Imperial Journal of Interdisciplinary Research (IJIR)
Vol-2, Issue-11, 2016
ISSN: 2454-1362, http://www.onlinejournal.in

Analytical Study of Ammonia –Water (NH3-H2O) Vapor Absorption Refrigeration System Based On Solar Energy

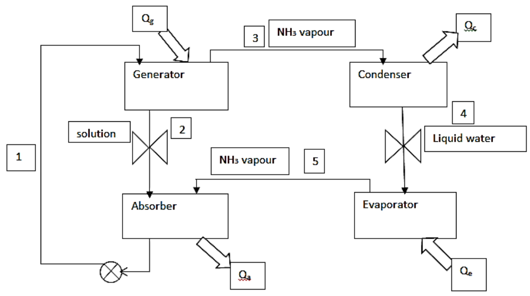
Rahul Yadav[1] & Mohini Sharma[2]
[1, 2] B.Tech (Energy Technology) +LLB Hons. With specialization in intellectual property right, University of Petroleum & Energy Studies, Dehradun, India

Abstract. *The continuous development of countries led in massive increase for the demand of energy utilization. For this implication of renewable energy, such as solar energy for an eco-friendly process of refrigeration by vapour absorption method is seemed to be a boon in the present scenario. Replacing the electrical energy with solar energy will reduce the consumption of high grade electrical energy. Also the replacement of compression system with absorption system eliminates the energy consumption by compressors. The objective of this work is to hypothetical design an ammonia water absorption Refrigeration system using solar energy. Our major challenge for this system is to increase COP and Efficiency. We have gone through various research papers and calculated the advancement in the system. The coefficient of performance (COP) varies to a small extent (0.65-0.75) with the heat source and the cooling water temperatures. This paper gives analytical usage of solar refrigeration, advanced method of refrigeration as vapour absorption method.*

Keyword. Fabrication, Vapour absorption, Refrigeration, NH_3-H_2O absorption refrigerator, solar energy.

"1. Introduction"

Refrigeration means cooling down certain substance by reducing temperature and heat extraction. In recent years, research has been devoted to improvement of Vapour Absorption Refrigeration Systems (VARS's) over Mechanical Vapour Compression Refrigeration System (MVCRS's). Refrigeration requires high grade energy for their operation. Apart from this, recent studies have also shown that the conventional working fluids of vapour compression system are causing ozone layer depletion and green house effects. However in VARS's we can use innocuous, inexpensive waste heat, solar, biomass or geothermal energy sources for which the cost of supply is negligible in many cases. "With the increasing carbon footprint it has become a global responsibility to reduce it, solar refrigeration is one of the technologies which will help in controlling carbon footprint." The working fluid in a Vapour Absorption refrigeration system is a binary solution consisting of refrigerant (NH_3) and absorbent (H_2O). 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. 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. However, the cooling effect cannot be produced continuously as the process cannot be done simultaneously. Therefore, an absorption refrigeration cycle is a combination of solar technology and VARS's.

2. Specification of Ammonia

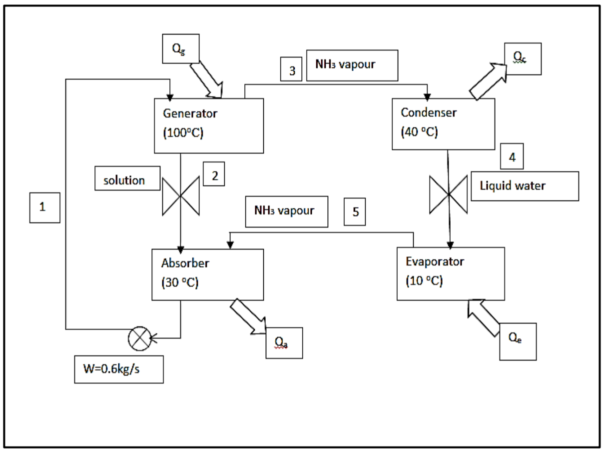
Now as know that most commercial and industrial refrigeration applications occur at temperatures below 0°C and many are -17.778°C. As a result, a fluid which is not subject to freezing at these temperatures is required. So the lithium bromide/water cycle is no longer able to achieve these conditions, because water is used for the refrigerant. Also the required heat input temperatures must be at least 110°C. It should also be remembered that the required evaporation temperature is (-12.22 to -9.44) °C below the process temperature. Use of **ammonia/water** equipment in conjunction with geothermal resources for commercial refrigeration applications is influenced by some of the same considerations as space cooling applications. In ammonia-water absorption refrigeration system, ammonia is used as the refrigerant, which is easily and cheaply available and water as absorbent, the refrigerant operating temperature in the evaporator has to be above the freezing point of water, The ammonia-water system is operated at pressures much higher than atmospheric, While water-lithium bromide systems operate under very low (high vacuum) pressures.

