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STATISTICAL THERMODYNAMIC INVESTIGATION OF LITHIUM BROMIDE-WATER (LIBR- H_2O) VAPOUR ABSORPTION REFRIGERATION SYSTEM BASED ON SECOND LAW OF THERMODYNAMICS

Mr. Satish Raghuvanshi, Research Scholar, MED, Sir Padampat Singhaniya University, Udaipur
Dr. Naveen Agrawal, Professor, MED, Sir Padampat Singhaniya University, Udaipur
Dr. Kamal Kumar Agrawal, Assistant Professor, Sir Padampat Singhaniya University, Udaipur

Abstract

Second law of thermodynamics is used to study the performance of Single Stage Lithium bromide - water (LiBr-H_2O) vapor absorption refrigeration system. When some input design parameters are varied. The entropy generation of each component and total entropy generation of all the system components as well as the Coefficient of performance of the vapour absorption system are calculated from the thermodynamic properties of the working fluids at various operating conditions. The goal of this paper is to show observational relations for finding the attributes and execution of a solitary stage Lithium bromide - water (LiBr-H_2O) vapor absorption refrigeration system. The present work has been simulated for low generator temperature heat source 50°C to 100°C and evaporator temperature and condenser temperature 30°C. It also should be noted that the COP initially increases in a slower pace with an increasing inlet water temperature to generator, and when the temperature is between the 50°C to 80°C and after that COP is rapidly increases. The Coefficient of performance of the system decreases and Exergetic Coefficient of performance increases with the condenser temperature Increase.

Keywords —
Absorption Refrigerator, Exergy, Exergy Rate, COP

1. Introduction:

Day by day the demand in power consumption is increases; we all are responsible to find the alternative source of power. The one of the major power consumption is refrigeration and air conditioning, one of the best choices is vapour absorption refrigeration system. Absorption systems can be driven by low grade thermal energy providing a means for converting waste heat in to useful purposes as well as help in reducing peak summer electric demands.

Aside from this, ongoing examinations have demonstrated that the regular working liquids of vapor compression system are causing ozone layer consumption and green house impacts. In any case, ARS's innocuous cheap waste warmth, sun based biomass or geothermal energy sources for which the expense of supply is insignificant as a rule. Besides, the working liquids of this system are environment friendly [1-3].

A number of researchers have used exergy analysis of refrigeration system. The general execution of the retention cycle as far as refrigerating impact per unit of energy input commonly poor, in any case, squander warmth, for example, that rejected from a power can be utilized to accomplish better by and large energy use. Alkali/water (NH_3/H_2O) frameworks are generally utilized where bring down temperature is required. In any case, water/lithium bromide (H_2O/LiBr) system are likewise broadly utilized where moderate temperatures are required (for example cooling), and the last system is more proficient than the previous [4-6].

The target of this paper is to calculate Exergetic Coefficient of Performance of LiBr-water vapor absorption refrigeration system by calculating exergy destruction in different components, think about the Second Law Thermodynamic for single stage Vapor Absorption Refrigeration System with the assistance of numerical model. This model is produced on MATLAB Software (Simulink Tool). This paper is differs from the above literature studies in that availability analysis is carried out for each component of the system. Here utilizing water/lithium bromide as working liquid and water is utilized as a refrigerant. Absorption system is divided in to eighteen states, for each and individual state we are finding exergy and exergy rate. These are calculated by empirical relations and input parameters. The consequence of this examination can be utilized either to measure another refrigeration cycle or rating a current framework.

1.1 Benefits of LiBr-H_2O over NH_3-H_2O

The NH_3-H_2O system is more complicated than the LiBr-H_2O vapour absorption refrigeration system, since it needs a rectifying column that assures that no water vapour enters the evaporator where it could freeze. The NH_3-H_2O system requires generator temperatures in the range of 125°C to 170°C with air-cooled absorber and condenser and 80°C to 120°C when water-cooling is used. These temperatures cannot be obtained with flat-plate collectors. The coefficient of performance (COP) is between 0.6 to 0.7.In the LiBr-H_2O system water is used as a coolant in the absorber and condenser and has a higher COP than the NH_3-H_2O systems. The COP of this system is between 0.6 and 0.8.

