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Received on: 14/12/2016

Accepted on: 27/04/2017

## Modeling and Simulation of an Absorption Solar Cooling System Under Iraqi Weather Conditions

**Abstract:** This work aims to model and simulate an absorption cooling system using solar flat-plate receiver with water lithium bromide (LiBr-H<sub>2</sub>O) mixture as a working fluid, and to select the optimum type for absorption cooling system, which have suitable application in Iraq. Weather conditions for Erbil city have been selected. Coefficient of performance (COP) for a single, double (series and parallel), half and triple effect of an absorption cooling system are calculated and optimized. COP Prediction, hot water temperature, and the rate of heat transfer have been simulated and represented by using TRNSYS and EES programs. Active area of the solar flat-plate receiver is calculated and optimized for five suggested areas of (140, 150, 160, 170, and 180 m<sup>2</sup>). Average heating load, average daily - radiation and cooling load for summer months (June, July, August, and September) have been calculated. The results indicated that, the superior type of the four absorption-cooling systems is a single effect, which has COP 80% at generator temperature of (81 °C). Also the results indicated that the optimum area of solar flat-plate receiver was 160 m<sup>2</sup> which has achieved the maximum capacity of cooling power and consumed capacity in the generator (50, and 62.5) kW respectively. I think, according to the previous studies, the current work is the first in Iraq because it approved that, single effect type is an efficient and more relevant type for good working under Iraqi climate by using solar flat-plate receiver and suitable to apply it experimentally in a wide range.

**Keywords:** Solar flat-plate receiver, An absorption cooling systems, TRNSYS, EES programs.

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How to cite this article: H.A. Hussein, "Modeling and Simulation of an Absorption Solar Cooling System Under Iraqi Weather Conditions," *Engineering and Technology Journal*, Vol. 35, Part A, No. 4, pp. 356-364, 2017.

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### 1. Introduction

The application of computer simulation and modeling of thermal cycles has a large number of advantages includes the reduction of the cost of building prototypes, the process of optimization of the cycle components, enhancing of thermal energy loads delivered or received from or into the cycle, and prediction of differences in the cycle parameters [1].

It is internationally confirmed that, the electric power consumption for cooling is drastically increasing. On the other hand the energy sources are decreasing; in addition, the heat emission phenomenon and desertification: 1. Justify the using of solar energy, 2. Availability of the sun and dust -free climate of Erbil compared to the other parts of Iraq. 3. Reduces the maintenance costs of the entire solar system. The annual average daily solar energy received from the sun ranges of (4.5–5.4) kWh/m<sup>2</sup>. Erbil city is located at 36° 11' 0" N, 44° 2' 0" E. The 36<sup>th</sup> parallel north is a circle of latitude that is 36° north of the Earth's equatorial plane. At this latitude the sun is visible for 14 hours, during the summer and 10 hours during the winter [2].

The alternative solution to meet the growing demand for electricity is solar radiation that is available in all areas of Iraq that represents a better supply source of thermal power than other new sources. There are many types of solar receiver's models that are functional. These models are divided in two general classes: - First, is flat-plate receiver, in which the absorbing surface is approximately as large as the overall receiver area that intercepts the sun's rays. Second, concentrating receivers, in which large areas of mirrors or lenses focus the sunlight onto a smaller absorber [3].

Flat-plate receivers are the most common solar receivers for solar water-heating cycles in houses and other applications such as solar space heating. A typical flat-plate receiver is an insulated metal case with a glass or plastic cover and a dark-colored absorber plate [4].

Figure 1 shows a flat-plate solar receiver which is one of the most widely used devices for harnessing solar energy.

A part of the absorbed radiation is transferred to a fluid like air or water. It can be used for a variety of applications in which the temperature ranging from 40 °C to 100 °C is required, [5,6].

Absorption cooling system of the single effect type is the simplest and the most common cycle, which is selected in this study, because the temperature required for working, is low and has the simplest cooling system as shown in Figure 2. It operates at an absolute pressure of less than 10 kP, and this internal machine operates at less than atmospheric pressure, so this requires a design that is impermeable to avoid air leakage, moreover, the low-pressure restricts the design components that should reduce the drop in pressure. It should be noted that the deep cooling points (point 5) or overheating (point 7) cannot be represented accurately on the chart and one must be thoroughly familiar with the thermodynamic state of all the points to understand the circuit [6].

