"MATHEMATICAL MODELLING AND ANALYSIS OF SOLAR ABSORPTION REFRIGERATION SYSTEM"

Research Paper

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ABSTRACT:
Consistently increasing CO2 emission and ozone depletion from CFC's are serious environmental issues challenging scientific community. The dependence on fossil fuels has to be reduced and alternative environmental friendly options need to be explored. In this aspect, vapour absorption system gives scope of utilizing low grade energy source i.e. solar panel for generating cooling effect which is dominated by high grade energy driven compression technology. The LiBr-water based absorption cycle consists of four stages: generation, condensation, evaporation and absorption with ideally no moving part. In this paper, LiBr-Water based absorption refrigeration system is presented. Mathematical model is developed for the system using EES. Then COP of the system and exchanged heat in different components are obtained and effect of various parameters has been presented. It is shown that an increase in the generator temperature increases the COP of the systems up to an optimum generator temperature.

Keywords: absorption, refrigeration, simulation, operating condition, EES.

INTRODUCTION:

Since the beginning of the last century, average global temperature has risen about 0.6 K according to UN Intergovernmental panel on climate change. It is also warned that the temperature may further increase by 1.4-4.5 K until 2100. Having realized the seriousness of the situation, the world community decided to take the initiatives to stop the process. One of such effort is the Kyoto protocol, a legally binding agreement under which industrialized countries will reduce their collective emission of greenhouse gases by 5.2% compared to the year 1990. Especially regarding the reduction of carbon dioxide, being the inevitable by-product of industrial activities, industries should improve facilities and processes to achieve the goals. Refrigeration industry is one of those hardest hit by the effect of the protocol. In Europe, use of HFC134a will be banned for the air conditioning units in new cars. Inspection and monitoring are required for all stationary HFC based refrigeration, air conditioning and heat pump units for the safe containment of HFCs. Reduction of energy consumption for refrigeration, however, cannot be relied solely on the improvement of efficiency. Reduction in use of synthetic refrigerants and production of co_2 provide a new opportunity for solar refrigeration. Considering cooling demand increases with intensity of solar radiation, solar refrigeration has been considered as a logical solution. In the 1970s solar refrigeration received great interests when the world suffered from oil crisis. There were many projects for the development of solar refrigeration technologies and solar refrigeration continued to be an important issue. A variety of solar refrigeration technologies have been developed and many of them are available in the market at much cheaper prices than ever.[1]

Solar energy is very large inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8×10^{11} MW which is much more larger than the present consumption rate on the earth of all commercial energy sources. Thus, solar energy could supply all the present and future energy needs of the world on the continuing basis. This makes it one of the most promising of the unconventional energy sources. In addition to its size, solar energy has two other factors in its favor. First unlike fossil fuels and nuclear power, it is an environmental clean source of energy. Second, it is free and available in adequate quantities in almost all parts of the world where people live. However, there are many problems associated with the use of solar energy. The main problem is that it is a dilute source of energy. Even in the hottest regions on earth, the solar radiation flux rarely exceeds 1kWh/m2 and the total radiation over a day is best about 6 kWh/m2.These are low values from the point of view of technological utilization. Consequently, large collecting areas are required in many applications and this result in excessive costs. A second problem associated with the use of solar energy is that its availability varies widely with time. The variation in availability occurs daily because of the day-night cycle and also seasonally because of the earth's orbit around the sun. In addition, variation occurs at a specific location because of local weather conditions. Consequently, the energy collected when the sun is shining must be stored for use during periods when it is not available. The need for storage significantly adds to the cost of the system. Thus, the real challenge in utilizing solar energy as an energy alternative is to address these challenges. One has to strive for the development of cheaper methods of collection and storage so that the large initial investments required at present in most applications are reduced.[2]

V.K.Bajpai designed and studied an environment friendly vapour absorption refrigeration system of unit capacity using R 717 (NH) and water as the working fluids. The system is designed and tested for various operating conditions using hot water as heat source. In that paper he described the performance of the fabricated system with respect to various operating conditions related to heat source, condenser, absorber and evaporator temperatures. The heat input required for the 1TR vapour refrigeration system with operating conditions designed was about 304.2kJ/min. this heat was supplied in generator through solar flat plate water heater and COP of the refrigeration was 0.58.[9]