1.2 Nomenclature –

S.No.	Symbol	Description	Units	Subscripts	Description
1	m	Mass flow rate	kg/s	o	Atmospheric
2	T	Temperature	°C	A	Absorber
3	P	Pressure	kPa	G	Generator
4	h	Enthalpy	kJ/kg	C	Condenser
5	X	Percentage of Solution	Dimensionless	E	Evaporator
6	Q	Heat Transfer	kJ	W	Weak Solution
7	COP	Coefficient of Performance	Dimensionless	S	Strong Solution
8	C_{pw}	Specific heat of water	kJ/kg K	In/out	Inlet/outlet to or from the System
9	E	Exergy at particular state	(kJ/kg)	In/out	Inlet/outlet to or from the System
10	S_i	Exergy rate at particular state	(kJ/s)	In/out	Inlet/outlet to or from the System
11	S	Entropy of solution(LiBr-Water) and water (Through external source) at particular state.	kJ/kg K		

2. Details and Methodology-

Figure 1 shows the schematic block diagram of complete Vapour Absorption Refrigeration System. Low pressure refrigerant vapour from the evaporator is absorbed by the liquid strong solution from the absorber, the pump receives low pressure liquid weak solution from the absorber, increase the pressure of the weak solution and the send it to the generator. By the weak solutions, it is meant that the ability of the solution to absorb the refrigerant vapour is weak. In the generator, heat from a high temperature source drives off the refrigerant vapour in the weak solution. In the solution heat exchanger heats the cool solution from the absorber on its way to the generator and cools the solution returning from the generator the absorber. Thus, the heat load decreases in the generator and the COP increases. The high pressure refrigerant vapour condenses into liquid in the condenser and enters the evaporator through a throttling valve, maintaining the pressure difference between condenser and the evaporator. The cycle performance is measured by the coefficient of performance (COP) which is defined as the refrigeration rate over the rate of heat addition at the generator plus the work input to the pump. It should be noted that the refrigerant in the LiBr-H_2O system is water and the LiBr acts as the absorbent, which absorbs the water vapour thus making pumping from the absorber to the generator easier and economical.

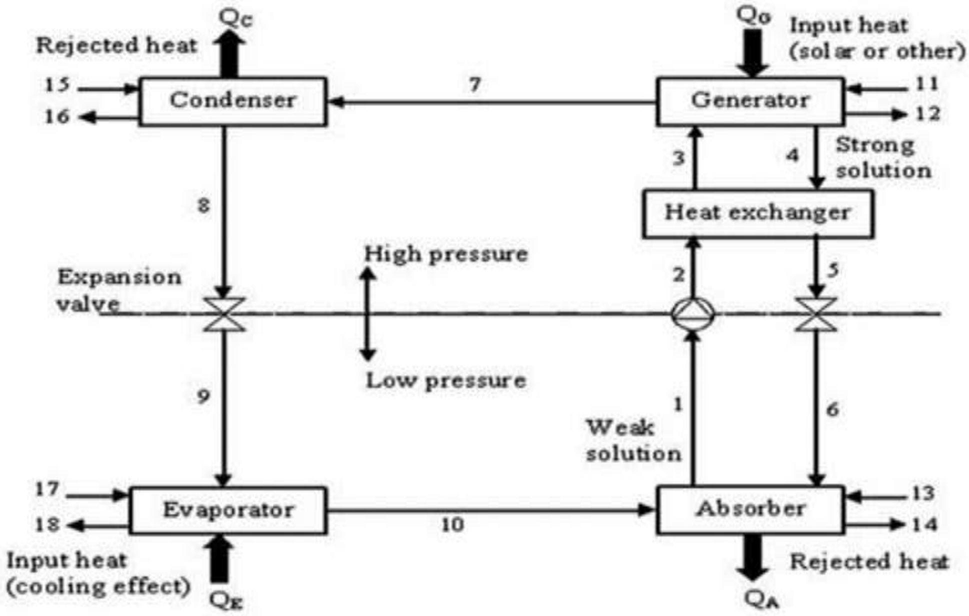

Figure 1 Schematic Diagram of Simple Vapour Absorption Refrigeration System

2.1 Assumptions: -

Following are the assumption made for carrying out the Energy analysis of (LiBr-H2O) Vapour Absorption Refrigeration System.