A single-effect absorption cooling system basically consists of four components that heat exchanger with the surroundings namely, the condenser, the generator, the evaporator and the absorber. It presents an internal heat exchanger for the (Li. Br. - H<sub>2</sub>O) working fluid, two expansion valves and a solution pump. [7] showed that the implementation of computer modeling of thermal systems has a series of advantages such as eliminating the cost of building prototypes, the optimization of the system components, estimation of thermal energy loads delivered, and prediction of variations of the system parameters. [8] studied and simulated the solar absorption cooling system under Tunisian climate conditions. They applied two programs which are TRNSYS and engineering equation solver. The cooling system was optimized for building area of 150 m<sup>2</sup> and Li. Br. - H<sub>2</sub>O mixture as working fluid with a load of 11 kW, and solar collector area (30 m<sup>2</sup>). The results of modeling and simulation indicated that an absorption cooling system is more suitable under Tunisian climate conditions.

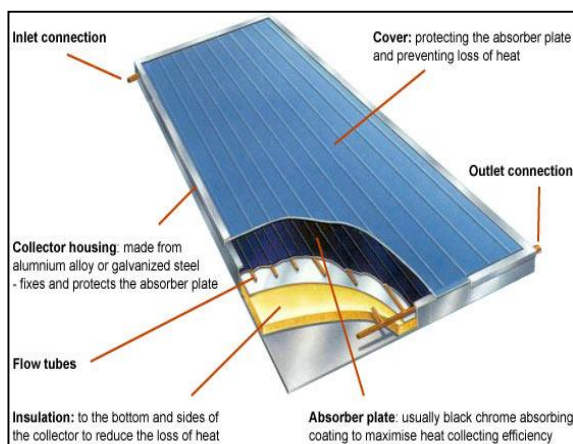


Figure 1: Schematic diagram of solar flat plate collector [5]

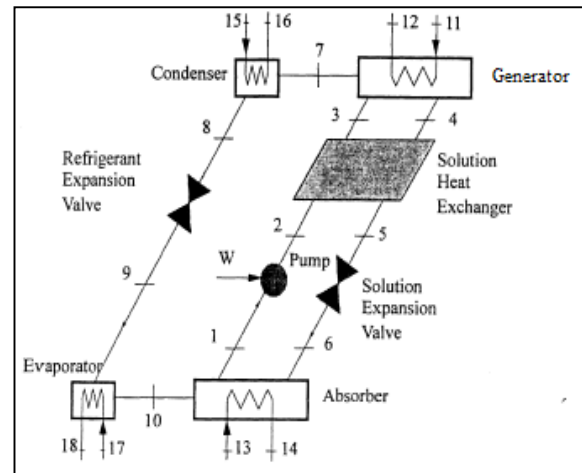


Figure 2: Schematic diagram of an absorption cooling system [8]

The present work demonstrates the optimum type of an absorption cooling system, and optimize the area required for solar flat-plate receiver to simulate the best performance of absorption cooling system using TRNSYS and EES programs for summer months (June, July, August, and September) for Erbil city to investigate: Coefficient of performance variation, the temperature of generator, the condensation temperature, the rate of heat transfer variation and hot water temperature variation with time.

## 2. Methodology

From Figure 2 a set of mathematical equations has been used to calculate the coefficient of performance (COP) for single-effect absorption cycles, as following relations [9,10].

$$\Sigma Q = Q_{gen.} + Q_e \quad (1)$$

$$Q_G + W + Q_o = Q_c + Q_a \quad (2)$$

$$Q_G = \dot{m} (h_7 - h_3) + (\dot{M} - \dot{m})(h_4 - h_3) \quad (3)$$

$$\frac{\dot{M}}{\dot{m}} = \frac{X_4 - X_7}{X_4 - X_3} = f \quad (4)$$

$$Q_{gen.} = h_7 + (F - 1) * (h_4 - f) * h_3 \quad (5)$$

$$Q_e = h_{10} - h_9 \quad (6)$$

$$COP = \frac{Q_e}{Q_{gen.} + W_p} \quad (7)$$

$$T_G = T_h - \Delta T \quad (8)$$

$$T_K = T_W + \Delta T \quad (9)$$

## 3. Model Solution

Equations (1-9) can be solved by using EES (Engineering Equation Solver) program. This

program is based on the numerical solution. There are two major differences between EES and existing numerical equation-solving programs. First, EES automatically identifies the equations that must be solving simultaneously. This feature simplifies the process for the user and ensures that the solver will always operate at optimum performance. Second, EES provides many built-in mathematical and thermo-physical functions useful for engineering calculations. Figure 3 shows Psychrometrics scheme of air in the climatic conditions of Erbil city and there are three dimensional quantities: X: expresses the ratio of the energy lost from the complex at a temperature of retaining heat to the heating load, Y: the proportion of the absorbed solar energy to the heating load, F: the proportion of convection covered by solar energy. The value of (X, Y and F) can be calculated from the following relationships [11].

