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Thermodynamic Analysis of Single-Effect Lithium Bromide–Water Vapour Absorption Refrigeraion System

B.Raja Narender [1],V.Srikanth [2]Raju Vemula[3]
[1 2 3] Department of Mechanical Engineering
Anurag Group of Institutions, CVSR college of Engineering, Venkatapur, R.R.Dist.
Telangana, India

Abstract:- The objective of paper analytical study of absorption refrigeration technology. The application of the first and second laws of thermodynamics upper and lower limits for the coefficient of performance (COP) of absorption cooling cycles are derived. These upper and lower limits, besides being dependent on the environmental temperatures of components of the cycle and also dependent on properties of refrigerants, absorbents, and their mixtures. The objective of this paper for calculation of single effect lithium bromide-water vapour absorption refrigerator with capacity of 7kW. The various stages of refrigeration system are presented including the design of the evaporator, absorber, solution heat exchanger, generator and condenser and finally Coefficient of Performance is calculated.

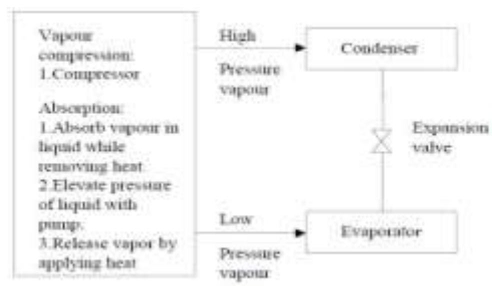
***Keywords:-* Refrigeration, Absorption, heat pump, Coefficient of Performance(COP).**

I. INTRODUCTION

In view of shortage of energy production and fast increasing energy consumption, there is a need to minimize the overall energy consumption. In Thermal analysis of vapour absorption refrigeration system [1] how to increase coefficient of performance.

The most popular refrigeration and air conditioning systems are based on the vapour absorption systems[2]. These type of systems are reliable, relatively inexpensive. These systems require high grade energy(mechanical or electrical) for its operation. The recent discovery that the conventional working fluid of vapour absorption systems are causing the ozone layer depletion and green house effects has forced the scientific researchers to look for alternative systems for cooling applications. Naturally alternate source of the absorption system, which uses heat energy for its operation. These type of working fluids are environment friendly[3].

The properties of refrigerant and absorbent and their mixtures effecting on coefficient of performance of the system. The most important thermo-physical properties are: heat of vaporization of refrigerant, heat of solution, vapour pressure of refrigerant and absorbent, solubility of refrigerant in solvent, heat capacity of solution, surface tension, viscosity of solution and thermal conductivity of the solution. Other selection criteria for the working fluid are their chemical stability, toxicity, and corrosivity. Vapour absorption refrigeration system accomplish the removal of heat through the evaporation of a refrigerant at a low pressure and the rejection of heat through the condensation of the refrigerant at higher pressure[4].



Components of a Vapour Absorption Cooling System[5]

A simple vapour absorption system consists of an absorber, pump, generator and a pressure reducing valve to replace the compressor of vapour compression system. Another components of simple vapour absorption system are condenser, receiver, expansion valve and evaporator in the vapour compression system.

Generator: Distillation of the vapour from the rich solution leaving the poor solution for recycling.

Condenser:

It is an important device used at high pressure side of the vapour absorption system. The primary purpose of condenser is to eliminate heat of the hot vapour refrigerant discharged from the compressor. Later heat is removed by Transforming it to the walls of the condenser tube the tubes are cooled through a cooling medium. This medium may be air or water.

Expansion Valve:. The throttling devise can be the valve or the copper tubing that allows the flow of the refrigerant through very small opening also called as the orifice. The throttling devices allow restricted flow of the refrigerant. The throttling devices are also called as the expansion valves because when the refrigerant passes through them the pressure of the refrigerant drops down or it expands..When the refrigerant passes through the orifice its pressure reduces due to friction and also the small opening of the orifice. The amount of the refrigerant flowing through the throttling valve depends on the amount of opening of the orifice. It also depends on the difference of pressure across two sides of the throttling devise that condenser and the evaporator.