- The Refrigerant is pure water.
- There are no pressure changes except through the flow pump.
- In above figure 1at point1, 4 and 8, there is only saturated liquid.
- In above figure 1 at point 10, there is only saturated vapour.
- In pump the Pumping process is isentropic.
- I assuming that the 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.
- I assume that the Percentage of weak solution at state 1, 2 and 3 and Percentage of strong solution at state 4, 5 and 6 will remain same.
- In above figure 1, The Temperatures at 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.
- in figure 1,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}).

P1=P6=P9=P10= Low pressure

P2=P3=P4=P5=P7=P8= High pressure

2.2 Input Parameters:-

Input Design parameters for Vapour Absorption Refrigeration system. [20]

S. No	Input Parameters	Values
1	Mass flow rate of Refrigerant (mr=m7=m8=m9=m10)	0.005 kg/s
2	Effectiveness of heat exchanger	0.7

3	Generator Temperature $=T_G=T_4=T_7$	80°C
4	Condenser Temperature$=T_C=T_8$	30°C
5	Absorber Temperature$=T_A=T_1=T_2$	30°C
6	Evaporator Temperature$=T_E=T_{10}=T_9$	5°C
7	Percentage of weak solution $Xw=X_1=X_2=X_3$	55.3
8	Percentage of strong solution $X_s=X_4=X_5=X_6$	56
9	The Temperature of water when it enters in to the Generator $=T_{11}$	100°C
10	The Temperature of water when it comes out from the Generator $= T_{12}$	90°C
11	The Temperature of water when it enters in to the Absorber$= T_{13}$	20°C
12	The Temperature of water when it comes out from the Absorber$= T_{14}$	24°C
13	The Temperature of water when it enters in to the Condenser$= T_{15}$	20°C
14	The Temperature of water when it comes out from the condenser$= T_{16}$	24°C
15	The Temperature of water when it enters in to the Evaporator $= T_{17}$	20°C
16	The Temperature of water when it comes out from the Evaporator$= T_{18}$	12°C

Table-1 Input Design parameters for Vapour Absorption Refrigeration system

3. Thermodynamic Analysis

For the thermodynamic analysis of the absorption system the principle of mass conservation, first and second laws of thermodynamic are applied to each components of the system. Each component can be treated as a control volume with inlet and outlet streams, heat transfer and work interaction. The governing equations of mass for steady state and steady flow system are as follows. According to the Second Law of Thermodynamics, Total heat supplied to the system is never equals to the work done by system. There is always loss of energy, Hence we can say that practically, there is no system, which is hundred percent efficient. So efficiency of every system is always less than hundred percent, on the basis of this law doing Exergy analysis of Vapour Absorption Refrigeration System.

$$\sum m_i - \sum m_o = 0 \quad (1)$$

$$\sum (mx)_i - \sum (mx)_o = 0 \quad (2)$$

Where m is the mass flow rate and x is mass concentration of LiBr solution. The first law of thermodynamic yields the energy balance of each components of the absorption system as follows.

$$\sum (mh)_i - \sum (mh)_o + [\sum Q_i - \sum Q_o] + W = 0 \quad (3)$$

The cooling COP of the absorption system is defined as the heat load in the evaporator per unit heat load in generator.

$$COP_{Cooling} = Q_E / Q_G \quad (4)$$

The second law analysis can be used to calculate the system performance based on exergy. Exergy analysis is the combination of first and second law of thermodynamics and is defined as the maximum work potential of material or energy stream, in relation surrounding environment. The exergy of a fluid stream can be defined as.

Exergy and exergy rate are calculated by the following relations

$$E = (h-h_o) - T_o \times (s-s_o) \quad (5)$$

Where E is the exergy of the fluid, at temperature (T). The terms h and s are the enthalpy and entropy of the fluid, whereas h_o and S_o are the enthalpy and entropy of the fluid at environment

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temperature T_o (in all cases absolute temperature used in K) in this study, T_o was taken as 298.15 K.