V.D.Patel et al. described vapour absorption system uses heat energy, instead of mechanical energy as in vapour compression system, in order to change the condition of the refrigerant required for the operation of the refrigeration cycle. In this system, the compressor is replaced by an absorber, a pump, a generator, and a pressure reducing valve. They made theoretical calculations for different components of the systems like evaporator, absorber, condenser and pump of vapour absorption system for a capacity of 0.25TR and experimentally developed and run system to validated for reducing the temperature for the free of cost of operation.[12]

F.L.Lansing describe and analyse the simulation and computer modelling procedure of one of the system namely lithium-bromide/water absorption refrigeration system. A new analytical expression that fits the three dimensional surface of LiBr concentration, refrigerant temperature and solution temperature in the range of interest from 0.50 to 0.65 kg LiBr/ kg solution is presented with a standard deviation of ±0.2 percent. This will save considerable computing time and effort required for evaluation of system performance. A numerical example from typical running condition is added to show the relative weight of each parameter used together with the sequence of programme steps followed. The results from this simulation are heat rates, line concentrations, pressures and overall coefficient of performance.[15]

M A Mehrabian_ and A E Shahbeik had developed a computer program for design and thermodynamic analysis of a single effect absorption chiller using LiBr– H_2O solution as working fluid. The conditions of hot water entering and leaving the desorber, cooling water entering the absorber and leaving the condenser, chilled water entering and leaving the evaporator, as well as the approach temperatures in condenser, evaporator, desorber, and absorber, the effectiveness of solution heat exchanger, the chiller refrigeration power, and the ambient temperature are used as input data. The program then gives the thermodynamic properties of all state points, the design information of all heat exchangers in the cycle and the overall cycle performance. The results deduced from the computer program are used to study the effect of design parameters on cycle performance. It is also noticed that the temperatures of hot water, cooling water, and chilled water, respectively, at the inlet of the desorber, condenser, and evaporator have a great effect on cycle coefficient of performance. The results of this program can be used either for sizing a new refrigeration cycle or rating an existing system. It can also be used for optimization purposes. The predictions of the present program are compared with other simulating programs and qualitative agreement is achieved.[16]

MATHEMATICAL MODEL:

In recent years, the lithium bromide/water absorption refrigeration system has become prominent in refrigeration for air conditioning. It possesses several advantages over the other types of absorption system, such as:

1.) It has the highest coefficient of performance(COP) compared to other single stage absorption units at the same cycle temperatures.

2.) It is composed of simpler component since it can work efficiently without the need of rectification columns. A basic generator is sufficient due to the non volatility of absorbent(LiBr) allowing only water vapour to be driven off the generator.

3.) Less pump work is needed compared to other units.