Evaporator: In evaporator the liquid refrigerant enters and boils to change its phase to vapour .The temperature of the boiling refrigerant in the evaporator will be less compared to the surrounding medium.

Absorber: The main function of an absorber in a simple vapour absorption system is to absorb the refrigerant and form it into a strong solution. In vapour absorption refrigeration system, the low pressure in the absorber, which contains absorbent. Due to its presense, the low pressure refrigerant is then changed into a strong hot solution. This strong solution of low pressure from the absorber is again pumped in to the generator.

Refrigerant-Absorbent combinations for Vapour Absorption Cooling Systems:

Absorption machines are commercially available today in two basic configurations. For applications above 5^0C (primarily air-conditioning) the cycle uses lithium bromide/water. For applications below 5^0C, ammonia/water cycle is employed with ammonia as the refrigerant and water as the absorbent.

Desirable Properties of Refrigerant-Absorbent mixtures:

- Refrigerant should be more volatile comparing with absorbent.
- Boiling point of refrigerant should be much lower than absorbent
- Refrigerant should exhibit high solubility with solution in the absorber.
- The refrigerant should have high heat vaporization
- The mixture should be non corrosive, chemical stable, inexpensive, safe and should be available easy.
- Absorbent should not under go solidification or crystallization inside the system.[6], [7].

Refrigerant-Absorbent pairs: The two most commonly used refrigerant-absorbent pairs in commercial systems are[7]:

Water-Lithium Bromide (H_2O-LiBr) system for moderate temperatures (above 5^0C) applications specifically air conditioning and water chiller. Here water as refrigerant and solution of lithium bromide as absorbent

Ammonia-Water (NH_3-H_2O) system for low temperature(less than 5^0 C) refrigeration applications with ammonia as refrigerant and water as absorbent.The Lithium Bromide-Water pair satisfies majority of the above listed properties. For these reasons Li-Br and Water systems are becoming more popular.

Ammonia-water Systems:

NH_3-Water has been widely used in vapour absorption refrigeration system. NH_3(refrigerant) and water(absorbent) are highly stable for a wide range of operating temperature and pressure. NH_3 has a high latent heat of vaporization, which is very useful for efficient of performance of the system. This can be used for low temperature applications, as the freezing point of NH_3 is -77^0C.But since both NH_3 and water are volatile, the cycle requires a rectifier , the water would accumulate in the evaporator and offset the system performance. Disadvantages of systems, its high pressure, toxicity, and corrosive action to copper and copper alloy. Ammonia /Air mixtures are inflammable and also may be explosive in the case of high percentages of ammonia between 15.5 and 27% by volume[8].

LiBr-Water Systems

LiBr-Water for absorption refrigeration system invented in 1930. Advantages of Li-Br-Water are non-volatility absorbent of LiBr and extremely high heat of vaporization of water(refrigerant).This type of system is using water as a refrigerant limits the low temperature application application to that above 0^0 C. Water is the refrigerant, The system must be operated under vaccum conditions. At high concentrations, The solution is prone to crystallization. One way to prevent this to add one or more extra salts e.g.ZnBr2, ZnCls. The addition of the third component into the basic water-lithium bromide solution pushes the crystallization limit away from the normal operating zone. Hence the strong solution can be cooled in the heat exchanger to near absorber temperature without salt crystallization, thus improving the performance of the system.[9],[10].

II.THERMODYNAMIC ANALYSIS OF SYSTEM

Thermodynamic analysis of the Vapour Absorption Refrigeration system involves determine important parameters like enthalpy, mass flow rates, flow ratio, Heat and Mass Transfers and finally calculate the system Coefficient of Performance (COP). These parameters are taken for design of the system. First select set of 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 calculate the COP value for the system [11], [12].Thermodynamic analysis of the system were made with the following assumptions:

A. Steady state and steady flow

B. No pressure drops due to friction

C. Only pure refrigerant boils in the generator.

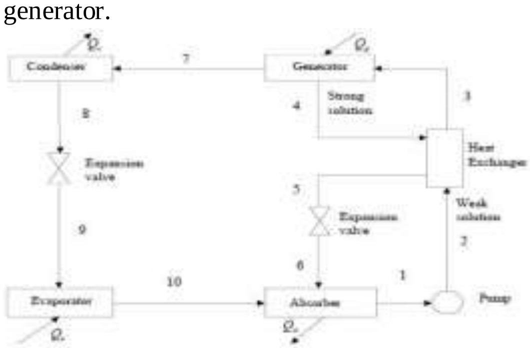


Fig.2 Block diagram of Vapor Absorption Refrigeration System**.**

Let m = mass flow rate of refrigerant, kg/s m_{ss} = mass flow rate of strong solution, kg/s m_{ws} = mass flow rate of weak solution, kg/s

Heat (Q) **and Mass** (m) **balance for each component[]**:

Condenser

$m_7=m_8=m$

$Qc = m(h_7-h_8)$

Expansion

$m_8 = m_9 = m$

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

Evoparator

$m_8 = m_9 = m$

$Qe = m (h9-h8)$kJ/kg

Absorber

From total Mass balance $m+m_{ss}=m_{ws}$

Now **Circulation Ratio**,

$\lambda=m_{ss}/m$

Therefore, $m_{ws}=(1+\lambda)m$

From Mass balance of pure water

$m+(1+\xi_{ss})m_{ss}=(1+\xi_{ws})m$

$_{ws}$ Solving for λ we get,

$\lambda= \xi_{ws}/ (\xi_{ss}- \xi_{ws})$

and

$Q_a=mh_{10}+\lambda mh_6 -(1+\lambda)mh_1$, KJ/s

Solution Pump

$m_1=m_2=m_{ws}$

$w_p=(1+\lambda)mV_{sol}(p_c-p_E)$ kJ/s

where V_{sol} . is specific volume of solution which can be taken as approx. 0.00055 m^3/kg.

Solution Heat Exchanger

$m_2=m_3=m_{ws}$

$m_4=m_5=m_{ss}$

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

Coefficient of Performance (COP):

In this system the net refrigerating effect is the heat absorbed by the refrigerant in the evaporator. The total energy supplied to the system is the sum of work done by the pump and the heat supplied in the generator. Therefore, the Coefficient of performance (COP) of the system 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

$COP=Q_e/Q_g$

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

III. MATHEMATICAL CALCULATIONS FOR EACH COMPONENT

Operating temperatures

The most favorable working temperature for single effect lithium-bromide and water refrigeration system (for a COP value between 0.7 and 0.9) are

Generator Temperature T_g = 55-90^0 C

Condenser Temperature T_c = 24- 46^0 C

Absorber Temperature T_a =16-32^0 C

Evaporator Temperature T_e = 2.5-10^{0}C

The operating temperatures chosen are

Generator Temperature T_g = 68 ^{0}C

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Condenser Temperature T_c = 34^0C
Absorber Temperature T_a = 24^0C
Evaporator Temperature T_e = 6^0 C

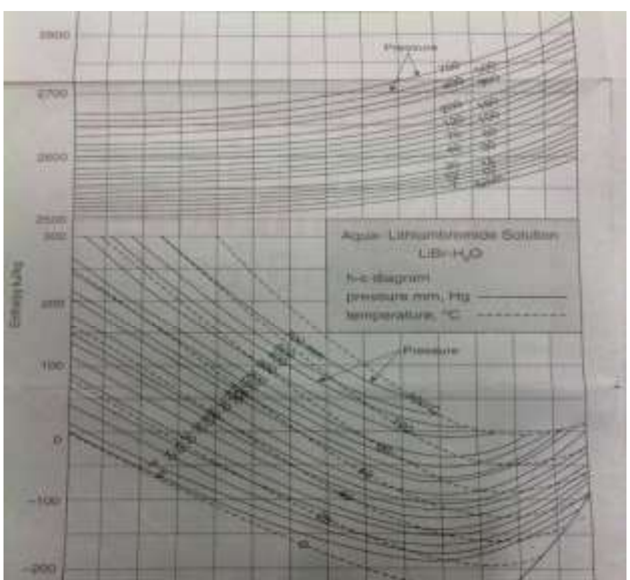
Operating Pressures

The operating Pressures can be known corresponding to the temperatures. Say for example the saturation pressure for condensation in the condenser at 34^0 C can be obtained from steam tables and is equal to 0.05318 . Also 1 bar = 750.06mm of Hg. Therefore 0.5318 = 40 mm of Hg which is also equal to Generator pressure because condenser and Generator operate at same pressure. Now the saturation pressure for saturated vapour formed in Evaporator at a temperature of 40^0c can again be obtained from steam table which comes to be 0.00935 or7 mm of Hg which will also be equal to the Absorber pressure as both operate under same pressure.

