Thermodynamic Analysis of Lithium Bromide-Water($LiBr-H_2O$) Vapor Absorption Refrigeration System Based on Solar Energy

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Abstract- *The continuous and rapid development of countries ran in a monumental increase in the demand of energy utilization. For this entailment of renewable energy, such as solar energy for an eco-friendly process of refrigeration by Vapor Absorption process is looked to be a blessing in present scenario. Putting back the electrical energy with solar energy will shorten the use of high grade electrical energy. Solar energy based refrigeration system is one of the best assuring technology to fulfill the boosting demand for refrigeration purpose. A solar dr-ivan Lithium-Bromide absorption cooling system was studied. It was an intermittent system in which water used as a refrigerant and Li-br used as a absorber. This paper provides an analytical approach to the study of the vapor absorption refrigeration system. By the application of first and second Law of thermodynamics with Mass and energy balance equation. The main aim of this work is to study of Lithium Bromide- Water ($LiBr-H_2O$) absorption System with the Capacity of 1.5 ton. The various components of VARS system Absorber, Heat-exchanger, Generator, Condenser, Expansion Valve and Evaporator. the COP of the system is calculated on the basis of hot water as a heat source. The basic idea of this work is taken from solar water heating system.*

Key Words- Vapor absorption system, Refrigerants, Coefficient of performance(COP),Solar heating, Environments.

1.INTRODUCTION

In 1858 a French scientist named Ferdinand Carré invented an absorption cooling system using water and sulphuric acid. In 1922 Baltzar Platen and Carl Munters, improved the system in principle with a 3-fluid configuration. This "Platen-Munters" design was capable of operating without a pump.

During 1926-1933 Einstein and Szilárd joined hands to improve the technology in the area of domestic refrigeration. The two were inspired by newspaper reports of the death of a Berlin family due to seal failure,which caused a leakage of toxic fumes into their home. Einstein and Szilárd proposed a device without moving parts that would eliminate the potential for seal failure, and worked on its practical applications for various refrigeration cycles. The two in due course were granted 45 patents in their names for three different models.

The main technical problem of solar refrigeration is that the system is highly dependent upon environmental factors such as cooling water temperature, air temperature, solar radiation, wind speed and others. On the other hand, its energy conversion efficiency is low, and from an economical point of view, solar cooling and refrigeration are not competitive with the conventional systems. At the same time by use of solar energy we can reduce the load of conventional fuels ,which are directly responsible for environmental pollution. Solar cooling eliminates the use of refrigerants like CFC, HFC highly hazardous for Ozone.

In recent developments of thermal engineering the Refrigeration technologies play an important role in today's industrial applications [1].

But as far as COP of these refrigeration systems is concerned, it is always a challenge to the researchers to significantly increase the COP for these systems. The most popular refrigeration and air conditioning systems at present are those based on the vapor absorption systems. These systems are popular because they are reliable, relatively inexpensive and their technology is well established. However, these systems require high grade energy (mechanical or electrical) for their operation. Apart from this, the recent discovery that the conventional working fluids of vapor absorption systems are causing the ozone layer depletion and greenhouse effects has forced the scientific researchers to look for alternative systems for cooling applications. The natural alternative is of course the absorption system, which mainly uses heat energy for its operation. Moreover, the working fluids of these systems are environment friendly [2].

A suitable working fluid is probably the single most important factor in any refrigeration system. The cycle efficiency and Operating characteristics of an absorption refrigeration system depend on the properties of refrigerant, absorbent and their mixtures. The most important thermo-physical properties are heat of vaporization of refrigerant, heat of solution, vapor pressure of refrigerant and absorbent, solubility of refrigerant insolvent, heat capacity of solution, viscosity of solution and surface tension and thermal conductivity of the solution. Apart from this, the other selection criteria for the working fluids are their toxicity, chemical stability and corrosively. Vapor Absorption Refrigeration Systems belong to the class of vapor cycles similar to vapor absorption refrigeration systems. However, unlike vapor absorption refrigeration systems, the required input to absorption systems is in the form of heat. Hence, these systems also called as heat operated or thermal energy driven systems. Both vapor absorption and absorption refrigeration cycles 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 a higher pressure. The basic difference is that a vapor absorption system employs a mechanical compressor to create the pressure differences necessary to circulate the refrigerant whereas an absorption system uses heat source and the differences cause an absorption system to use little to no work input, but energy must be supplied in the form of heat. This makes the system very attractive when there is a cheap source of heat, such as solar heat or waste heat from electricity or heat generation [3].