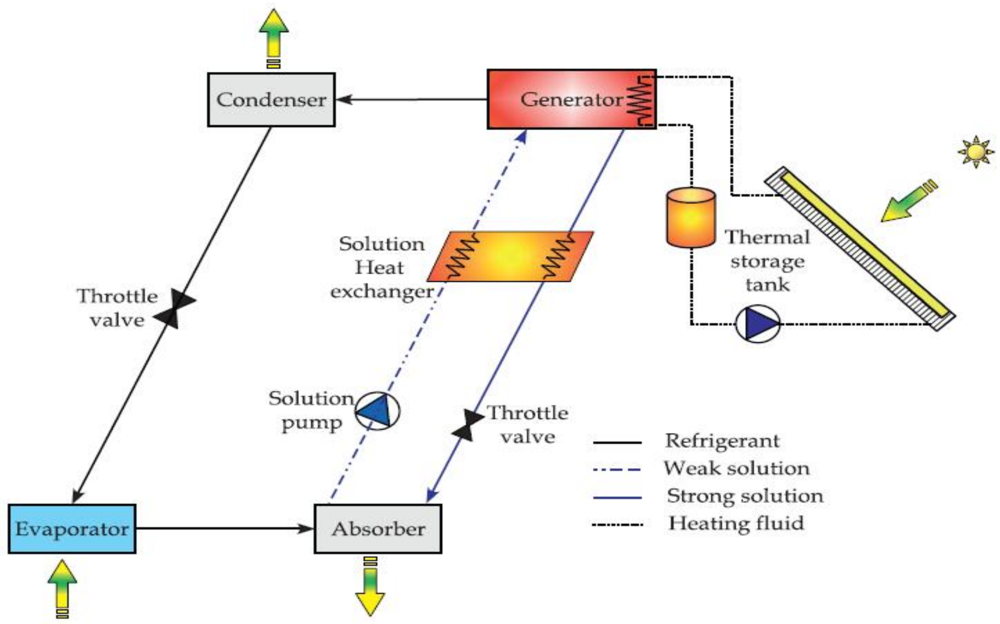

Fig. 1 Schematic diagram of solar absorption refrigeration system

Fig. 1 shows the schematic diagram of solar absorption refrigeration system. This article describes and analyzes the computer modelling of such units. The modelling procedure is generalized to enable those concerned with use or evaluation Of cycles employing this material to save considerable time and effort required for calculations.

Heat transfer in condenser, generator and absorber:
The heat balance of the condenser gives,

$$Qc=mR(H7-H8) \quad (1)$$

Heat balance for the combined generator and heat exchanger control volume gives,

$$Qg=mwH5+mRH7-msH2 \quad (2)$$

Heat balance of absorber gives,

$$Qa=mwH6+mRH10-msH1 \quad (3)$$

Table 1 Input parameters:

T_g=generator temperature(°C)	90(°C)
T_e=evaporator temperature(°C)	7(°C)
T_c=condenser temperature(°C)	40(°C)
T_a=absorber temperature(°C)	40(°C)
E_L=exchanger effectiveness	0.8
Q_E=load(kcal/hr)	3024(kcal/hr)

SYSTEM ANALYSIS:

System analysis is based on certain fixed parameters which are shown in table 1. Using this fixed parameters COP, Mass flow rate of refrigerant, mass flow rate of strong solution, mass flow rate of weak solution, heat transfer in generator, condenser and absorber

Issue 3, Vol.2 (May 2013)
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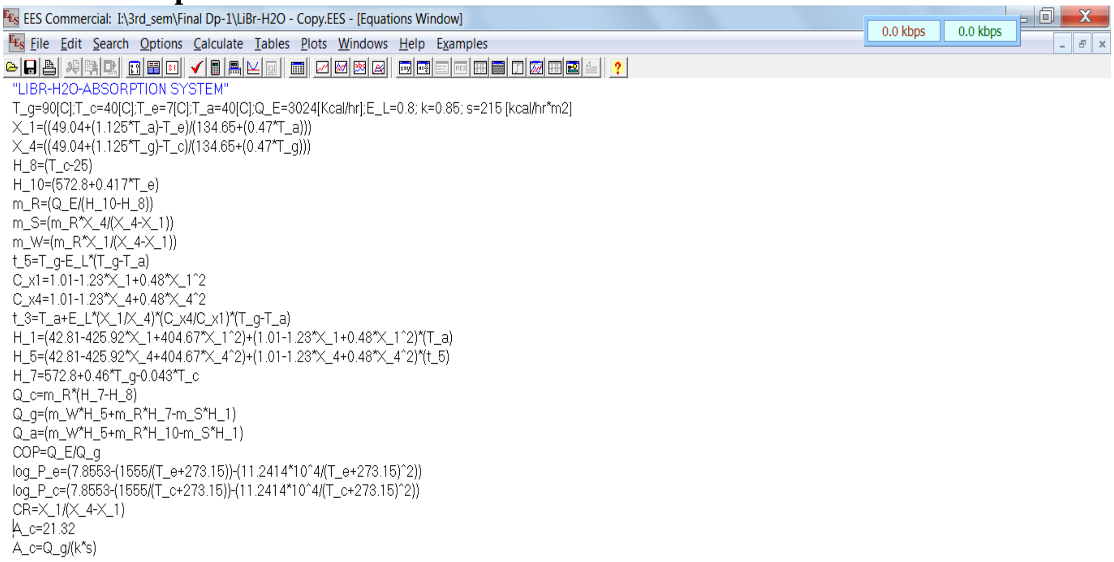
are find out using EES software and the effect of generator temperature, evaporator temperature, condenser temperature and absorber temperature on system COP is analysed using EES software.