$$X = F_R \cdot U_L \cdot \left( \frac{F_R'}{F_R} \right) \cdot (\overline{T}_{REF} - \overline{T}_a) \cdot \Delta t \cdot \frac{A}{L} \quad (10)$$

$$Y = F_R (\tau\alpha)_n \left( \frac{F_R'}{F_R} \right) \cdot \frac{(\tau\alpha)}{(\tau\alpha)_n} \cdot \overline{H}_T \cdot N \cdot \frac{A}{L} \quad (11)$$

$$F = 1.029.Y - 0.065.X - 0.245.Y^2 + 0.0018.X^2 + 0.0215.Y^3 \quad (12)$$

$$0 \leq X \leq 18, \quad 0 < Y < 3$$

$$F = \frac{\sum(Li \times Fi)}{\sum Li} \quad (13)$$

$$P = \frac{\sum(Li \times Fi)}{A} \quad (14)$$

$$A_{optimal} = (F \times P)_{max} \quad (15)$$

#### 4. Computer Simulation

Computer simulation software has become a very attractive tool for engineers and researchers because of its ability to predict the system behavior. TRNSYS program is applied by engineers and researchers around the world to validate new energy concepts, from simple solar domestic hot water systems to the design and simulation of buildings and their equipment, including control strategies, resident behavior, alternative energy systems (wind, solar, photovoltaic, hydrogen systems), [12,13]. It is necessary to determine the range of temperature in the generator ( $T_g$ ) on (pressure-temperature-concentration) scheme to draw the field variation of performance coefficient scheme, which depends

on the value of the single-effect as shown in Figure 4.

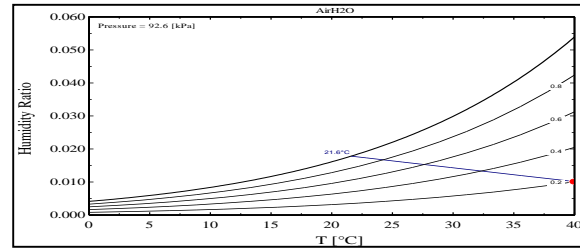


Figure 3: Psychrometrics scheme of air in the climatic conditions of Erbil city [3]

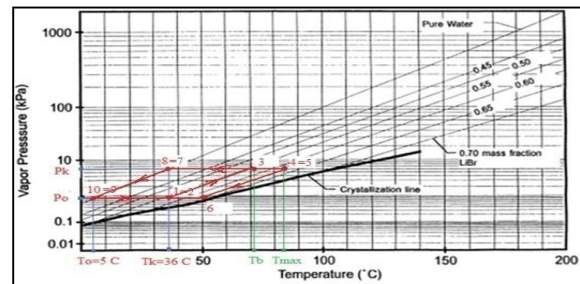


Figure 4: Determination of the generating temperature on P-T-X scheme [10]

The thermal load ( $Q_l$ ), cooling of the evaporator  $Q_e$ , thermal possible generator ( $Q_g$ ) and the value of ( $\eta$ ) for months of June, July, August and September can be calculating from the following relations [14]:-

$$Q_g = \frac{Q_L}{\eta} \quad (16)$$

$$L_{month} = 3.6 \times N \quad (17)$$

The mean load of generator for capacity cooling  $Q_e = 50$  kW, COP = 0.8, then the possible required power in generator will be determined from the following formula [14]:-

$$Q_g = \frac{Q_e}{COP} \quad (18)$$

The simulation of this work is based on TRNSYS program. From the curve of efficiency of the detector used (flat-German type viessmann vitosol-100) and the curve of performance when solar radiation intensity  $G = 800$  W / m<sup>2</sup> ,  $F_R \cdot U$  and  $F_R (\tau\alpha)_n$  can be calculated:  $F_R U = 3.94$  W/m<sup>2</sup> °C,  $\eta = F_R (\tau\alpha)_n = 0.791 C_0 = 0.8$  ;  $C_1 = 13$

$kJ/h.m^2.k$  and where these values are entered as data entry in the TRNSYS program in addition to the flat-plate solar collector used ( $A = 160$  m<sup>2</sup>) .The angle of inclination axes ( $S = 48.3$ ) is chosen to be greater than latitude angle by 15 °.