- The liquid boil at (-33.3) °C (-27.94)°F and freezes at (-77.7) °C (107.86) °F
- Boiling point of NH3-H2O solution = 27°C (81°F ,300K)
- Specific heat of constant pressure C_p = 2.05 KJ/kg K
- Specific heat of constant volume C_v = 0.6552 KJ/kg K
- Density = 0.772 kg/m^3
- 100 Tonne require of refrigeration = 88 KW
- Hence 1 tonne of refrigeration requires = 0.88 KW

3. Vapour Absorption Method

Coefficient of performance COP (Ideal) = refrigeration rate / amount of heat added to generator

Refrigeration cycle = Q_e / W = (T_r / T_a-T_r)
Work cycle = Q_g / W = (T_s / T_s-T_a)
C.O.P = Q_e/Q_g = T_r (T_s-T_a) / T_s (T_a-T_r)
T_s - Source temperature
T_a - Ambient temperature
T_r - Refrigeration temperature
Problem: - Calculation of mass flow rate in the absorption cycle



Input mass flow rate (W_1) =0.6kg/s is feeded

T_a=30°C, T_s=100°C, T_c=40°C, T_r=10°C,

Output:- T_c=40°C, Pc=7.38KPa,

T_r=10°C, Pr=1.23KPa

Absorber X_1 (T_a=30°C , Pr=1.23KPa concentration % by mass H_2O & NH_3)= 0.50

Generator X_2 (T_s=100°C ,Pc=7.38KPa concentration % by mass H_2O & NH_3)= 0.664

For getting the above values need to refer Temperature-Pressure-Concentration diagram of saturated NH_3 - water solution.

Mass balance = W_2+W_3=W_1=0.6(as supplied)

W_1X_1 = W_2X_2 ……..eq 2
(0.6)(0.5) = W_2 (0.664)
W_2=0.452kg/s
W_1=0.6kg/s
W_3=0.148kg/s
Now as per above calculation we can analyse for 4 kg of H2O solution requires 1kg of NH_3 as (Refrigerant).

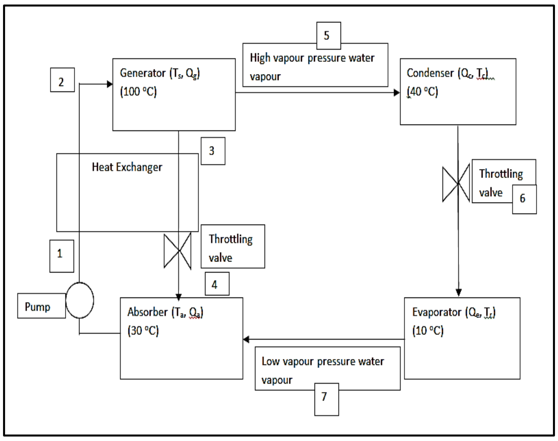
W_1=0.6kg/s
W_2=0.452kg/s
W_3=0.148kg/ (W_3=W_4=W_5)
X_1=0.50=50%, X_2=0.664=66.4%
Now we can get enthalpy (H_1, H_2) from Enthalpy and mass percentage of ammonia graph

(30°C, 0.50) H_1 = -168 KJ/kg

(100°C, 0.664) H_2 = -52 KJ/kg

H_1 = -168 KJ/kg
H_3 (100°C) = 2676.0 KJ/kg
H_2 = -52 KJ/kg
H_4 (40°C) = 167.5 KJ/kg
H_5 (10°C) = 2520.0 KJ/kg

The value of H_3, H_4, and H_5 can be obtained from water properties of liquid and saturated vapour
$Q_g = W_3H_3 + W_2H_2 – W_1H_1 = 473.3KW$
$Q_c = W_cH_3 – W_4H_4 = 371.2KW$
$Q_a = W_5H_5 + W_2H_2 – W_1H_1 = 450.3KW$
$Q_e = W_5H_5 – W_4H_4 = 348.2$ KW
C.O.P = Q_e/Q_g = 348.2 / 473.3 = 0.736.