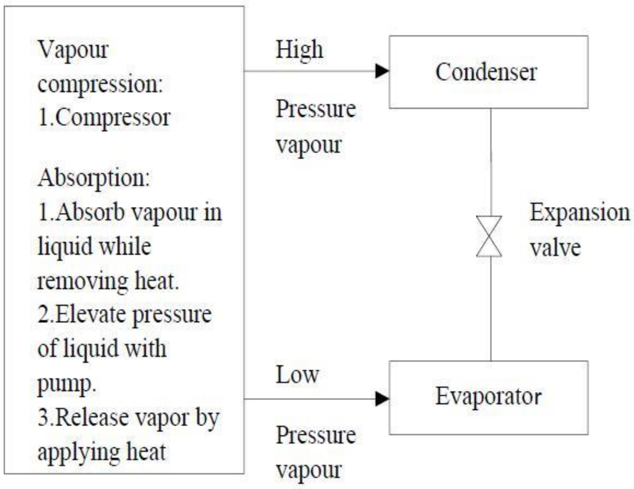

Fig-1. Method of transforming low pressure vapor into high pressure vapor in a refrigeration system.

Vapor Absorption Systems offer many advantages like it offers flexibility to utilize any sort of low grade, low cost heat energy available to produce cooling and thus giving a high savings in operating costs. It can operate on steam or any other waste heat source as the energy source instead of costly and unreliable electric power. No moving parts ensure noiseless, vibration-less and trouble free operation. Moreover maintenance costs are negligible as compared to power driven mechanical systems. Refrigerating effect is produced using a clean refrigerant in place of ozone-depleting chlorine based compounds[2].

2. PRINCIPLE OF ABSORPTION SYSTEM

The working fluid in an absorption refrigeration system is a binary solution consisting of refrigerant and absorbent. In Fig. 2(a), two evacuated vessels are connected to each other. The left vessel contains liquid refrigerant while the right vessel contains a binary solution of absorbent/refrigerant. The solution in the right vessel will absorb refrigerant vapor from the left vessel causing pressure to reduce. While the refrigerant vapor is being absorbed, the temperature of the remaining refrigerant will reduce as a result of its vaporization. This causes a refrigeration effect to occur inside the left vessel. At the same time, solution inside the right vessel becomes more dilute because of the higher content of refrigerant absorbed. This is called the "absorption process". Normally, the absorption process is an exothermic process, therefore, it must reject heat out to the surrounding in order to maintain its absorption capability. Whenever the solution cannot continue with the absorption process because of saturation of the refrigerant, the refrigerant must be separated out from the diluted solution. Heat is normally the key for this separation process. It is applied to the right vessel in order to dry the refrigerant from the solution as shown in Fig. 2(b). The refrigerant vapor will be condensed by transferring heat to the surroundings. With these processes, the refrigeration effect can be produced by using heat energy.

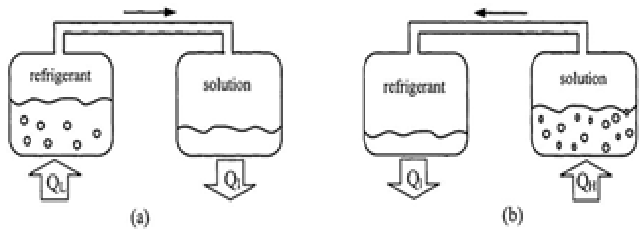

Fig.-2(a) Absorption process occurs in right vessel causing cooling effect in the other;

Fig-2(b) The Refrigerant separation process occurs in the right vessel as a result of additional heat from outside heat source.

3. Components of a Vapor Absorption Cooling System

The components of Vapor Absorption Refrigeration Cooling System are as[4].

Generator: The purpose of the generator is to deliver the refrigerant vapor to the rest of the system. It accomplishes this by separating refrigerant from the solution. In then generator, the solution vertically falls over horizontal tubes with high temperature energy source typically steam or hot water flowing through the tubes. The solution absorbs heat from the warmer steam or water, causing the refrigerant to boil (vaporize) and separate from the absorbent solution. As the refrigerant is boiled away, the absorbent solution becomes more concentrated. The concentrated absorbent solution returns to the absorber and the refrigerant vapor migrates to the condenser.

