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Research Article

THE PARAMETRIC STUDY OF AN ABSORPTION REFRIGERATION SYSTEM SINGLE EFFECT WITH WATER-LITHIUM BROMIDE

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ABSTRACT

Absorption machines present an interesting alternative to conventional air conditioning systems. The Absorption machines offer an ecological aspect, in terms of the possibility of using solar energy as a heat source, and refrigerant having no ozone – depleting potential or global warning effect reported in literature.

In this paper a performance of a single effect absorption refrigeration systems of Water-Lithium Bromide are studied, some physical quantities were modelled and Plots, in particular the effect of operating temperatures on the coefficient of performance and the impact of solution exchanger efficiency and the system efficiency.

Keywords: Absorption Refrigeration; Cooling; EES; Water-Lithium Bromide.

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1. INTRODUCTION

Due to the high electricity consumption by compression chillers, todays, the cooling techniques use the solar energy became very well-known.

The absorption chillers use thermal energy instead of electrical energy to produce cooling one

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of the main advantages of this system lies in the synchronization between cooling demand and the availability of solar radiation.

In recent decades, it has been detected that several studies have aimed at improving the coefficient of performance and the reliability of absorption techniques using LiBr-H_2O promoting the application of cooling absorption [1-4].

However, the improvement of the effectiveness of these devices, in addition to lower its cost, remains targets that researchers are still studying to compete with traditional cooling systems that still dominate the market.

Kohlenbach et al. [5-6] developed a dynamic model for single effect H_2O/LiBr absorption chillers based on external and internal steady-state enthalpy balances for each main component. The work focused on modeling the dynamic behavior of absorption chiller using mass and thermal storage terms in all vessels, and a delay time in the solution cycle.

Erregueragui et al. [7] presented the analysis of the performance of different H_2O/LiBr refrigeration cycles as a function of external stresses (temperature of the heat source, condensation temperature, evaporation temperature, Insolation, etc.) and also gives the results of the optimization of the absorption machine.

Boudehenn et al. [8] presented a comparison of different absorption chiller modeling methods. Models were validated using experimental data of a single effect water-lithium bromide absorption chiller. Six of the models considered are empirically based ones and the last considered model is a physical one. These models are used to predict the effects of external water operating condition on cooling capacity and thermal COP.

Bonab et al. [9] simulated a single effect water/lithium bromide absorption chiller with additional heat exchanger in refrigerant side using EES and ASPEN Plus. The results show that COP and exergetic efficiency of the cycle with heat exchanger at refrigerant side are higher than conventional absorption cycle. Also, with increasing generator temperature, COP and exergetic efficiency first increases and reaches a peak then declined slightly and remained relatively constant but exergetic efficiency reduces, also the results show that probability of crystallization phenomenon increases with increasing the generator temperature.

A single- and double-effect water/lithium bromide absorption chiller designs are numerically modeled using ASPEN by Somers et al. [10], the verification with reference data reveals 3% and 5% discrepancy for the main single- and double-effect water/lithium bromide absorption cycles parameters. This indicates that the models provide sufficiently accurate results.