Exergy rate is calculating by the following equation

$$S_i = m \times E \quad (6)$$

Where,

S_i= Exergy rate in kJ/s
E= Exergy kj/kg
m = mass flow rate of refrigerant

Exergy Destruction in various components of Vapour Absorption Refrigeration System, destruction in exergy is the difference between total exergy in to the system and total exergy comes out from the system. In Vapour Absorption Refrigeration System, we are taking eight components. These components are Absorber, Pump, Heat exchanger, Generator, Condenser, Expansion valve, Evaporator, Pressure reducing valve. Every component in the system is considered as single system.

The availability loss in each component is calculated by

$$\Delta E = \sum m_i E_i - \sum m_o E_o - [\sum Q(1 - T_0/T)_i - \sum Q(1 - T_0/T)_o] + W \quad (7)$$

Where, ΔE is the lost of exergy or irreversibility that occurred in the process. The first two terms of right hand side of equation (7) are the exergy of the inlet and outlet of streams of the control volume. The third and fourth terms are the exergy associated with the heat transferred from the source maintained at temperature T. The last term is the exergy of the mechanical work added to the control volume. This term is negligible for absorption system as the solution pump has the very low power requirements.

4. Simulation Model

The summary of the thermodynamic properties at the various thermodynamic states, energy flows at the various components of the system, the coefficient of Performance, exergy rate, Exergy destruction for each and every component and exergetic Coefficient of Performance of the system by using the input parameter. Other thermodynamics properties are calculated in the Table 1, 2, 3, and 4 respectively through the mathematical model. Analysis of single stage vapor absorption refrigeration system with the assistance of numerical mathematical model. This model is produced on MATLAB Software (Simulink Tool), and we have obtained all the results by simulation technique.

STATES	P (kPa)	H (kJ/kg)	T (°C)	X% LiBr	M (kg/s)	S (kJ/kg K)
1	0.8728	74.1	30	55.3	0.4	0.1745
2	4.247	74.1	30	55.3	0.4	0.1745
3	4.247	145.6	64.7	55.3	0.4	0.3966
4	4.247	178.6	80	56	0.395	0.4804
5	4.247	105.4	45	56	0.395	0.2712
6	0.8728	105.4	45	56	0.395	0.2712
7	4.247	2643	80	0	0.005	1.059
8	4.247	126	30	0	0.005	0.4368
9	0.8728	126	5	0	0.005	0.4368
10	0.8728	2510	5	0	0.005	9.025
11	-	378	100	0	0.6071	1.193
12	-	420	90	0	0.6071	1.307
13	-	84	20	0	1.462	0.2965
14	-	100.8	24	0	1.462	0.3531
15	-	84	20	0	0.7491	0.2965
16	-	100.8	24	0	0.7491	0.3531
17	-	50.4	20	0	0.04893	0.1805
18	-	294	12	0	0.04893	0.9551

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Table-2 General Results obtained from thermodynamic simulation.

S.No.	Description	Notations	Calculated Value (k J/s)
1	Heat load in Evaporator	Q_e	11.92
2	Heat load in Condenser	Q_c	12.58
3	Heat load in Absorber	Q_a	24.56
4	Heat load in Generator	Q_g	25.5
5	Coefficient of Performance	COP	0.4675 (Dimensionless)

Table-3 Heat Load Obtained from thermodynamic simulation

STATES	P (kPa)	h (kJ/kg)	T (°C)	X% LiBr	m g/s)	s J/kgK)	E J/kg)	S_i kJ/s)
1	0.8728	74.1	30	55.3	).4	1745	6.71	0.68
2	4.247	74.1	30	55.3	).4	1745	6.71	0.68
3	4.247	145.6	64.7	55.3	).4	3966	6.31	4.52
4	4.247	178.6	80	56	395	4804	7.34	8.7
5	4.247	105.4	45	56	395	2712	9.42	1.62
6	0.8728	105.4	45	56	395	2712	9.42	1.62
7	4.247	2643	80	0	005	.059	332	1.66
8	4.247	126	30	0	005	4368	4188	0020
9	0.8728	126	5	0	005	4368	4188	0020
10	0.8728	2510	5	0	005	).025	76.2	.881
11	-	378	100	0	5071	.193	6.99	9.38
12	-	420	90	0	5071	.307	4.91	5.07
13	-	84	20	0	462	2965	2492	4262
14	-	100.8	24	0	462	3531	1858	3178
15	-	84	20	0	7491	2965	2492	1891
16	-	100.8	24	0	7491	3531	1858	.141
17	-	294	20	0	4893	9551	3.89	6795
18	-	50.4	12	0	4893	1805	.247	0609