The average monthly direct daily- radiation rate  $R_b$  can be calculated by using graphs and charts for a special relationship between  $\phi$  latitude and laboratories and that at a specific angle for (S-  $\phi$ ). In order to find out the performance throughout the year per month, demand for energy is higher in summer than in winter, the optimum tilt angle is greater at a rate of (10-20) ° of latitude angle. Therefore, monthly average calculation of the value of ( $\tau\alpha$ ) can be found from the following formula [14, and 15]:

$$\eta_{coll} = c_0 - c_1 \cdot \frac{\bar{T}_{abs} - T_{amb}}{I_g} - c_2 \cdot \frac{(\bar{T}_{abs} - T_{amb})^2}{I_g} \quad (19)$$

$$R = \left(1 - \frac{H_d}{H}\right) R_b + \frac{H_d}{H} \left(\frac{1 + \cos S}{2}\right) + \rho \left(\frac{1 - \cos S}{2}\right) \quad (20)$$

$$\frac{H_d}{H} = 1.39 - 4.03K_T + 5.53K_T^2 - 3.11K_T^3 \quad (21)$$

$$\frac{(\tau\alpha)}{(\tau\alpha)_n} = \left(1 - \frac{H_d}{H}\right) \cdot \frac{R_b}{R} \cdot \frac{(\tau\alpha)_b}{(\tau\alpha)_n} + \frac{H_d}{H} \cdot \frac{1}{R} \left(\frac{1 + \cos B}{2}\right) \cdot \frac{(\tau\alpha)_d}{(\tau\alpha)_n} + \rho \cdot \frac{1}{R} \cdot \left(\frac{1 - \cos B}{2}\right) \cdot \frac{(\tau\alpha)_r}{(\tau\alpha)_n} \quad (22)$$

**5. Results and Discussion**

The results of this work have gained importance, relying on computational programs and the introductions of reliable information were taken for the most important area of Erbil city - Iraq, because it is free of dust. The available of dust in air affects negatively on the performance of the solar collector and this increases the maintenance costs of the system. The results of simulation are presented by tables and graphs to predict the variation of COP, hot water temperature and the rate of heat transfer during the summer months as shown the following: Tables 1, 2, 3, 4 and 5 present the results of the key variables for each of the important coverage F x P productivity and energy to the area of the detector when changed a flat- plate solar collector's area (140,150,160,170 and180 m<sup>2</sup>) for the four summer months under weather data of Erbil city - Iraq. From the values of these tables, it is found that the best area was 160 m<sup>2</sup> since achieved the max. Value of (F x P). Table 6 summarizes the results of the monthly average of the daily calculation of the solar radiation falling on the sloping surface of the four months (June, July, August, and September), while table 7 shows the results of thermal load of the middle generator for these months. It indicates that the highest load average is for the months of July and August. Table 8 summarizes the results of the average monthly account to the permeability of the compound covers and absorbency board absorber of solar radiation falling vertically on the surface of the compound four months.

**Table 1: Results of calculation of the coverage F and production capacity P at the solar collector area (A = 140 m<sup>2</sup>)**

A=140 m <sup>2</sup>	June	July	Aug.	Sept.	F	P	F×P
X	1.913	1.860	1.868	1.939			
Y	1.260	1.233	1.239	1.112	0.801	1256.968	1007.267
Fi	0.824	0.814	0.817	0.748			
L	54000	55800	55800	54000			

**Table 2: Results of calculation the coverage coefficient and production capacity at the solar collector area (A = 150 m<sup>2</sup>)**

A=150 m <sup>2</sup>	June	July	Aug.	Sept.	F	P	F×P
X	2.050	1.993	2.001	2.077			
Y	1.350	1.321	1.328	1.192	0.833	1220.831	1018.053
Fi	0.856	0.846	0.849	0.781			
L	54000	55800	55800	54000			

**Table 3: Results of calculation the coverage coefficient and production capacity at the solar collector area (A = 160 m<sup>2</sup>)**

A=160 m <sup>2</sup>	June	July	Aug.	Sept.	F	P	F×P
X	2.187	2.126	2.135	2.216			
Y	1.440	1.409	1.416	1.271	0.863	1184.694	1022.587
Fi	0.884	0.876	0.878	0.811			
L	54000	55800	55800	54000			

Table 4: Results of calculation the coverage coefficient and production capacity at the solar collector area (A = 170 m<sup>2</sup>)

A =170 m <sup>2</sup>	June	July	Aug.	Sept.	F	P	F*P
X	2.324	2.259	2.268	2.354			
Y	1.530	1.497	1.505	1.351	0.889	1148.557	1021.226
Fi	0.910	0.901	0.904	0.839			
L	54000	55800	55800	54000			

Table 5: Results of calculation the coverage coefficient and production capacity at the solar collector area (A = 180 m<sup>2</sup>)

A=180 m <sup>2</sup>	June	July	Aug.	Sept.	F	P	F×P
X	2.460	2.392	2.401	2.493			
Y	1.620	1.585	1.593	1.430	0.911	1112.420	1014.327
Fi	0.931	0.924	0.926	0.863			
L	54000	55800	55800	54000			