2. SINGLE EFFECT LITHIUM BROMIDE-WATER ABSORPTION SYSTEM

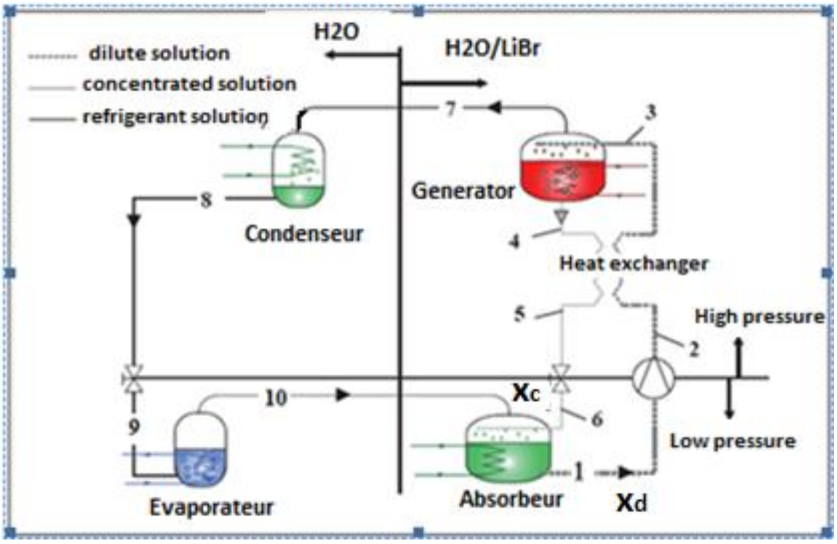

Fig.1. Single effect LiBr -Water absorption cycle

Figure 1 shows a single-effect LiBr-Water absorption cycle, basic components are the absorber, the condenser, the generator, and the evaporator, it is optional to install a heat exchanger in the basic single effect absorption refrigeration System, to increase refrigeration performance, and such a unit should be attached [11]. As well as one solution pump and two expansion valve. Among the most common combinations of cooling liquids, we find water - lithium bromide (LiBr-H_2O) where water vapor is the refrigerant.

Absorption machines operate with two levels pressure, low pressure at the absorber where the refrigerant is absorbed, and high pressure at the generator where the refrigerant desorbed [12]. The internal process of a cooling device is affected by the absorption of lithium bromide by water with pressure and working fluid concentration [13].

2.1 Operation and Performance

The absorption cycle works in the same way as the compression refrigeration cycle only the mechanical compressor is replaced by a thermo-chemical compressor, containing a mixture of a refrigerant which will flow in the condenser/evaporator and an absorbent which interacts strongly with the refrigerant. This interaction is the cause of the refrigerant absorption phenomenon in the solvent which forming a liquid solution.

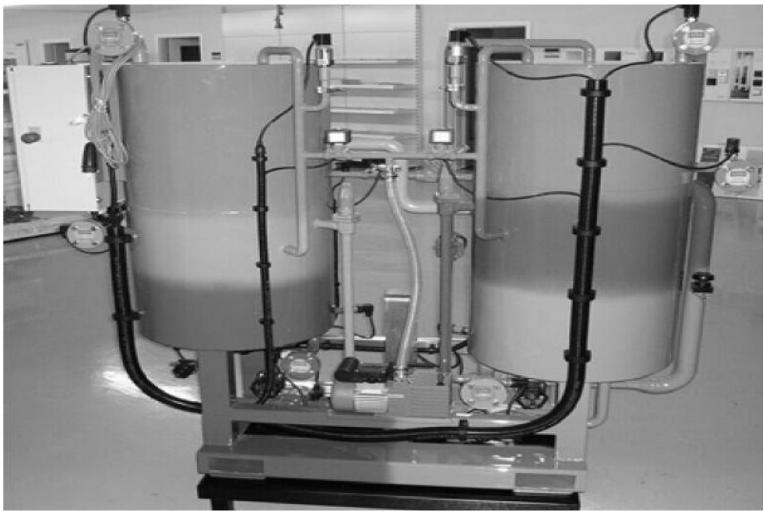

Fig.2. Small size single effect absorption cooling machine

A solution of LiBr-H_2O is heated in the boiler (generator) through external heat gains, the solution boils, sending refrigerant vapor into the condenser and leaving concentrated lithium bromide.

The refrigerant vapor condenses on the tubes, after the refrigerant liquid moves from the condenser to the evaporator where cooling is provided, as the refrigerant vapor leaves to the absorber from the evaporator at low pressure it is again absorbed by the absorbent in the boiler [14].

2.2 System Process Development

In (1850), the first absorption chiller was developed by (Edmond Carré) using water and sulphuric acid, and in 1873 (Ferdinand Carré) patented a commercial ammonia water refrigerator [15], but this technology began to deployment until the late (1960s).

In these periods the absorption chillers were characterized by their large size and low COPs, which hindered the application of such chillers in air conditioning.

In (1970, Trane company) provided the first mass produced double-effect LiBr-H_2O absorption chiller [16]. Since then LiBr-H_2O absorption chillers become one of the main tools for the production of thermal energy, particularly in the field of refrigeration.

(Uchida, 1996) [17] Constructed a unit Absorption cooling system comprising a number of cooling devices connected to one another, in which chilled water flows through the chiller units in series while cooling water flows through the chiller units in parallel, the absorption solution is sprayed in one or more stages in the absorber.