T_2 = 52 °C
H_2 = -120 KJ/kg
X_2 = 0.50
$W_1=W_2=0.6$ kg /s
$W_3=W_4=0.452$ kg/s
$W_5=W_6=W_7=0.148$kg/s
If heat exchanger is coming in work cycle than (mass flow rate (w) & concentration % remain at input & output) changes comes in (Temperature, Enthalpy, COP) As we can see earlier example.

H_1 = -168 KJ/kg
$(H_3=H_5)=H_5=2676.0$ KJ/kg
H_3= -52 KJ/kg (earlier as H_2)
$(H_4=H_6)=H_6=167.5$ KJ/kg
H_2 = -120 KJ/kg (52 °C.50%)
$(H_5=H_7)=H_7=2520.0$ KJ/kg
Q_c & Q_e remains same
Q_c = 371.2 KW , Q_e = 348.2 KW
(Generator & Absorber) 4 ⟹ 3
Qhx = W_1 (H_2-H_1) = 0.6[-120-(-168)]
Qhx = 28.8 KW
(Generator & Absorber) 3 ⟹ 4
Qhx=28.8 KW =W_3 (H_3-H_4) = 0.452[-52-(H_4)]
H_4= -116 KJ/kg
Here X would remain same as X_2=66.4% and enthalpy obtained of H_4 is -116 KJ/kg

Now, from Enthalpy and mass percentage of ammonia graph (T_4 can be obtained)

T_4=64 °C

(Rate of heat transfer in generator)

$Q_g=W_5H_5+W_3H_3-W_2H_2=444.5KW$

(Rate of heat transfer in Absorber)

$Q_a=W_7H_7+W_4H_4-W_1H_1 = 421.3KW$

Hence coefficient of performance of the system can be obtained as: COP = Qc/Qg

= 348.2/444.5
=0.783

4. Refrigeration Effect

It is occurred by maintaining a very low pressure in evaporator and absorber, the water boil at a very low temperature. This boiling causes the water to absorb heat from medium to cooled, thus lowering its temperature. There is limitation of max & min pressure which is determined by taking into account the climatic restriction as per the climatic condition of that region. As given pressure and temp (refrigeration) are directly proportional to each other.

- Pressure 4.5 KPa, refrigeration temperature -31∘c
- Pressure 0.87 KPa, refrigeration temperature -5∘c

EVACUATED TUBE COLLECTOR (ETC)

PRINICIPLE: - The ETC absorbs heat from solar radiation and convert it into heat output which heats water flowing through the collectors.

BETTER EFFICIENCY: - ETC is filled with vacuum in order to reduce losses due to convection and re-radiation. This can be calculated by an instrument known as pyrometer. It is especially used in colder conditions.

The average incident solar beam radiations for each month were calculated.

$I_b = I_{sc}$ (cosφcos□ cosω-sinφsin□)

Terms are denoted as:
  I_b Beam radiation
  I_s Solar constant (1367 W/m^2)
  Cosω hour angle
  Sinφ latitude position (-90° to +90°)
  Sin□ declination angle □ = 23.45 sin (360/365(284+n))
Example: - For location of Dehradun,
Ø = 30.3165 °N
For day 10 (n=10) of the year (10th January),
δ = 23.45 sin (360/365(284+n))= 23.45 sin (360/365(284+10))
δ = -22.0396 °
For n=10, δ = -22.0396°

Calculating incident solar radiation at 2 PM as
IST=2 PM
ω = [14:00-12:00]*15=30°
For 2 PM, ω = 2*15 = 30°
Therefore, I_b was calculated as
I_b = 1367 [Cos30.3165 Cos (-22.0396) Cos30 – Sin30.3165 Sin (-22.0396)]
I_b = 1096.56 KW/m^2
For a particular month, we take the average of all the values of solar radiation in that month