Table 6: Results of the monthly average of daily radiation incident on the sloping surface for summer months

Month	T <sub>a</sub> C°	H MJ/m <sup>2</sup> day	H <sub>a</sub> MJ/m <sup>2</sup> day	H <sub>a</sub> /H	R <sub>b</sub>	R	H <sub>T</sub> MJ/m <sup>2</sup> day
June	24.7	28.48	6.52	0.229	0.80	0.84	23.92
July	26.8	27.86	6.30	0.226	0.80	0.84	23.40
Aug.	26.5	24.98	5.90	0.236	0.93	0.94	23.48
Sept.	23.7	20.56	5.29	0.257	1.13	1.09	22.41

Table 7: Results of the thermal load of middle generator for summer months

Month	Monthly heating load $L_{month}$
June	54000
July	56000
Aug.	56000
Sept.	53000

Table 8: Results of the monthly average for the complex permeability covers and absorbcency board absorber of solar radiation falling vertically on the surface of the compound

Variable	June	July	Aug.	Sept.
$\theta_b$	53	51.5	53	41
$\theta_r$	67	67	67	67
$\theta_d$	57	57	57	57
$\left(\frac{\tau}{\tau_n}\right)_b$	0.92	0.94	0.92	0.98
$\left(\frac{\tau}{\tau_n}\right)_r$	0.77	0.77	0.77	0.77
$\left(\frac{\tau}{\tau_n}\right)_d$	0.9	0.9	0.9	0.9
$\left(\frac{\alpha}{\alpha_n}\right)_b$	0.96	0.97	0.96	0.99
$\left(\frac{\alpha}{\alpha_n}\right)_r$	0.86	0.86	0.86	0.86
$\left(\frac{\alpha}{\alpha_n}\right)_d$	0.93	0.93	0.93	0.93
$\frac{(\tau\alpha)}{(\tau\alpha)_n}$	0.865	0.886	0.865	0.932

Figures 5, 6, 7, 8, 9 and 10 show the variation of performance coefficient COP and coverage coefficient on the temperature change for four types of absorption cooling system (single, series double, parallel double half and triple effect). It is found that for single effect, increasing rapidly for the coefficient of performance in the beginning with increasing  $T_g$  and explains the large decrease in the value of coverage coefficient and then it increases COP very slow, ranging from the value of the coefficient of performance  $COP = (0.30 - 0.81)$  at a temperature generator ( $T_g = 71 - 82$ ) $^{\circ}C$ , but approaching the value of  $COP = 0.80$  when  $T_g = 76^{\circ}C$ . Figure 10 show COP variation with evaporation temperature at different temperatures generator (80, 92 and 107  $^{\circ}C$ ) for a single effect of absorption cooling system. Figure 11 explains the comparison of COP with generating temperature for four absorption cooling systems types' select appropriate type. It is found that a single effect is the optimum type. As it demonstrates the effect of changing of the degree of condensation (due to changes in ambient conditions) on the performance of the system and to the extent permitted any change in the degree of condensation either plus or minus, without access to an incident to take shape at the entrance to the pot until absorption can overcome the problem of crystallization of the solution. The concept of physical or technical for the selection of the optimal thermally area of solar flat-plate requires that the  $(F \times P)$  at the designated area, and this means that to achieve thermal performance optimized for system solar water heating is designed to have at the studied area is achieved when the  $(F \times P)$  and competencies forming system items when the studied area as is shown in Figure 12 which shows the relationship between the collector area of solar flat change with  $(F \times P)$  has resulted in this change that the best and the best area is  $(A = 160 \text{ m}^2)$  because it gave the greatest  $(F \times P)$  that is sufficient to operate the system cooling an impact absorbency mono solar-powered. After being values as data entry in the TRNSYS program and solar collector area used the introduction of the flat  $(A = 160 \text{ m}^2)$ . As well as entry the weather data of Erbil city, then was got after the completion of linking collectors in the TRNSYS program components process the scheme gives the changes in the degree of hot water outside temperature of the thermal reservoir in solar collectors circle and going to the generator  $T_h$  during the summer months as well as changes assistant heater capacity which provides its thermal reservoir  $Q_{aux}$  to cover periods weakness

or absence of solar radiation. The results of the simulation work solar receiver to run an absorption cooling system with single effect using simulation by TRNSYS program can be seen in Figures 13, 14, 15 and 16 and observed from the curves that there are periods of solar collectors cannot then secure the desired temperature in the generator, heaters can be used to help certain ability extracted from the scheme in the required time moment.