Condenser: The purpose of the condenser is to condense the refrigerant vapors. Inside the condenser, cooling water flows through tubes and the hot refrigerant vapor fills the surrounding space. As heat transfers from the refrigerant vapor to the water, refrigerant condenses on the tube surfaces. The condensed liquid refrigerant collects in the bottom of the condenser before travelling to the expansion device. The cooling water system is connected to a cooling tower.

Expansion Valve: From the condenser, the liquid refrigerant flows through an expansion device into the evaporator. The expansion device is used to maintain the pressure difference between the high-pressure (condenser) and low-pressure (evaporator) sides of the refrigeration system. As the high-pressure liquid refrigerant flows through the expansion device, it causes a pressure drop that reduces the refrigerant pressure to that of the evaporator. This pressure reduction causes a small portion of the liquid refrigerant to boil off, cooling the remaining refrigerant to the desired evaporator temperature. The cooled mixture of liquid and vapor refrigerant then flows into the evaporator.

Evaporator: The purpose of evaporator is to cool the circulating water. The evaporator contains a bundle of tubes that carry the system water to be cooled/chilled. At low pressure existing in the evaporator, the refrigerant absorbs heat from the circulating water and evaporates. The refrigerant vapors thus formed tend to increase the pressure in the vessel. This will in turn increase the boiling temperature and the desired cooling effect will not be obtained. So, it is necessary to remove the refrigerant vapors from the vessel into the lower pressure absorber. Physically, the evaporator and absorber are contained inside the same shell, allowing refrigerant vapors generated in the evaporator to migrate continuously to the absorber.

Absorber: Inside the absorber, the refrigerant vapor is absorbed by the solution. As the refrigerant vapor is absorbed, it condenses from a vapor to a liquid, releasing the heat it acquired in the evaporator. The heat released from the condensation of refrigerant vapors by their absorption in the solution is removed by the cooling water circulating through the absorber tube bundle. The weak absorbent solution is then pumped to the generator where heat is used to drive off the refrigerant. The hot refrigerant vapors created in the generator migrate to the condenser. The cooling tower water circulating through the condenser turns the refrigerant vapors to a liquid state and picks up the heat of condensation, which it rejects to the cooling tower. The liquid refrigerant returns to the evaporator and completes the cycle.

3. Refrigerent-Absorbent combinations for Vapor Absorption Cooling Systems

Absorption machines are commercially available today in two basic configurations. For applications above 50^0C (primarily air-conditioning) the cycle uses lithium bromide/water.

For applications below 50^0C ammonia/water cycle is employed with ammonia as the refrigerant and water as the absorbent.

4.Desirable Properties of Refrigerant-Absorbent mixtures

Refrigerant-absorbent mixtures for Vapor Absorption Cooling System should possess some desirable properties like the refrigerant should be more volatile than the absorbent in other words the boiling point of refrigerant should be much lower than the absorbent. There must be large difference in the boiling points of refrigerant and absorbent (greater than 2000 ^{0}C), so that the solution in the Generator need only to be heated to the temperature required to boil off only the refrigerant. This ensures that only pure refrigerant circulates through refrigerant circuit (condenser-expansion valve-evaporator). The refrigerant should exhibit high solubility with solution in the absorber. The absorbent should have strong affinity for the refrigerant. This will minimize the amount of refrigerant to be circulated. Operating pressures should be preferably low, so that the walls of the shells and connecting pipes need not to be thick. It should not undergo crystallization or solidification inside the system. Because crystallization will block the free flow of solution in the line. The mixture should be safe, chemically stable, non-corrosive, inexpensive and should be available easily. The refrigerant should have high heat of vaporization[5], [6].

5. Refrigerant-Absorbent pairs

The two most commonly used refrigerant-absorbent pairs in commercial systems are[6]:

5.1. Water-Lithium Bromide (H_2O-LiBr) system for moderate temperatures (above 50^0C) applications specifically air conditioning. Here water is the refrigerant and lithium bromide is the absorbent.