5. Component Specification of GOLGH Company

i. **Condenser**
- Voltage – 120 V (D.C)
- Type – Scroll
- Model – ZF18k4e–TFP
- Capacity (90°C) = 25 mop

ii. **Generator**
- Temp – 100 °C
- Capacity – 0.462 kg/s
- Model – mba3sussman
- Electric boiler

iii. **Evaporator**
- Voltage – 110 V
- Model – GE16-41bd
- Capacity (10°C) – 1 Tonne

iv. **Absorber**
- Temp – (105/95)°C {inlet/outlet}
- Capacity – 0.6 kg/s flow rate
- Model – 16 JLR
- Working pressure – 24.5 KPa (2.5 kg/cm^2)
- If we take area of 400 cm^2 – 175 °C (2hr) through solar panel

v. **Solar evacuated tube (copper coated)**
- Co. pressure – 1kg/cm^3
- Operating pressure – 10 bars

vi. **Hot water tank**
- Stand made out of angle iron frame of 35*35*4mm
- Up to 2000 lt

The manufacturer of vapour absorption refrigeration in Dehradun

- ABDUL refrigeration centre
- Industrial refrigeration (equipment & product)
- AAHAR kitchen equipment

6. Final Calculation for the Fabrication of Refrigeration Using Vapour Absorption Method

We have analyzed as 0.3kg of ammonia and 0.7kg of water to get the ammonia water solution of 1kg.

Mass fraction: 0.3 = X_{NH3}

(1-0.3) = X_{H2O}

Mole fraction:- =0.3/17{1/ ((0.3/17) + ((1-0.3)/18))}
X_n = 0.312
At 90°C saturation pressure NH_3 = 511167 KPa
=511.67 bar
At 90°C saturation pressure of H_2O = 70.14 KPa
=0.7014 bar
From saturation table of water and ammonia
P_{NH3} = 0.312*511.67=159.64 bar
P_{H2O} = 0.312*0.7014=0.2188 bar
Total pressure = 159.64 + 0.218
=159.85 bar
Specific volume (of gas) by interpolation of pressure
V_{NH3} at 90°C = P_{NH3} at 159.64 bar = 0.080967 m^3/kg
V_{H2O} at 90°C = P_{H2O} at 0.2188 bar = 7.1092 m^3/kg
Mass fraction
X' (ammonia) =1/0.080967*{1/ [(1/0.080967) + (1/7.1092)]}
= 0.9887
(1-X') (Water) = 0.0113
Mole fraction
X''_{NH3} = 0.9887/17*{1/ [(0.9887/17) + (0.0113/18)]} = 0.9893
$(1-X')_{H2O}$ = 0.011067
P_{NH3} = 0.9893 * 159.85 = 158.139 bar
P_{H2O} = 0.01067 * 159.85 = 1.7055 bar
Total pressure = 159.84 bar

<u>By interpolation</u>
H_{NH3} = 1634.19 KJ/kg
H_{H2O} = 2528.906 KJ/kg
H = 0.9893(1634.19) + 0.01067(2528.96)
= 1643.688 KJ/kg at 90°C
At 90°C ammonia vapour enthalpy
H_g = 1602.3 KJ/kg
At 90°C water enthalpy
H_L = 801.76
At -5°C ammonia vapour enthalpy
H_v = 1599.8 KJ/kg=H_1
M_1 = {(Q_e*210) / (H_1-H_g)}
Q_e = capacity of refrigeration (2tonne)
H_1 = enthalpy of pure ammonia evaporator
H_g = enthalpy of ammonia liquid in generator
M_1 = ({210*2)/ (1599.8-801.76)} = 0.526 kg/min
Mass balance of NH_3 in the absorber
$M_1 + M_4 = M_2$

Mass balance of NH_3

$M_1 X_1 + M_4X_4 = (M_1+M_4) X_2$

$M_1 X_1 + M_4X_4 = M_1 X_1 + M_4 X_2$

$M_1 X_1 – M_1X_2 = M_4X_2 – M_2X_4$

$M_1(X_1-X_2) = M_4(X_2-X_4)$

(M_1 = 0.526 kg/min)

Input parameter mass flow rate of refrigerant is 0.526 kg/min hence we can take

$X_1 = 1$.