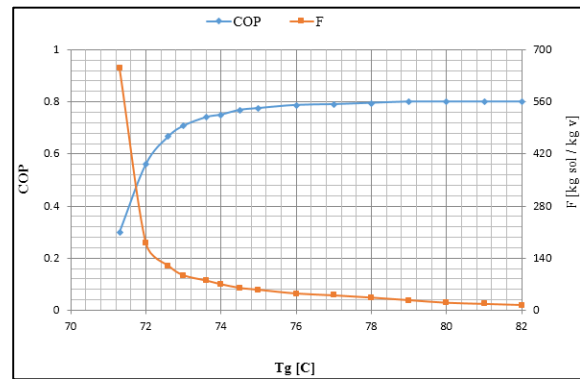


Figure 5: COP variation with coverage coefficient and temperature generator for a single effect

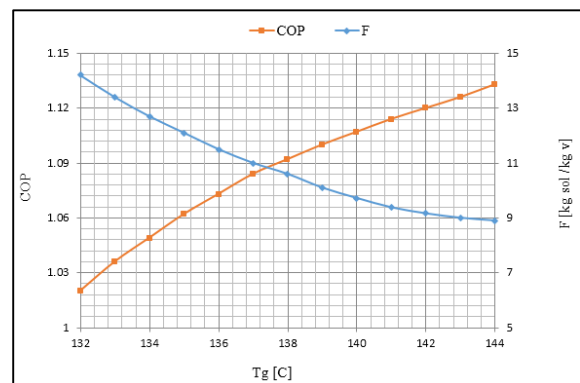


Figure 6: COP variation with coverage coefficient and temperature generator for series double effect

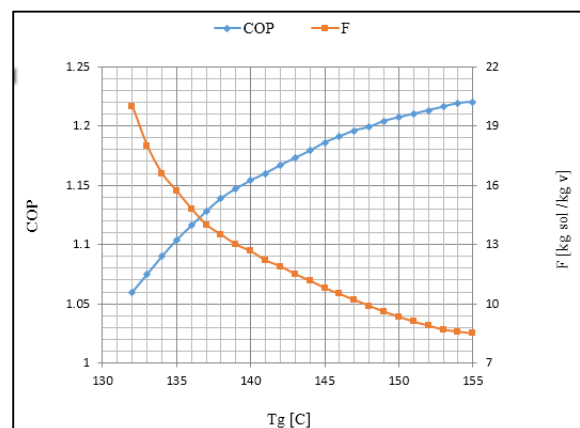


Figure 7: COP variation with coverage coefficient and temperature generator for parallel double effect

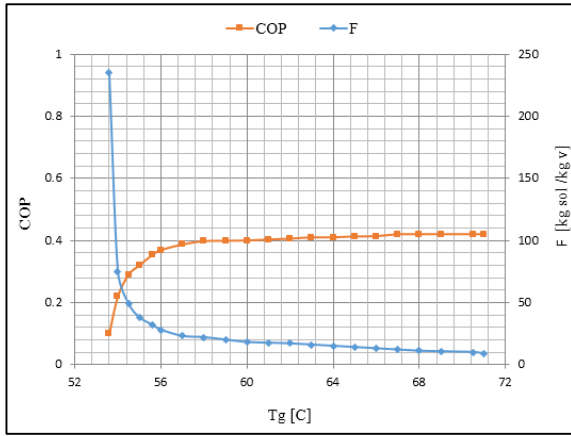


Figure 8: COP variation and solution circulation ratio at different generator temperature for a half effect

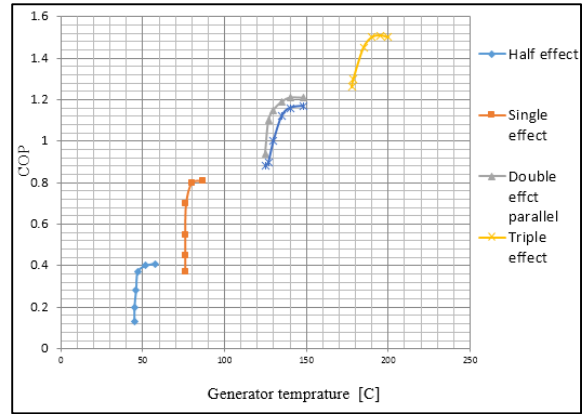


Figure 11: Comparison of COP with generating temperature for four absorption cooling systems types