In this invention the temperature difference is 1,4 times larger than that in a conventional absorption machine and reduces the amount of chilled water to 70%, and it also reduces the amount of cooling water to 75% of that in a conventional machine through exploiting the biggest difference in the temperature of cooling water. Moreover, because the average temperature of chilled water is higher, and the average cooling water temperature is lower, it making the efficiency of this refrigeration unit better than that at conventional machine. Thus, it reduces the capacity required for the pipe sizes, transportation pump and cooling tower.

To reduce the size of the cooling system and increasing its efficiency, (Inoue et al, 2002) [18], discovered an absorption machines for the cooling machine which uses plate type heat exchangers in the absorber and the condenser where cooling water flows in the absorption and condensate at the same time. This arrangement greatly reduces the flow rate into the absorber and condenser in turn, reduces the size of the plate type heat exchanger. The water distribution is mainly based on fluid resistance and therefore, this system eliminates the complicated flow regulating valve system [13].

2.3 Crystallization problem

Lithium bromide aqueous solution is one of many other solutions widely used in the operation of the absorption heat pumps that are used for cooling purposes. It has been used since the 1950s when the technology was pioneered by several manufacturers in the U.S.

In absorption chillers, the crystallization line for lithium bromide and water is very close to the working concentrations needed for practical LiBr/H_2O absorption chiller (Figure 3). If the solution concentration is too high or the solution temperature is reduced too low, the crystallization may occur and interrupting machine operation.

In cooling machines that use lithium bromide, it is necessary to avoid the phenomenon of crystallization, because the formations of salt in the piping network block the flow very quickly [19].

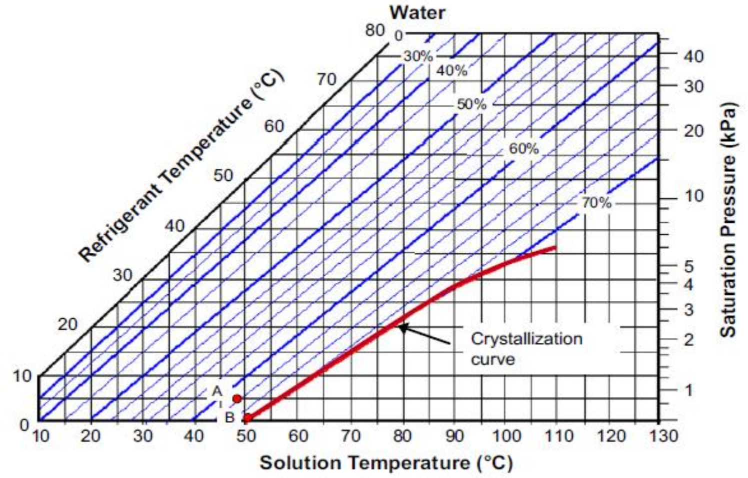

Fig.3. The property chart of LiBr/H_2O solution with crystallization curve.

3. METHODOLOGY OF SIMULATION

A thermodynamic model of the absorption cycle was studied using the Engineering equation solver (EES) program [20]. EES, solves nonlinear algebraic and differential equations [21], EES discretizes the equations so that they are numerically solved. It also offers the advantage of containing in its database, the characteristics relating to the majority of the fluids currently used in such machines. This approach was adopted in the modelling of absorption heat pump cycles by Keith Herold who made in a special version of the EES [22].

3.1. Modelling

This section presents the results obtained through the models thereby permitting to analyse and studying the effects of various parameters on the machine efficiency.

Many simulations have been done using EES to evaluate performance system. The program is based on mass balances and enthalpy balance in each component of the machine [23], and state equations of lithium bromide - water. The state equations were evaluated by the thermodynamics properties of LiBr and water is available in the EES library [24].

4. MATHEMATICAL MODELS

Mass and energy balance is based on the first law of thermodynamics meaning that the mass and energy flow into a system is equal to the change of mass and energy inside the system and the mass and energy flow out of the system. The same goes for all individual components in the flow when no reaction occurs between the components (figure 1).

4.1. Solution balance

mf, md, mc : are the mass flow rates of refrigerant, dilute solution and concentrated solution respectively.

$$mf + mc = md \tag{1}$$

4.2. Lithium-bromide mass balance

$$mc * xc = md * xd \tag{2}$$

xd, xc: Respectively the concentration of dilute solution and concentrated solution.