5.2. Ammonia-Water (NH_3-H_2O) system for low temperature(less than 50^0C) 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. Comparison of Lithium Bromide-Water systems and Ammonia-Water Systems

6. Ammonia-Water Systems

Since the invention of absorption refrigeration system, NH_3-Water has been widely used. Both 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 necessary for efficient performance of the system. It can be used for low temperature applications, as the freezing point of NH_3 is -77°C. But since both NH_3 and *water* are volatile, the cycle requires a rectifier to strip away water that normally evaporates with NH_3 .Without a rectifier, the water would accumulate in the evaporator and offset the system performance. There are other disadvantages such as its high pressure, toxicity, and corrosive action to copper and copper alloy. Ammonia/Air mixtures are barely inflammable but may be explosive in the case of high percentages of ammonia between 15.5 and 27 % by volume[7].

7.LiBr-Water Systems

The use of LiBr-Water for absorption refrigeration systems began around 1930. Two outstanding features of LiBr-Water are non-volatility absorbent of LiBr (the need of a rectifier is eliminated) and extremely high heat of vaporization of water (refrigerant). However, using water as a refrigerant limits the low temperature application to that above 0°C. As water is the refrigerant, the system must be operated under vacuum conditions. At high concentrations, the solution is prone to crystallization. One way to prevent this to happen is to add one or more extra salts e.g., ZnBr2, ZnCl2 .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. COP is high (0.7 to 0.9) as compared to (0.5 to 0.6) for Ammonia-Water systems[8],[9].

8.MATHEMATICAL ANALYSIS OF THE SYSTEM

Thermodynamic analysis of the system involves finding important parameters like enthalpy, mass flow rates, flow ratio, Heat and Mass Transfers for the whole system to finally calculate the system Coefficient of Performance (COP). These values are to be then used for design of the system. First some 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 obtain the COP value for the system [10], [11].Thermodynamic analysis of the system is carried out 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.

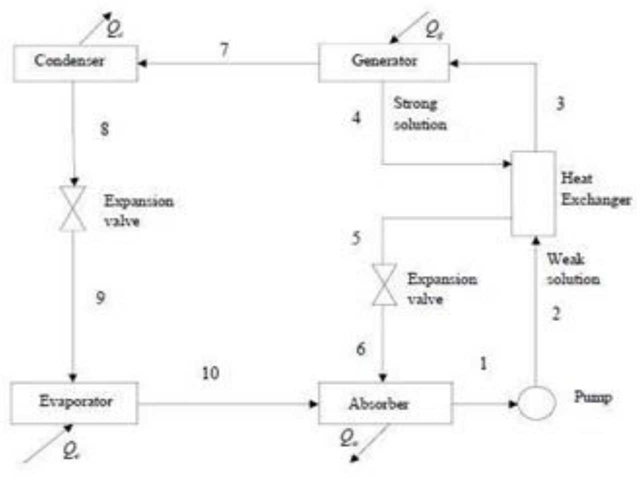

Fig.3 Block diagram of Vapor Absorption Refrigeration System**.**

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/

Heat (Q) and Mass (m) balance for each component
For Condenser

$m_7 = m_8 = m$
$Q_c = m(h_7 - h_8)$, kJ/s

For Expansion Valve

$m_8 = m_9 = m$
$h_8 = h_9$(isenthalpic), kJ / kg

For Evaporator

$m_9 = m_8 = m$
$Q_e = m(h_9 - h_8)$, kJ/s

For 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 for 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.

For 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

For 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-

$$COP = \frac{\text{Heat Absorbed in the Evaporator}}{(\text{Work done by pump} + \text{Heat Supplied in the Generator})}$$

$$COP = Q_e/(Q_g+W_p)$$

Neglecting the Pump work

$$COP=Q_e/Q_g$$

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

9.MATHEMATICAL CALCULATIONS FOR EACH COMPONENT

9.1 The operating temperatures chosen in °C

Generator Temperature, Tg =60°C

Condenser Temperature, Tc = 28°C

Absorber Temperature, Ta =21°C

Evaporator Temperature, Te =5°C

9.2 The Operating Pressures in mm of Hg

The operating Pressures can be known corresponding to the temperatures. Say for example the saturation pressure for condensation in the Condenser at 28°C can be obtained from steam tables and is equal to 0.03779bar. Also 1bar = 750.06mm of Hg.