Effect of temperatures:



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EES Commercial: I:\3rd_sem\Final Dp-1\LiBr-H2O - Copy.EES - [Equations Window]
File Edit Search Options Calculate Tables Plots Windows Help Examples
"LIBR-H2O-ABSORPTION SYSTEM"
T_g=90[C];T_c=40[C];T_e=7[C];T_a=40[C];Q_E=3024[Kcal/hr];E_L=0.8; k=0.85; s=215 [kcal/hr*m2]
X_1=((49.04+(1.125*T_a)-T_e)/(134.65+(0.47*T_a)))
X_4=((49.04+(1.125*T_g)-T_c)/(134.65+(0.47*T_g)))
H_8=(T_c-25)
H_10=(572.8+0.417*T_e)
m_R=(Q_E/(H_10-H_8))
m_S=(m_R*X_4/(X_4-X_1))
m_W=(m_R*X_1/(X_4-X_1))
t_5=T_g-E_L*(T_g-T_a)
C_x1=1.01-1.23*X_1+0.48*X_1^2
C_x4=1.01-1.23*X_4+0.48*X_4^2
t_3=T_a+E_L*(X_1/X_4)*(C_x4/C_x1)*(T_g-T_a)
H_1=(42.81-425.92*X_1+404.67*X_1^2)+(1.01-1.23*X_1+0.48*X_1^2)*(T_a)
H_5=(42.81-425.92*X_4+404.67*X_4^2)+(1.01-1.23*X_4+0.48*X_4^2)*(t_5)
H_7=572.8+0.46*T_g-0.043*T_c
Q_c=m_R*(H_7-H_8)
Q_g=(m_W*H_5+m_R*H_7-m_S*H_1)
Q_a=(m_W*H_5+m_R*H_10-m_S*H_1)
COP=Q_E/Q_g
log_P_e=(7.8553-(1555/(T_e+273.15))-(11.2414*10^4/(T_e+273.15)^2))
log_P_c=(7.8553-(1555/(T_c+273.15))-(11.2414*10^4/(T_c+273.15)^2))
CR=X_1/(X_4-X_1)
A_c=21.32
A_c=Q_g/(k*s)
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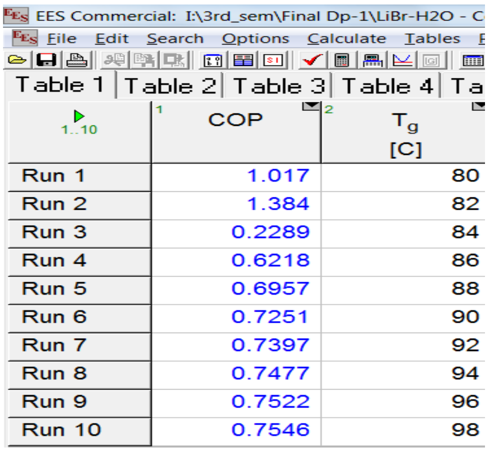

EES Commercial: I:\3rd_sem\Final Dp-1\LiBr-H2O - C

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Table 1 | Table 2 | Table 3 | Table 4 | Ta

1..10	COP	T_g [C]
Run 1	1.017	80
Run 2	1.384	82
Run 3	0.2289	84
Run 4	0.6218	86
Run 5	0.6957	88
Run 6	0.7251	90
Run 7	0.7397	92
Run 8	0.7477	94
Run 9	0.7522	96
Run 10	0.7546	98