From (1) and (2) we deduce the expression of md and mc as a function of the flow rate of the refrigerant as follows:

$$md = \left(\frac{xc}{xc - xd}\right) * mf \tag{3}$$

$$mc = \left(\frac{xd}{xc - xd}\right) * mf \tag{4}$$

4.3. Energy balance

The simulation of the single-effect absorption cycle proceeds by writing appropriate steady state mass and energy balance equations for each of the components.

Absorber:

The refrigerant in the vapor state coming from the evaporator is absorbed in the absorber solution which is enriched in refrigerant, we have:

$$Q_a = m_f * h_{10} + m_c * h_6 - md * h_1 \tag{5}$$

Generator:

The refrigerant is separated from the solution under the effect of heat supplied to the generator by a source external thermal, the balance is written:

$$Q_g = m_f * h_7 + m_c * h_4 - m_d * h_3 \tag{6}$$

Condenser:

At the outlet of the condenser, the refrigerant becomes a fluid.

$$Qc = m_f * (h_8 - h_7) \quad (7)$$

Evaporator:

At the level of the evaporator we have the useful effect, thermal power is absorbed by the fluid refrigerant to allow its evaporation.

$$Qe = m_f * (h_{10} - h_9) \quad (8)$$

Solution pump:

The circulation pump transfers the rich solution with refrigerant to the generator at high pressure.

$$W = m_c * (h_2 - h_1) \quad (9)$$

Solution heat exchanger:

At this element, the energy balance is written as follows:

$$m_d * (h_3 - h_2) = m_c * (h_4 - h_5) \quad (10)$$

4.4 Coefficient of Performance

The coefficient of performance is a qualitative criterion characterizing the reliability of the machine. The practical coefficient of performance of a refrigerating cycle, which must not exceed that of Carnot, is defined as the ratio of quantity of heat supplied to the evaporator Qe, to the quantity of heat supplied to the generator Qg.

$$COP = \frac{Qe}{Qg + W} \simeq \frac{Qe}{Qg} \text{ [25-26]} \quad (11)$$

Due to the small work for the pump relative to the heat input at the generator is often neglected [27].

4.5 The Theoretical Coefficient

The performance coefficient of the Carnot reference cycle is expressed by the following relation:

$$COPn = \left(\frac{Tg - Ta}{Tg}\right) * \left(\frac{Te}{Tc - Te}\right) \quad (12)$$

4.6 The Flow ratio

The flow ratio (Fr), is the ratio of the mass flow rate of the rich solution (md) coming from the absorber to the generator to the mass flow rate of the working fluid (mf).

The flow ratio is an important criterion for improving machine operation, it is directly related to the size and cost of absorption generator, heat exchanger and pump [28].

$$Fr = (\frac{md}{mf}) = (\frac{xc}{xc - xd}) \tag{13}$$

4.7 The effectiveness of the system

Defines as follows:

$$n = \frac{COP}{COPn} \tag{14}$$

4.8 Efficiency of Solution Heat Exchanger

At the level of this element, heat exchange takes place between the poor solution and the rich solution, the efficiency of solution heat exchanger is defined as follows:

$$EFF = \frac{T4 - T5}{T4 - T2} \tag{15}$$

5. RESULTS AND DISCUSSIONS

5.1 Effect of the generator temperature on the COP

The upper part of the figure shows the evolution of the COP shows that the increase in condensation temperature Tc results in the decrease in the COP , which due to the increase in the value of enthalpy at the regulator, therefore it decreases the value of flow rates (Fr).

The second part of the figure shows that the decreases in condensation temperature Tc and the increase in generator temperature Tg increases the $COPn$.