Therefore 0.03779bar= 28.50mm 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 Evaporator at a temperature of 5°C can again be obtained from steam table which comes to be 0.00872bar or 6.54mm of Hg which will also be equal to the Absorber pressure as both operate under same pressure.

9.3 Capacity of the system or Refrigerating Effect

$$(Q_e) = 1.5\text{ton} = 5.25\text{kW}$$

9.4 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 Lithium bromide (LiBr) and Water Pressure-Temperature-Concentration-Enthalpy(P-T-ξ-h) Chart.

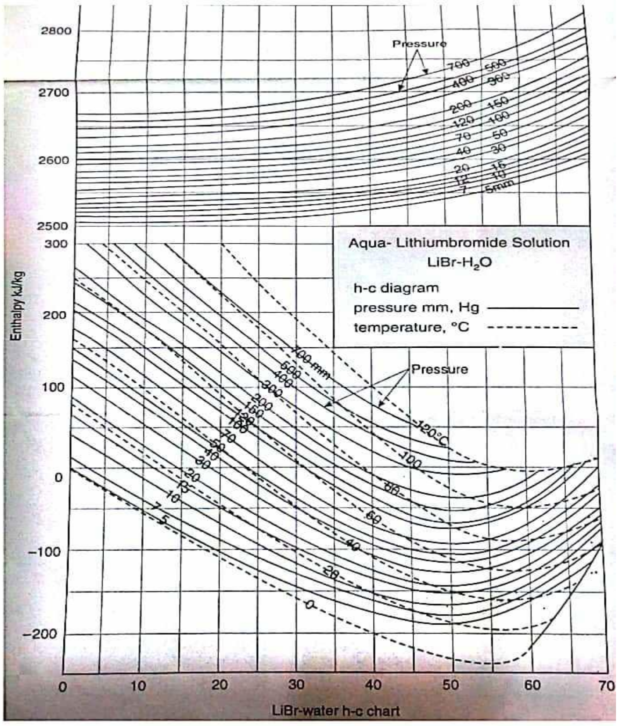

Fig.4-LiBr-H_2O Pressure-Temperature Concentration-Enthalpy Chart

Table I: Li-Br-Water Enthalpy-Pressure-Temperature-Concentration

State Points	Temp.in °C	Pressure in mm of Hg	Enthalpy *h* ,Kj/kg	Concentration ξ
7	60	28.50	2609.65	-
8	28	28.50	117.30	-
9	28	6.54	117.30	-
10	5.0	6.54	2509.96	-
1	21	6.54	-170.0	0.48
2	21	28.50	-170.0	0.48
3	52.25	28.50	-110.004	0.48
4	60	28.50	-108.0	0.56
5	21	28.50	-178.0	0.56
6	21	6.54	-178.0	0.56

9.5 Calculation of Heat transfers for each component

Evaporator:-Applying the Energy balance

Qe = Refrigerating effect = 5.25kW = $m(h_{10} - h_9)$

$= m \times (2509.96 - 117.30)$

$m = 5.25/(2509.96 - 117.30)$

or

$m = 2.19421\times10^{-3}$ kg/s = mass flow rate of refrigerant.

Now,

Circulation Ratio

$\lambda = \xi_{WS}/(\xi_{SS} - \xi_{WS})$

$\lambda = 0.48/(0.56-0.48)$

$= 6$

therefore, $m_{ss.} = \lambda \times m = 13.1652 \times 10^{-3}$kg/s

and

$m_{ws} = (1+\lambda)m = (1+6) \times 2.1942 \times 10^{-3} = 15.3594 \times 10^{-3}$ kg/s

Absorber: Applying the Energy balance

$$Qa = mh_{10} + m_{ss}h_6 - m_{ws}h_1$$
$$= (2.19421\times10^{-3} \times 2509.96) + (13.1652\times10^{-3} \times -178) - (15.354\times10^{-3} \times -170)$$
$$= 577435W = 5.7743 \text{ KW}$$