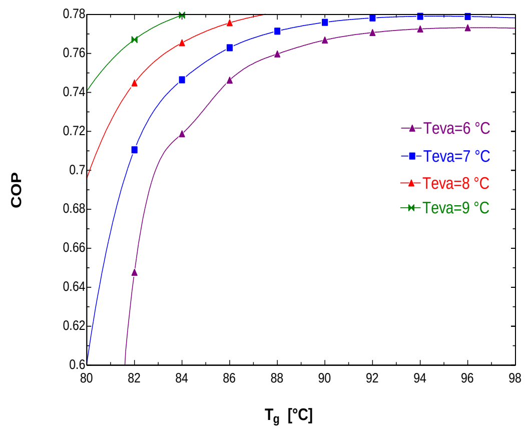
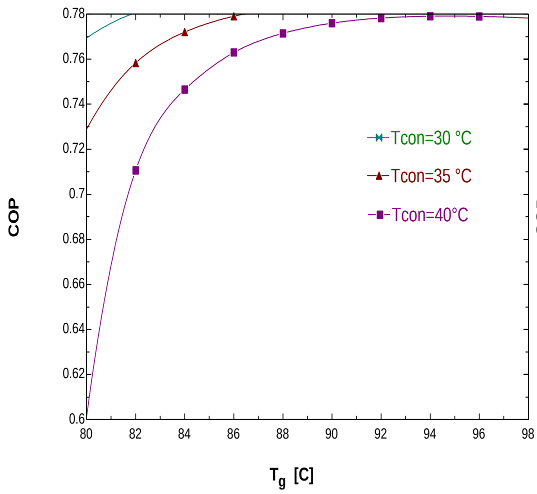


Fig.2 T_g vs COP(varying evaporator temp.)



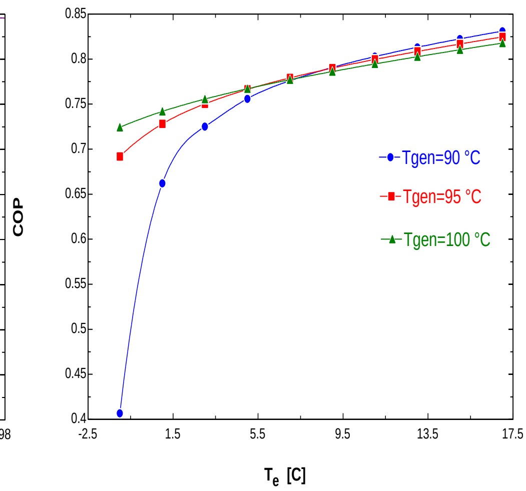


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Fig. 3 T_g vs COP(varying condenser temp.)

fig. 4 T_e vs COP(varying generator temp.)