$Te = 6$°C, $Ta = 38$°C, $EFF = 70\%$

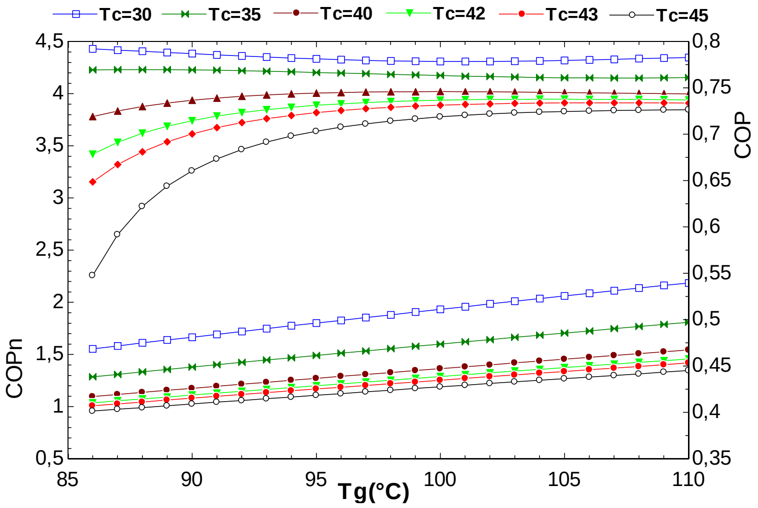

Fig.4. Variation of COP and $COPn$ against generator temperature Tg

5.2 The effect of the condensation temperature Tc on the COP

When Tg has a step change from 80°C to 105°C and Tc from 30°C to 45°C, Figure 5 shows that the coefficient of performance decreases with the increase of the condensation temperature Tc and it is important when the condensation temperature is high.

And when the temperature of the generator is less than 85°C the COP is downfall. And $COPn$ decreases with increasing condenser temperature.

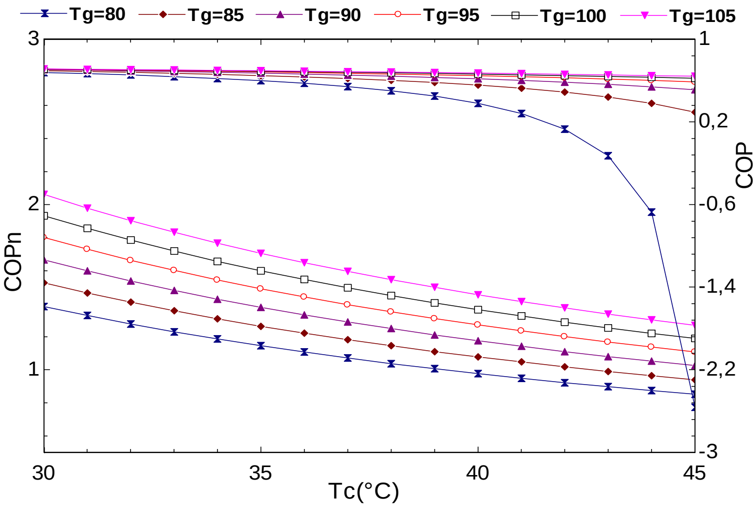

Fig.5. Effect of the Tc on the (COP) and ($COPn$)

5.3 The effect of evaporator temperature Te on COP

Tc =43°C, Ta =38°C, EFF =70%

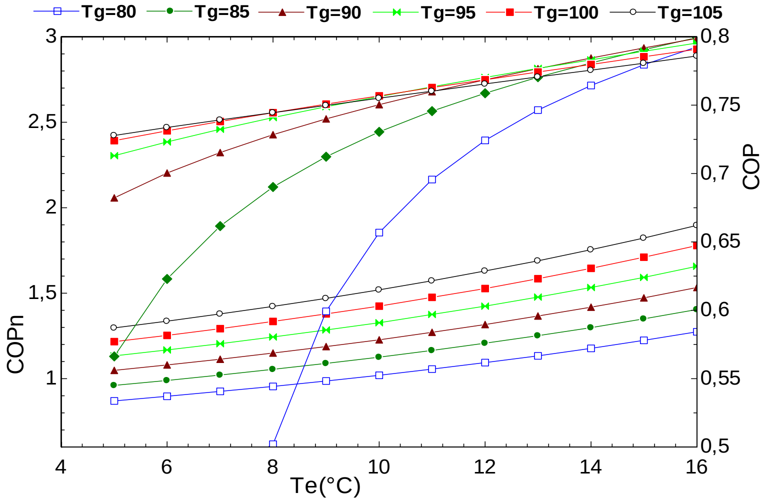

Fig.6. Variation of (COP) and ($COPn$) against Te

The temperature of the evaporator is a very important parameter on the machine. The increase in the temperature of the evaporator causes increase in the enthalpy of the evaporator an effect that also increases in the value of the COP .