Table- 4 Exergy Analysis obtained from thermodynamic simulation

S.No	Components	Exergy Destruction
1	Absorber	0.7151
2	Pump	0
3	Heat Exchanger	2.126
4	Generator	19.45
5	Pressure Reducing Valve	0
6	Condenser	11.71
7	Evaporator	0.2645
8	Expansion Valve	0

Table 4 Exergy destruction/ exergy losses from thermodynamic simulation

We have found out Exergetic Coefficient of Performance of the system by using the following expression.

As such we have found out Q_e and Q_g by using the input parameters

$$E_{COP} = \frac{Q_e\left[1-\frac{T_o}{T_E}\right]}{Q_g\left[1-\frac{T_o}{T_G}\right]}$$

Where,

T_o= 25°C/298.15 K = Atmospheric temperature

T_E = Evaporator temperature [From input parameters]

T_G= Generator temperature [From input parameters]

Hence, Exergetic Coefficient of Performance = 0.7012

5. Result & Discussion

5.1. Losses & Irreversibility

The availability analysis for each components of the system is also carried out. The exergy losses are obtained by using Equation (6) and (7). The exergy losses at various components of the system are given in table (4).The Exergy loss is the amount of availability consumed in the process.

The Irreversibility in absorption system that reduce the COP and exergy efficiency to a lower value than the ideal one are due to three main factors

i. Imperfect heat and mass transfer in the system
ii. Mixing losses
iii. Circulating losses

The mixing losses are associated with the evaporation of the refrigerant in the generator from a concentrated solution, which requires a greater amount of heat than to evaporator it in pure state, In addition the refrigerant vapour leaves the generator superheated, as the temperature required for the generator is higher than the evaporation temperature of pure refrigerant under the same pressure. The superheat energy spent in the generator constitutes a thermodynamic loss, which leads to extra cooling requirement in the condenser. Therefore seen in the table (4) the absorber and generator have the highest exergy loss. The exergetic efficiency can be improved by a better matching of the heat source with the temperature of working fluid in the generator.

5.2. Comparison of work with others

Tausif Ahmad et al. (2022) focused on comparative study on energy analysis of Lithium bromide and lithium chloride water based single effect vapour absorption refrigeration system. They fixed the capacity of the system is 300 kW and calculated the heat load of the components at different operating generator operating temperatures. The work is simulated for the evaporated temperature 5, 10 and 15 ˚C while the condenser temperature of 25, 30 and 35 ˚C. Comparison shows that lithium chloride water system has better COP and minimum generator temperature load as compare to Lithium bromide water system specially lower evaporator temperature. COP of system lies in between LiCl water 0.80906 - 0.926 and LiBr water 0.741 – 0.902.

Bhaumik Modi and Mudgal et al. (2022) Low grade thermal energy driven-small scale absorption refrigeration system Design, fabrication and cost estimation. Design methodology of small-scale single effect LiBr (Lithium bromide)/water absorption refrigeration system with a capacity of 1.5 Ton is prepared and tested. The system delivers cooling by using solar thermal or any low-grade thermal energy. In the design, evaporator is a double pass flooded heat exchanger, the cross-section of the evaporator is set based on the hydrostatic pressure effect. In experiments, the generator temperature of the proposed unit varied in the range of 80 ˚C to 100˚C and results indicate that the maximum system COP of 0.35 at the generator temperature of 92˚C. Simultaneously, the cooling load of the system increased from 4.6 kW to 5.16 kW by raising the evaporator temperature from 8 to 15 ˚C.

Sathiamourty et al. (2020) focused on Thermodynamic analysis of Vapour absorption refrigeration system using different working fluid. They found the better performance of Ammonia- Lithium Nitrate and water solution having a COP in between 0.75 to 0.88 when the generator temperature is 64 to 80˚C. While the Ammonia- Sodium water hydroxide solution having a COP in between 0.35 to 0.78 when the generator temperature is same as 64 to 80˚C.
A Ponshanmug kumar and R Rajave (2019) they designed and fabricated a new modal generator heater. The generator design is modified for a phase change material containment. The average temperature of heat energy available will be around 60^0C to 80^0C. In these temperature ranges a suitable phase change material is selected for thermal storage tank.