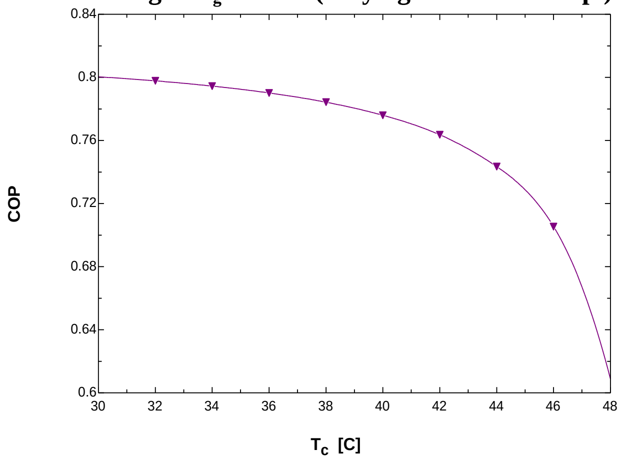

Fig. 5 T_c vs COP

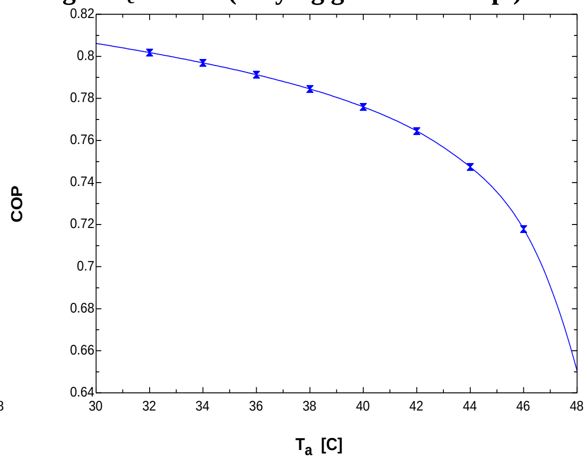

Fig. 6 T_a vs COP

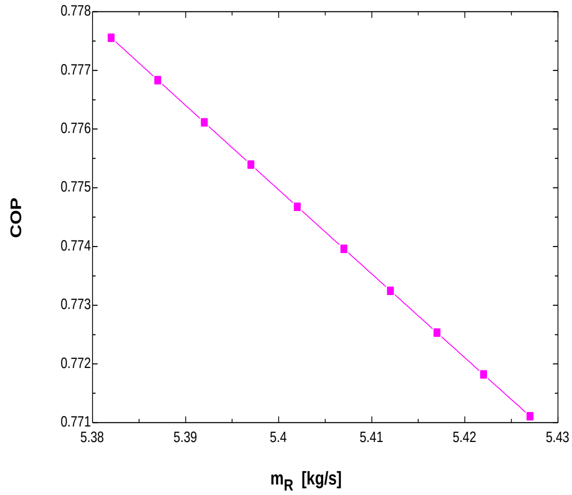

Fig. 7 Refrigerant flow rate vs COP

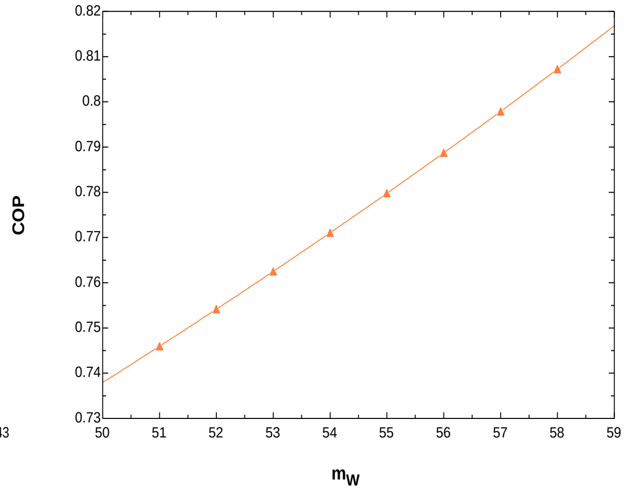

Fig. 8 Weak solution flow rate vs COP

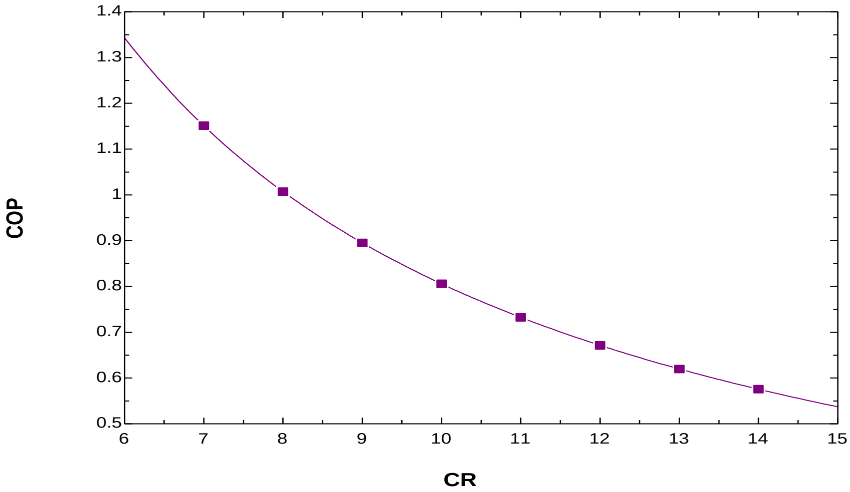

Fig. 9 Circulation ratio vs COP

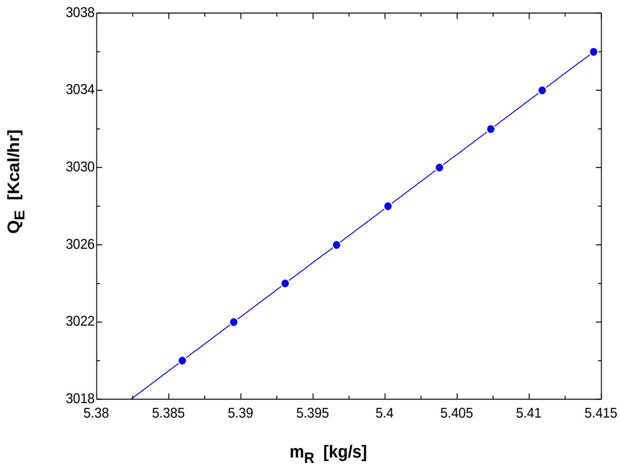

Fig. 10 Refrigerant flow rate vs Q_E

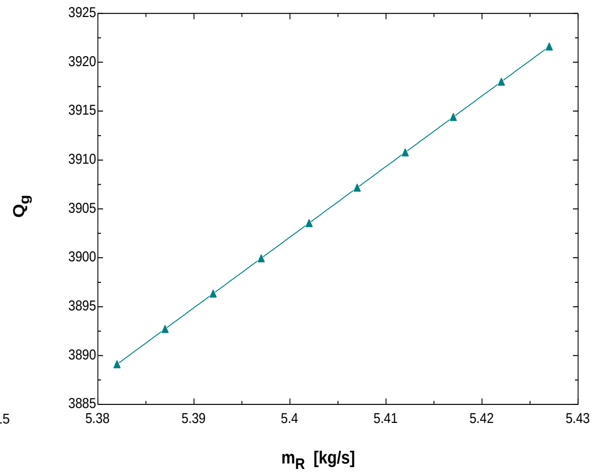

Fig. 11 Refrigerant flow rate vs Q_g

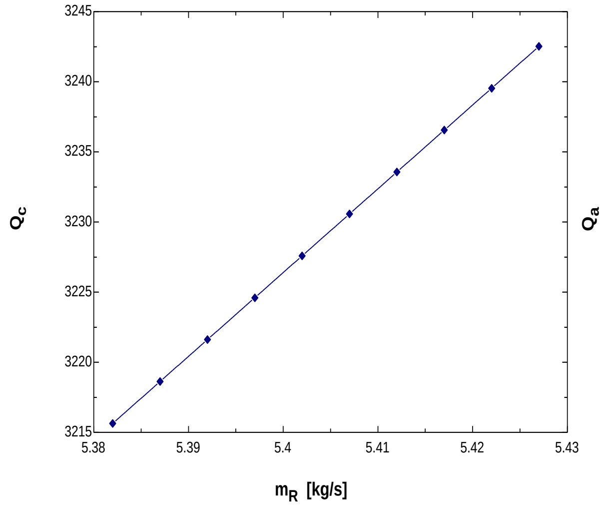

Fig. 12 Refrigerant flow rate vs Q_c

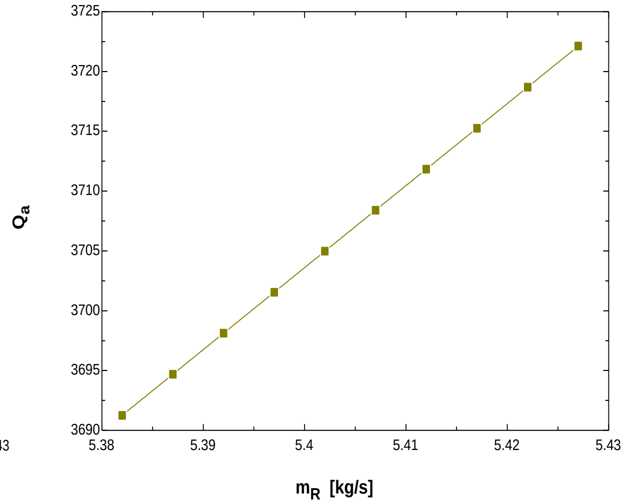

Fig. 13 Refrigerant flow rate vs Q_a

CONCLUSION:

From all this analysis it is seen that COP of system increases with increase in generator temperature and evaporator temperature but it reduces with increase in condenser and absorber temperature. There is optimum value of generator temperature above which COP reduces. Mass flow rate of refrigerant, weak solution and circulation has considerable effect on COP of the system. COP increases with increase in m_W but it decreases with increase on m_R and CR. With increase in mass flow rate of refrigerant heart transfer increases.

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