The $COPn$ increases linearly with the elevation of Te .

5.4 The effect of the absorption temperature on the COP

The variation of the system thermal performance (COP) with Ta , Tg is illustrated in figure 7, the increase in the temperature of the absorber Ta increases the circulation flow rate Fr and, therefore the decrease in the COP .

It observed that the COP fall when the generator temperature Tg is between 85 and 90°C, and it stabilizes when the temperatures Tg more than 90°C. The condensation temperature Tc has a positive effect on the efficiency of the system. Also the increase of the temperature of the absorber leads to the decrease of $COPn$.

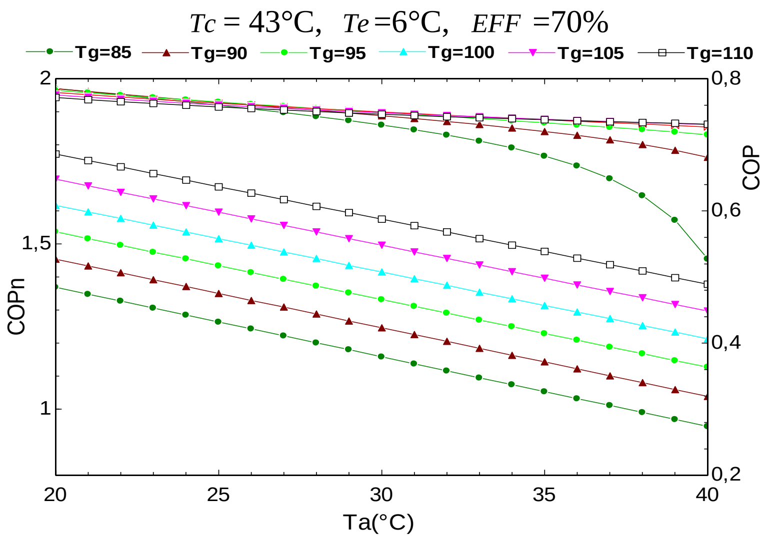

Fig.7. Variation of (COP) and ($COPn$) against Ta

5.5 Effect of solution exchanger efficiency on the COP

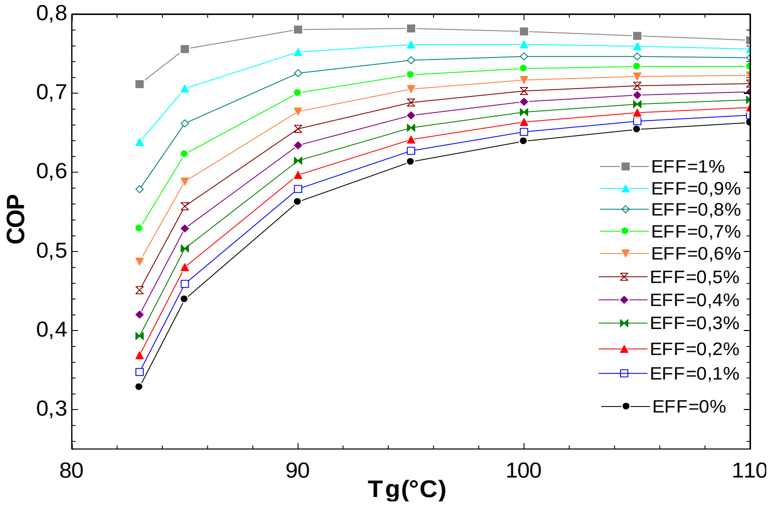

Fig.8. Variation of (COP) for different efficiencies of the solution exchanger

For different values of Tg (from 83 to 110°C), and progressive values of the effectiveness of heat exchanger from 0% to 100%, we see that the COP increases with increasing of the solution heat exchanger effectiveness value. This shows that this progressive increase of COP was interesting when Tg in the range of 85 to 90°C, then it becomes low for values of Tg more than 95°C until becomes constant.

5.6 Effect of the generator temperature Tg on the Flow ratio Fr

The circulation flow rate Fr decreases with the increase of the generator temperature Tg . In the interval of Tg (83-90°C) the fall of Fr is considerable, it increases with the decrease of the value of Tc, for the value of Tg =95°C (Fr) can be considered constant.