Percentage of weak solution X_w 10% = 0.1 = X_4

Percentage of strong solution X_s 38% = 0.38 = X_2

$M_4 = M_1(X_1-X_2)/(X_2-X_4)$

=0.526(1-0.38)/ (0.38-0.1)

= 0.32612/0.28

= 1.164 kg/min

$M_2 = M_1+ M_4$

= 0.526+ 1.164

= 1.69 kg/min

M_1 = 0.526 kg/min , H_1 = 1599.8 KJ/kg

M_2 = 1.69 kg/min , $\{M_2 = M_3\}$

M_4 = 1.164 kg/min , $\{M_4 = M_6\}$

M_7 =?

$M_6H_6 = M_7H_7$

$M_7 = M_6H_7/H_7$

= 1.164*1602.3/456.03

= 4.089 kg/min

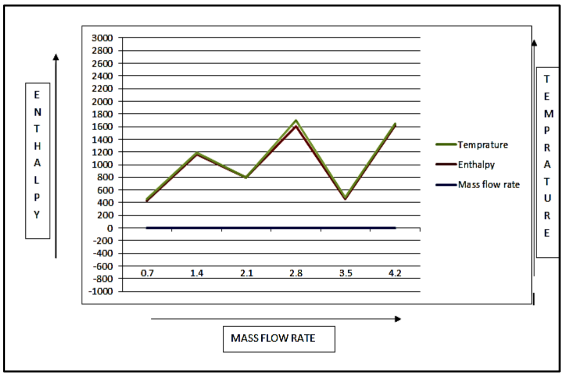
M_8 =?

$M_1H_1 = M_8H_8$

$M_8 = M_1H_1/H_8$ = 0.526*436.94/1626

= 0.141 kg/min

Graph 1.



M_1 = 0.526 kg/min

H_1 = 436.94 KJ/kg (liq T_1 = 20°C)

M_2 = 1.69 kg/min

H_2 = 1167.9 KJ/kg (liq vap T_2 = 24°C)

M_4 = 1.164 kg/min

H_4 = 801.76 KJ/kg (liq weak solution)

M_6 = 1.164 kg/min

H_6 = 1602.3 KJ/kg (vap strong solution T_6 = 90°C)

M_7 = 4.089 kg/min

H_7 = 456.03 KJ/kg (liq (H.P) T_7 = 24°C)

M_8 = 0.1468 kg/min

H_8 = 1626.00 KJ/kg (vap (L.P) T_8 = 24°C)

$Qa = M_1H_1 + M_4H_4 – M_2H_2$ = -810.68kJ

$Qg = M_4H_4 + M_6M_6 – M_2H_2$ =824.51kJ

$Qc = M_6 (H_7-H_6)$ = -1334.25Kj

7. Thermal Design

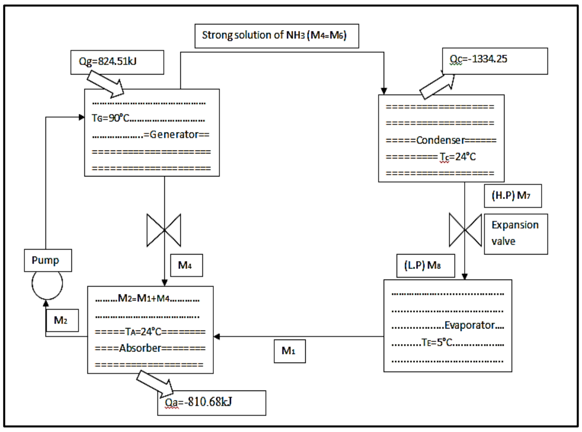


Figure 1

8. Blog Diagram

System consists of solar panel, hot water reservoir, generator, condenser, evaporator, pressure reducing valve (throttling valve), pump, and analyser is used. Water is heated by absorbing solar energy from sun using flat plate collector. It is designed in such a way that they are liquid flowing through the tubes get heated by absorbing heat from absorber plate which is integral with collector. Collecting tank, solar panel's riser pipes, header pipes and generator coil filled with cold water to raise the hot water in raiser pipe to collect it into hot water tank. Because density of hot water is lesser than cold water hence it gets raised up into hot water tank. Hot water from tank then goes to the generator coil in which refrigerant is filled which get heat from hot water. Due to the absorption of heat aqua ammonia separated out and ammonia gets vaporize and ammonia vapour flows to circuit and then to the condenser, in condenser ammonia vapour heat loss to the atmosphere and vapour ammonia converted to liquid ammonia. Expansion valve is used to reduce the pressure before liquid refrigerant entering to evaporator. The low pressure low temperature liquid refrigerant receives heat into evaporator where we get refrigerating effecting in the evaporator cabinet. The refrigerant gets converted into vapour after receiving the heat. The vapour refrigerant is then goes to absorber where refrigerant is absorbed by water in the absorber and aqua ammonia solution formed. This solution is pumped to the generator using HP pump. And cycle is repeated