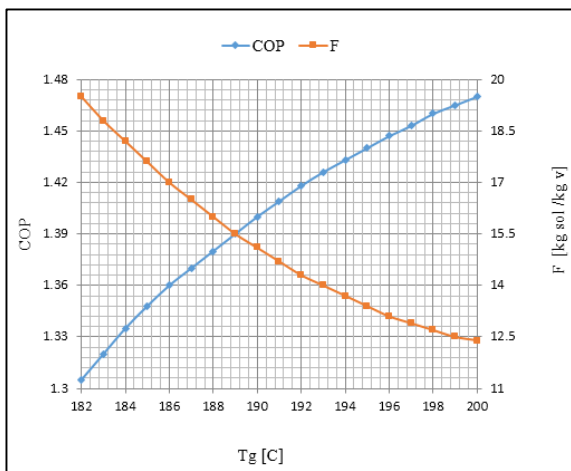


Figure 9: COP variation and solution circulation ratio at different generator temperature for a triple effect

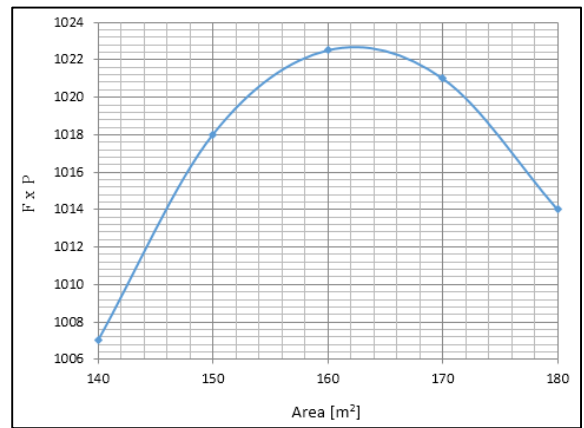


Figure 12: Variation of coverage coefficient and the production capacity with different area for solar flat-plate collector

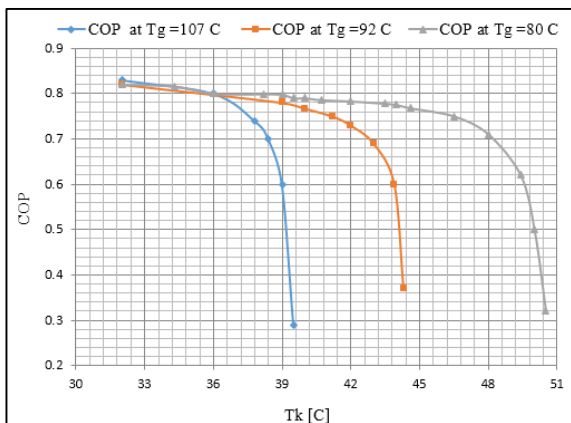


Figure 10: COP variation with evaporation temperature at different temperatures generator for a single effect

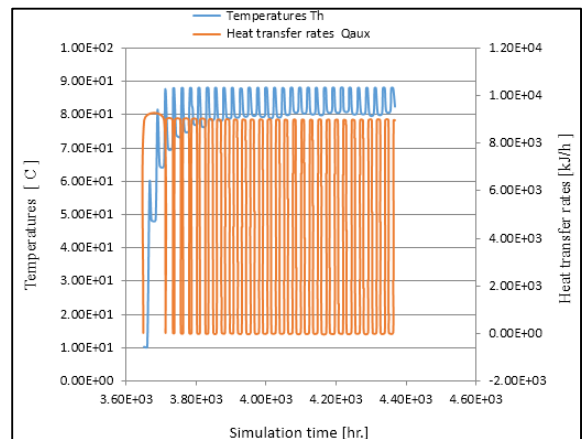


Figure 13: Variation of hot water temperature and the rate of heat transfer during June

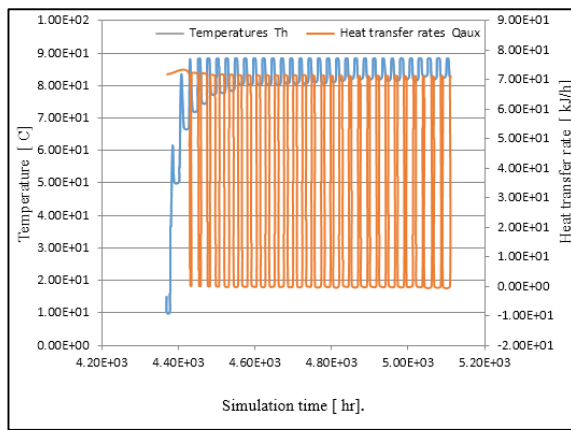


Figure 14: Variation of hot water temperature and the rate of heat transfer during July

