h_2)=mss\times(h_4\text{-}h_5)$

$=15.42\times(h3+180)=13.22\times(-120+195)$

$h_3=-115.70$ kJ / kg

Generator

$Q_G=mh_7+mssh_4 -mwsh_3$

$= (2.203\times10^{-3}\times2621.32) + (13.22\times10^{-3}\times-120)-(15.42\times10^{-3}\times-115.70)$

$=6330W=6.33kW$

Condenser

$Qc=m (h_7\text{-}h_8)$

$=2.203\times10\text{-}3\times (2616.50\text{-}125.70)$

$=5487W=5.487kW$

COP $= Q_E/ Q_G$

$=3788/6330$

$=0.598$

X. RESULT

In this paper, we have devised a proper method for the calculation of the COP of the system. The method is based on simple analytical data which relate the thermodynamic variables of the fluid couple of Ammonia and Water. Detailed analytical procedure for the calculation of the COP have been carried out in the above sections and the COP of the vapor absorption system have been found to be approximately equal to 0.598, keeping all the factors in mind.

XI. CONCLUSION

COP of the system is greatly influenced upon the system temperatures. The effect of parameters like Condenser, Generator, Absorber and Evaporator temperature on system COP have been studied. Particularly, the model is based on a number of fundamental assumptions. These are used to enable a closed system of equations and maintaining enough simplicity to be able to extend the program for an analysis of a more complicated system. The results have shown that all these four parameters greatly influence the system COP.

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