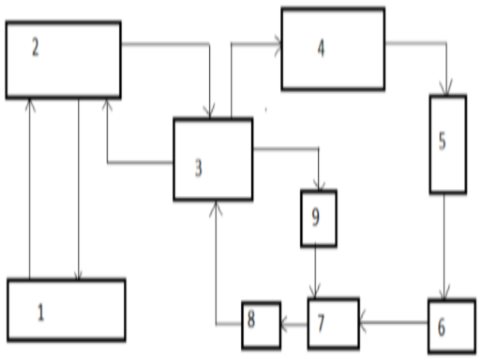


Figure 2

	Table 1.
Block	Description
1	Solar Panel
2	Hot Water Reservoir
3	Generator
4	Condenser
5	Expansion Valve
6	Evaporator
7	Analyzer
8	Pump
9	Pressure reducing valve

9. Conclusion

It is concluded in this research that water (H_2O) and Ammonia (NH_3) combination is the most suitable working fluid pair for vapour absorption refrigeration system and that the problem of fossil fuel and ozone layer depletion together with some other advantages of ammonia water vapour absorption system and this system is showing tremendous potential for (NH_3- H_2O) absorption refrigeration system to flourish.

In light of the above results, the feasibility of the solar powered vapour refrigeration system has been reasonably proved. The COP values as calculated by us are on a little higher side than the actual COP's, because we have assumed ideal processes in heat exchanges etc., this obliquity can be understood. Hence, a solar water heating unit can be usefully employed for water cooling purposes. In the month of summers, when the solar heating unit is closed and even the solar potential is quite high, the unit can be used for refrigeration. This will actually justify the huge investments made on these units, and the energy source will not remain idle during its peak producing times.

10. References

[1] http://www.goodway.com/hvac-blog/2009/08/ammonia-as-a-refrigerant-pros-and-cons/

[2] http://nptel.ac.in/courses/112105129/pdf/RAC%20 Lec ture%2017.pdf

[3] http://absorptionchiller4u.blogspot.in/2013/02/ ammonia water-absorption-refrigeration.html

[4] http://www.ignou.ac.in/upload/Unit%202-32.pdf

[5] Raghuvanshi Satish and Maheshwari Govind, Analysis of Ammonia –Water (NH3-H2O) Vapour Absorption Refrigeration System based on First Law of Thermodynamics.

[6] Mohanty Dillip Kumar and Padhiary Abhijit, Thermodynamic Performance Analysis of a Solar Vapour Absorption Refrigeration System.

[7] Munusami Achuthan, Energy, Economic and Environmental Analysis of Compact Solar Refrigeration System. International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 3 Issue 8, August - 2014.

[8] Bajpai V.K., Design of Solar Powered Vapour Absorption System, World Congress on Engineering 2012 Vol III WCE 2012, July 4 - 6, 2012, and London, U.K.

[9] Rajkumar P, Economic Analysis of Solar Collector with Different Thermic Fluids of LiBr-Water Vapour Absorption Refrigeration System.

[10] Preethu Johnson and K. B. Javare Gowda, FABRICATION OF SOLAR THERMALVAPOUR ABSORPTION REFRIGERATION SYSTEM, (IRJET) p-ISSN: 2395-0072 Volume: 02 Issue: 05 | Aug-2015.

[11] Christy V Vazhappilly et al., Modelling And Experimental Analysis Of Generator In Vapour Absorption Refrigeration System, Int. Journal of Engineering Research and Applications, Vol. 3, Issue 5, Sep-Oct 2013, pp.63-67.

[12] Mohd Aziz Ur Rahaman, Md. Abdul Raheem Junaidi, Mohd. Rizwan and Naveed Ahmed, Design and Fabrication of Vapour Absorption Refrigeration System [Libr-H20].