Capacity of the system or Refrigerating Effect (Qe) = 2 ton = 7 kW

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. Enthalpies of solutions are calculated from LiBr-Water Pressure-Temperature-Concentration-Enthalpy(P-T-ξ-h) Chart.



LiBr-Water Pressure-Temperature-Concentration-Enthalpy Chart.

The results obtained from chart:
Li-Br-Water Enthalpy-Pressure-Temperature-Concentration

Table-I

State points	Temp 0^0 C	Pressure in mm of Hg	Enthalpy h kj/kg	Concentration ξ
1	24	7	-180	0.47
2	24	40	-180	0.47
3	40	40	-163.96	0.47
4	68	40	-160	0.59
5	24	40	-180	0.59
6	24	7	-180	0.59
7	68	40	2623.5	-
8	34	40	142.4	-
9	34	7	142.4	-
10	6	7	2512.6	-

Obtaining Heat transfers for each component:

Evaporator: Applying the Energy balance
$Qe = Refrigerating\ effect = 7kW = m(h_{10} - h_9)$
$= m\ (2512.2 - 142.4)$
or $m = 2.95\times10^{-3}$ kg/s = mass flow rate of refrigerant.
Now, Circulation Ratio ,
$\lambda=\xi_{WS}/(\xi_{SS}-\xi_{WS})$
$\lambda=0.47/(0.59-0.47) = 3.91$

therefore, $m_{SS}= \lambda\times m=0.0155kg/s$

and $m_{ws}=(1+ \lambda)m=(1+3.91)\times2.95\times10^{-3} = 0.0144\ kg/s$

Absorber: Applying the Energy balance

$Qa=mh_{10}+m_{ss}h_6-m_{ws}h_1$

$=(2.95\times10^{-3} \times2512.6)+(0.01155\times-180)-(0.0144\times-180)$

$=7923=7.923kW$

Energy balance for **Heat Exchanger,**
$m_{ws}\times(h_3\times-h_2)=m_{ss}\times(h_4-h_5)$

$0.0144\times(h_3+180)=0.0155\times(-120+180)$

$h_3=-163.96\ kJ / kg$

Generator

$Q_G=mh_7+m_{ss}h_4 -m_{ws}h_3$

$=(2.295\times10^{-3}\times2623.5)+(0.0155 \times-160)-(0.0144\times-163.96)$

$=8243=8.243kW$

Condenser

$Q_c=m(h_7-h_8)$

$= 2.295\times10^{-3}(26.23.5-142.4)$
$=7319W=7.319kW$

COP = Q_E/ Q_G
$=7000/8243$
$=0.847$

IV. RESULT

In this paper, we have implemented a method of calculation that is based on simple analytical data which relate the thermodynamic variable of the H_2O-LiBr fluid couple. analytical procedure can be done for the system and also calculation of the COP for the design is given and the COP of the system for the different parameters is calculated to be 0.849. The results have shown in table-II. From the results when generator temperature increases, COP decreases. The following parameters are affecting on performance of the system.

Table-II

S.No	Component	Heat Transfer rate	Value(kw)
1	Evaporator	Q_E	7.0
2	Absorber	Q_A	7.92
3	Generator	Q_G	8.24
4	Condenser	Q_C	7.31

V.CONCLUSION

COP of the system is depending upon the system temperatures. The effect of parameters are Condenser, Generator, Absorber and Evaporator. These parameter temperatures are effect on system COP have been studied. The results are shown in table-II. all these four parameters mostly influence the Vapour absorption Refrigeration system COP.

VI. FUTURE WORK

Varying any one parameter can be done and to improve an overall improvement in the system COP ,or material saving or more simple design procedure. Any other parameters effect can be analyzed on performance of system.

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