Solution Heat Exchanger (H_X) Energy balance for Heat Exchanger,

$$m_{ws}\times(h_3\times - h_2) = m_{ss}\times(h_4 - h_5)$$

$$= 15.3594\times10^{-3}\times (h_3 + -170) = 13.16526\times10^{-3} \times (-108+178)$$

$$h_3 = 110.0041 \text{ KJ/kg}$$

Generator

$$Q_G = mh_7 + m_{ss}h_4 - m_{ws}h_3$$
$$= (2.19421\times10^{-3} \times 2609.655) + (13.1652\times10^{-3} \times -108) - (15.3594\times10^{-3} \times -110.0041)$$

$$= 59938W = 5.993KW$$

Condenser

$$Q_c = m(h_7 - h_8)$$
$$= 2.19421\times10^{-3} \times (2609.655-117.30)$$
$$= 54687W = 5.4687kW$$

Thus,

COP $= Q_E / Q_G$

$= 5250/5993$

$= 0.876$

COP = 0.876

9.6 Calculation of solar Collector

Useful energy (energy absorbed by the collector plate) is given by,

$$Q_u = K \times S \times A$$

Where,

K = efficiency of collector plate(assuming k=0.85)

S = average solar heat falling on earth's surface $= 6\text{kW/hr/m}^2\text{/day} = 250\text{W/m}^2$

A = area of collector plates

Now

Heat required in the generator,

$Q_g = 5993$Watt

Hence approximate area of the collector plates required for providing the above amount of energy

$= 5993/(250\text{x}K)$

$= 5993/(250\text{x}0.85)$

$= 28.20$Sq.m

Total area of collector plates A = 28.20Sq.m

Therefore we can use 5 collector plates having dimension of 3x2 Sq.m.

Thus,

$Q_u = 0.85\text{x } 250\text{x } 28.20 = 5993W = 5993$ J/Sec

The energy absorbed by the collector helps in heating of the water flowing in the tubes of the collector plates.

$U = m \times C_p\,(T_o - T_i)$

Let the rate of water flowing through the tubes,

m= 1.2Kg/min

= 0.02kg/s, (example)

Specific heat of water, $C_p = 4.187$ KJ/KgK

T_o =outlet temperature of water in the collector

T_i = inlet temperature of water in the collector plates

$= 21^0C$

Therefore,

$Q_u = 0.02 \times 4187 \times (T_o - 21) = 5993 = 92.^0C$

The temperature, T_o should be the inlet temperature of generator, but assuming water loses heat while flowing through the pipes. Also there is certain effectiveness of the generator as a heat exchanger, less than 100%. Hence net heating in the generator can be assumed to be taking place at 60^0C.

Temperature at generator = 60^0C

This is the net heat input to the system, which is running as a refrigeration unit of 5.25kW capacity.

COP of the system-

The COP of the unit can be calculated by the following equation:

COP = Refrigeration effect / heat input in generator

COP = Qe/ Qg

= 5250/59938

= 0.876

The COP of the system including Solar water heater

$$\frac{\text{Net refrigeration effect}}{\text{heat input at the solar collector}}$$

Heat input at the solar collector = Solar constant x Area

= $250 W/m^2 \times 28.20 m^2$

= 7050 W

COP = 5250 W/7050 W

= 0.7446

COP = 0.7446

Hence the theoretical COP of the system comes to be 0.7446

10 Results –

The Evaporator is a chamber that has to be maintain at the low temperature but the main objective of the study is not to attain very low value of evaporator temperature but to provide the desired cooling effect. the Condenser and Absorber are maintained to be at a temperature of 28^0C and 21^0C respectively. Generator at maintain at the temperature of 60^0C.

Table.2. Components Wise heat capacity of Different systems

S.No.	COMPONENT	HEAT TRANSFER RATE	VALUES
1	Evaporator	Q_E	5.250
2	Absorber	Q_A	5.774
3	Generator	Q_G	5.933
4	Condenser	Q_C	5.468

11. Conclusion-

A small capacity (1.5ton) intermittent vapor absorption refrigeration system using LiBr-H_2O solution was designed based on some thermodynamic correlations. By analytical calculation the COP was 0.876.it was ascertained that the solar collector efficiency, clearness of sky play a big role for overall efficiency. The study suggests that, with a accurate theoretical design and thermodynamics analysis there is a scope for improving the performance of vapor absorption refrigeration system applying low grade thermal energy source. COP of the system is greatly acted upon the system temperature. The heat input can be provided by solar collector. It brings into light that solar collector can not only be used for heating, it can also be used for cooling purpose.

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