Te=6°C, Ta=38°C, EFF =70%

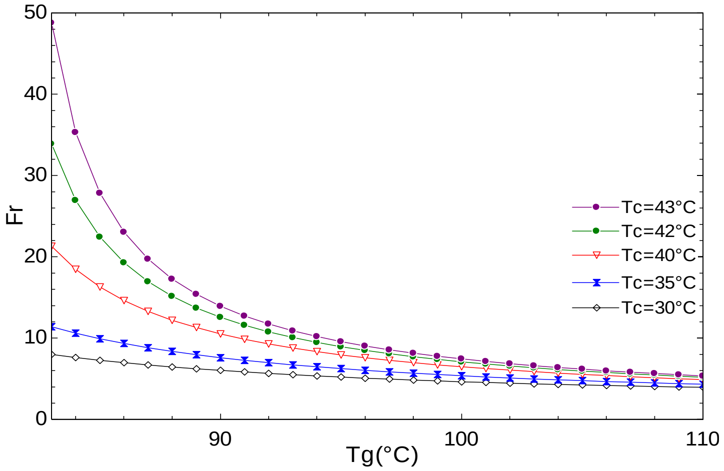

Fig.9. Variation of the Fr according to (Tg)

5.7 Effect of the generator temperature Tg on the efficiency of the system (η)

Figure 10 displays the effect of different Tc on the (η) when Tg from 80 to 110°C, so the efficiency of the system decreases with the rise of generator temperature. This is due to the rapid increase in $COPn$ compared to the increase in COP when Tg increases. On the other hand, the increases in Tc decrease the $COPn$, thereby (η) increases.

Te=6°C, Ta=38°C, EFF =70%.

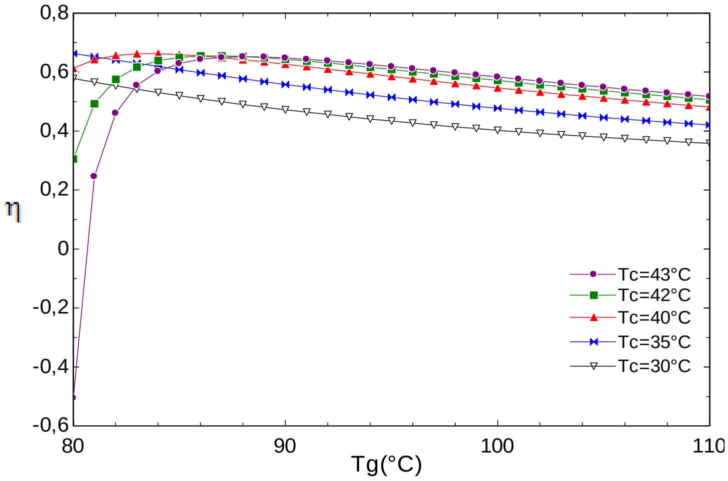

Fig.10. Variation of (η) as a function of (Tg)

6. CONCLUSIONS

The various results presented in this work are obtained from the analysis of model equations developed using EES, allowing our model to analyze and study different Parameters on system efficiency and performance of each component of the system.

To study the effect of a parameter, we alter the reference state and keep the other parameters constant, we find that:

The coefficient of performance COP, the circulation rate (Fr) and the efficiency of the system (η) are important parameters to evaluate the performance of the system.

The COP goes rises highly when the temperature at the generator is increased, it decreases when the temperature at the condenser or the absorber increases and increases with the evaporation temperature.

Concern temperature of the generator, there is a maximum value where the coefficient of performance is maximal and is suits more the working cycle that cannot be exceeded because of the crystallization of LiBr.

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NOMENCLATURE

COP	coefficient of performance (dimensionless)
COPn	coefficient of performance of Carnot (dimensionless)
EFF	efficiency of solution heat
Fr	exchanger flow ration (dimensionless)
h	enthalpy (KJ/Kg)
m	masse flow rate ($Kg.s^{-1}$)
Q	heat load (Kw)
T	temperature (°C)
W	work(KW)
x	Concentration (%)

Greek symbols

a	absorber
c	concentrated
C	condenser
d	dilute
e	evaporator
f	refrigerant
g	generator
n	effectiveness of the system (dimensionless).

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