6.Effect of Temperature on COP and ECOP

The present work has been simulated for very low generator temperature heat source 50°C to 100°C and evaporator temperature and condenser temperature 30°C. It also should be noted that the COP initially increases in a slower pace with an increasing inlet water temperature to generator, and when the temperature is between the 50°C to 80°C and after that COP is rapidly increases. The Coefficient of performance of the system decreases and Exergetic Coefficient of performance increases with the condenser temperature Increase.

6.1. Variation in COP and ECOP with Temperature of inlet water

Fig. 1 Represents that the comparison of the Coefficient of Performance and Exergetic Coefficient of Performance of the absorption system, versus inlet water temperature to generator (T_{11}). It is shown that from 50°C to 83°C the exergetic Coefficient of Performance will decrease in a slower pace and declines continuously as the T_{11} increases. It also should be noted that the COP initially increases in a slower pace with an increasing T_{11}, and when the T_{11} is between the 50°C to 80°C than the slope of the COP curves becomes almost flat. This suggests that, increasing the T_{11} higher than a certain value will not provide much improvement in COP. This can be explained by the fact that although a system with a high T_{11} can produce more hot water vapour, more input exergy is supplied; it also generates more exergy losses in the generator, condenser and absorber as their average temperatures rise up. This contributes negatively to the exergetic Coefficient of Performance of the system. This negative result on the Exergetic Coefficient of Performance and COP trades off the beneficial effect of the T_{11} increase. After 83°C of T_{11}, the COP increases and ECOP decreases rapidly. But as the heat source temperature increases, the heat transfer in all heat exchangers of the system also increases. The increased heat also results in increased heat transfer, irreversibility and smaller increases of the COP.

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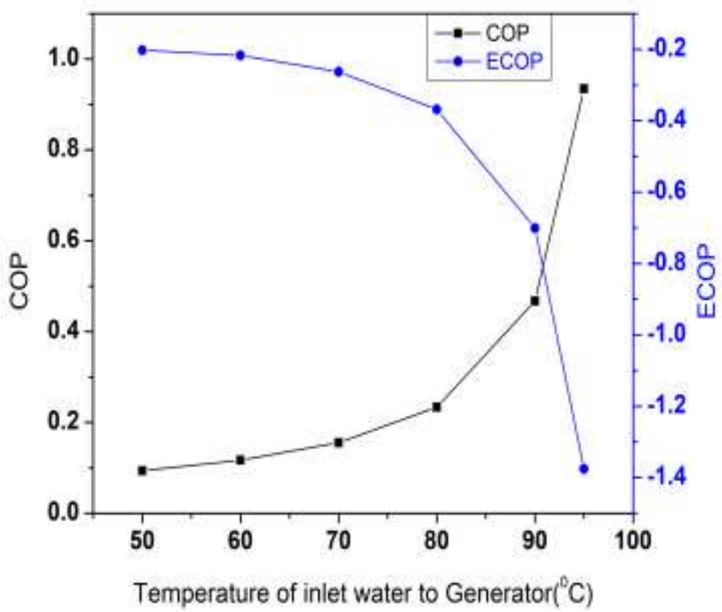

Figure 1: Variation in COP and ECOP with Temperature of inlet water to Generator (T_{11})

6.2. Variation in COP and ECOP with Generator Temperature

Fig. 2 shows the influence of Generator temperature on the system performance. The system COP decreases and ECOP increases with the Generator temperature increase. This system can be operated with a relative low generator temperature (T_7) to reach low Evaporator temperature with an acceptable system COP, which is a main advantage of this refrigeration system, as it could then utilize industry or civil waste heat and solar energy since fluid temperatures of this kind of heat source are generally low. When the generator temperature is increases the COP values are decreasing why because the heat input to the generator is increases and heat absorbing capacity of the evaporator is kept at constant so therefore the COP are decreases.