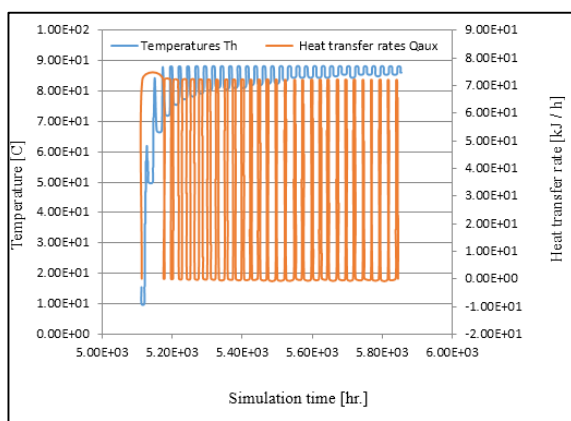


Figure 15: Variation of hot water temperature and the rate of heat transfer during August

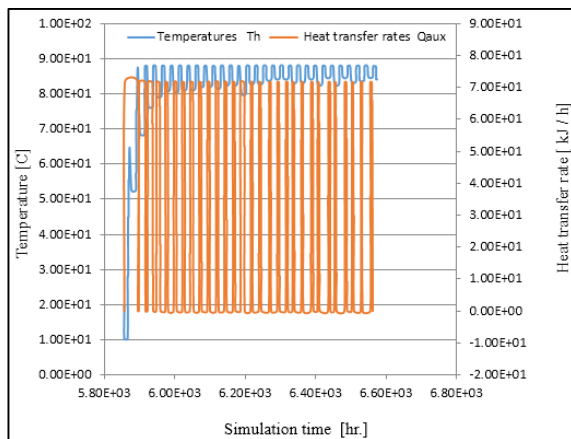


Figure 16: Variation of hot water temperature and the rate of heat transfer during September

## 6. Conclusions

This work predicts the performance coefficient of flat-plate solar receiver for four types of absorption cooling system with water- lithium bromide. There are important conclusions investigated from the results of current work as following:-

1. The optimum area of solar receiver is very important factor since it gives prediction the

maximum required value of the coverage coefficient (F) and the production capacity (P).

2. The present work indicated that the area required of solar flat-plate of German type (vitosol-100 viessmann) is about 160 m<sup>2</sup>, which can supply cooling loads of a typical residential place for sunshine hours in all hot climate conditions of Erbil city where maximum cooling load is within 62.5kw.

3. The performance of solar collectors can be predicted during the period of work by knowing the changes in hot water of the generator (feeder degree heat generator), which give a clear idea of the value of the coefficient of performance of the department of cooling absorbance at any moment in time.

4. The performance coefficient of single effect cooling system was COP= 0.8. Single effect cooling system is more suitable than other types of absorption cooling system to apply the solar energy because the temperature required for working is low and it is a simplest cooling system. Simulation of thermal systems is very close to the reality by using TRNSYS program because of the realism of data and data that could be given to components as data weather.

5. Using of lithium bromide with water as a medium to work the cooling system absorbance of single effect is more convenient to work in the conditions of Erbil city site for the purposes of air-conditioning, especially the possibility of operating the solar flat-plate, in addition to the safety factor.

6. TRNSYS cooling system model has provided performance information that has proved useful in optimizing design and operating conditions and in suggesting alternate configurations and equipment selections for this solar thermal driven cooling system. The mixture of working fluid (Li.Br-H<sub>2</sub>O) has an excellent performance for generator temperatures (76–82°C.)

## Nomenclatures

A : Area of solar collector [m<sup>2</sup>]

C<sub>i</sub> : Correlated constants [-]

COP: Coefficient of performance

f : Recycling ratio per 1kg

F<sub>R</sub> : Collector heat removal factor (%).

G : Solar radiation [kw. h /m<sup>2</sup> day].

h<sub>i</sub> : Enthalpy [kJ /kg]

H<sub>T</sub> : Monthly average daily radiation J/m<sup>2</sup>.day.

q<sub>e</sub> : Heat provided in the generator [kw].

L : Total required heating load [J /month]

N : Number of days in the month

R<sub>b</sub> : Monthly average.

S : Tilt angle oblique surface on the horizontal.

T<sub>a</sub> : Ambient temperature (°C)



$T_{ma}$  : Monthly average ambient temperature (°C).  
 $T_{REF}$ : Degree of retaining heat (100 °C).  
 $U_L$  : Overall heat transfer coefficient (w/m<sup>2</sup> °C)  
 X: Concentration of lithium bromide in solution

### Greek symbols

$\rho$  : Reflectivity of the land (0.2 - 0.7)  
 $\Delta t$  : Number of hours of use per day.  
 $\alpha_{abs.}$  : Absorptency coefficient  
 $(\tau\alpha)_n$  : Transmittance - absorptance  
 $\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n}$  : Correction due to change (  $\tau\alpha$  )

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