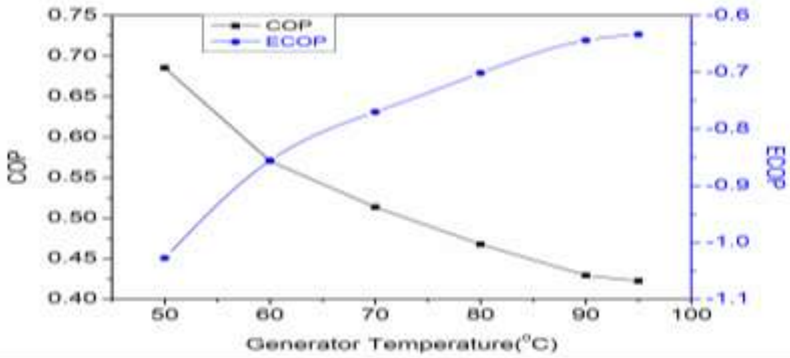

Figure 2: Variation in COP and ECOP with Generator Temperature (T_7)

6.3. Variation in COP and ECOP with Evaporator Temperature

Fig. 3 shows comparison of the COP and Exergetic Coefficient of Performance of the absorption system with the evaporator temperature. As it can be seen, the cooling COP increases when the evaporator temperature increases. The reason is that a higher evaporator temperature will cause a higher absorbing pressure, which will greatly increase the absorption efficiency the strong solution. Unlike COP, the Exergetic Coefficient of Performance of the system decreases with the increase of the evaporator temperature. It can also be explained by the definition of the second law of thermodynamics that the lower evaporator temperature has a bigger potential to create cooling effect.

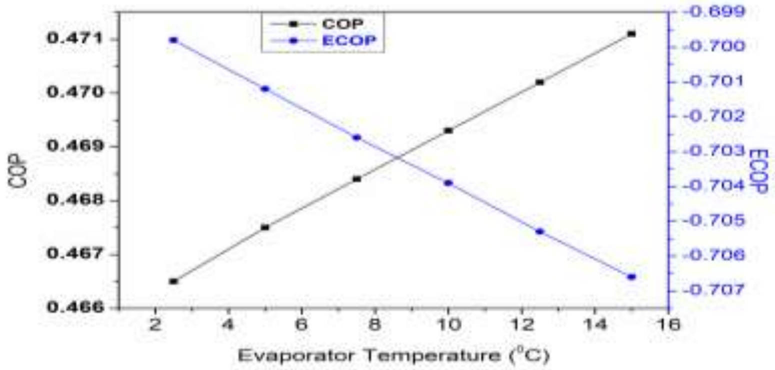

Figure 3: Variation in COP and ECOP with Evaporator Temperature (T_{10})

7. Conclusion

In this Paper second Law of Thermodynamics is applied to a single stage LiBr-Water absorption system. The performance analyses of each component are calculated through mathematical model on MATLAB 7.0.1. Following are the major outputs from the work.

1. Coefficient of Performance (COP) and Exergetic Coefficient of Performance (ECOP) of the system increases and decreases respectively, with increase in inlet water temperature to generator (T_{11}) and evaporator temperatures (T_E=T_{10})
2. As the effectiveness of Heat exchanger increases, COP of the system also increases.
3. It has been observed that in certain operating conditions, while the COP increases the efficiency of the second law of thermodynamics (Exergetic efficiency) decreases. The reason is that more exergy loss occurs in some components of the system. In these cases, attention can be focused on such components that have high exergy losses in order to increase the exergetic Coefficient of Performance of the system.
4. Finally, the results of the energy and exergy analysis presented in paper can be applied as a useful tool for evaluation and improvement of the absorption systems. It may provide a simple and effective method to identify how losses at different devices are interdependent and where a given design should be modified for the best performance.

In this Work we have developed mathematical model of Vapour Absorption Refrigeration system (LiBr-Water) on MATLAB 7.0.1. We obtained all results through the simulation technique. Hence one can say that this model become versatile. After changing any parameter in input box, all results will be changed. We have analyzed this system by varying input parameters and found out optimal Coefficient of Performance of the system. Moreover exergy analysis of Vapour Absorption Refrigeration system by generating empirical relations through curve fitting tool of MathCAD, and inserted these empirical relations in to the MATLAB. As for as my knowledge is concern no one has carried out energy and exergy analysis of Vapour Absorption System by generating empirical relations and developing mathematical model of system on MATLAB.

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