Basrah Journal of Engineering Sciences, Vol. 20, No. 1, (2020), 23-29

Basrah Journal of Engineering Sciences

Journal homepage: www.bjes.edu.iq
ISSN (Online): 23118385, ISSN (Print): 18146120

OPEN ACCESS

# Acetone - Zinc Bromide as Working Fluids in Solar Absorption Cooling System

Nabeel A. Ghyadh [1],*, Salman H. Hammadi [2], Haroun A. K. Shahad [3]

*[1]Department of Mechanical Engineering, College of Engineering, University of Kufa, Najaf, Iraq*
*[2]Department of Mechanical Engineering, College of Engineering, University of Basrah, Basrah, Iraq*
*[3]Department of Mechanical Engineering, College of Engineering, University of Babylon, Babylon, Iraq*
*E-mail address: nabeel.ghayadh@uokufa.edu.iq , slmanhm@gmail.com*

*Received: 20 October 2019; Accepted: 11 December 2019; Published: 2 February 2020*

## Abstract

**In the present research, experimental and theoretical work is carried out using ecofriendly refrigeration as working fluid in the absorption system. The working pair is considered in the analysis, namely, acetone and zinc bromide. The system is designed to work under outdoor conditions in Hila city-Iraq. In the test, the outdoor conditions are varied and the hot water is used as heat source. To check the performance of the system, various operating conditions are included in this study. These varied conditions include heat source, absorber, condenser, and evaporator temperatures. The system is tested during September 2019. The results show that the COP of the absorption cooling system ranged from 0.13 to 0.487, while the temperature drop in evaporator is 16 °C. Condensation and absorption temperatures are under 41 °C, while the maximum temperature of the driving water is 80 °C. The steady-state model is analyzed by using EES program. Energy and mass balance achieved on absorption system to predict some parameters such as temperature, pressure and (COP) to compare it with the measured parameters. The results of the model satisfied the experimental results for temperatures as well as the coefficient of performance. The results also show that the generator temperature had a great effect on the system performance.**

***Keywords:*** Acetone-Zinc bromide pair, Vapor absorption cooling system, Coefficient of performance.

## 1. Introduction

Research over the past few decades has focused on the utilization of renewable energies. Solar energy is distributed on the surface of the earth and reaches everyone without the need to transfer and distribute it, which is practical in terms of its use and can be switched to other types of energy, such as thermal energy, mechanical, and electrical. Using solar energy has many advantages. Firstly, it is also a clean source of energy which means causing no harm on the environment. Secondly, the solar systems are easy to be used and operated. Finally, it is considered a sustainable source of energy making it not to be subjected to monopoly of companies or investors, but can benefit all the inhabitants of the earth.

Solar energy serves as a good replacement to traditional source of energy such oil and natural gas. The problem of using conventional source of energy; oil and natural gas; is the emission of greenhouse gases, while solar energy do not provoke the greenhouse gases making it safer to environment compared to fossil fuels [1].

Conventionally, heat pumps and refrigerators are assembled using the vapor compression cycle. The use of vapor compression cycles is dominant, though on rare occasions, absorption cycles are used in commercial heating ventilation and air conditioning systems, where large quantities of inexpensive or waste heat are available. In the vapor compression cycles, the operation of compressor depends on the mechanical work. On the other hand, the compressors in the absorption cycles rely on thermos chemical process in their operations [2]. The refrigerant-absorption solution is often used in the absorption refrigeration systems as the working fluid but not pure refrigerant is used in such systems. The aim of the absorbent in these systems which is considered as a secondary fluid is to absorb the primary fluid. Primary fluid in this case is in the vapor phase. The absorption refrigeration systems widely use ammonia-water ($NH_3/H_2O$) solution with ammonia as the refrigerant and water-lithium bromide ($H_2O/LiBr$) solution with water as the refrigerant [3].

In the vapor absorption refrigeration systems, since the properties of the working fluid play important role in the performance of the cycles, the working fluid should be chosen carefully. Many researchers have put a significant effort in this area of research in the recent years [4]. Two substances are used as working fluid in the absorption refrigeration cycles. One of these substances act as refrigerant, and the other act as absorbent. The solution consists of primary and secondary fluids having good absorption properties at temperature up to 40 °C and these two fluids are separated at 50 °C. The working solution is required to have the following conditions:

- The physical and thermal properties of the working fluids must be stable and the chemical compositions of these fluids must be compatible.
- It is necessary to assure that the working solution is not toxic neither has ability to explode.
- The viscosity is required to be low.

- The heat of vaporization of the refrigerant must be high.
- The specific heat capacity is necessary to be low.
- For economic purposes, the cost is reasonable.

Riffat et al. [5] investigated the absorption and desorption of two types of working pair solutions. The first solution is water-potassium and the other solution is water-lithium bromide. It was noticed that the water-lithium bromide have lower desorption rates than that of water potassium. They reported that the required energy is decreased and therefore the efficiency is enhanced as the desorption rate is increased. It is coming to the conclusion that using water-potassium as a working solution is better than water-lithium bromide. They justified their conclusion from the fact that the water-potassium has less corrosive properties, less expensive and environmentally friendly compared to water lithium bromide.

IERRA et al. [6] studied a solar energy as an energy source in various refrigeration applications, especially in refrigeration machines absorbency. Experiments were carried out on a laboratory model of an absorption refrigeration machine operating on the $NH_3$-$H_2O$ solution. The machine gave a cooling temperature of less than $-2$ °C at a temperature of the generator 73 °C, while the performance factor cop reached for the machine range (24-28) % [1, 2].

Sabah Abdul Ameer [7] designed and fabricated a continuous solar absorption refrigeration system. The experimental system was tested under Iraqi weather conditions at Babylon province at 32.39° N latitudes and 44.39° E longitudes. Two pairs of working fluid were tested namely, lithium bromide-water and diethyl ether-ethanol. The theoretical and experimental coefficient of performance of the absorption system for two pairs and at different solution concentrations are (0.31-0.72) for lithium bromide/water and (0.6-0.82) for Diethyl Ether/Ethanol. The steady-state model and dynamic model were analyzed by using linking between Matlab software and EES program. The results of the model satisfied the experimental results for temperatures and pressure as well as the coefficient of performance.

Pilatowsky et al. [8] suggested the working solution monomethylamine-water to run the plant at low temperatures of 60-80 °C. The operating characteristic of the plant with this new working solution were analyzed and discussed theoretically, obtaining evaporation temperatures from – 5 °C to 10 °C and COP from 0.05 to 0.55 at desorption temperature of 60 °C. However, the disadvantage of this solution is that the COP is low and a rectification for the vapor produced in the generator is required.

Zhu and Cu [9] carried out a theoretical investigation on the vapor absorption refrigeration system. The used working solution in this study is $NH_3$-NaSCN. $NH_3$ acts as a refrigerant, while NaSCN acts as absorbent. It was revealed that the selected working solution in this study has better performance than $NH_3$-$H_2O$ at similar working conditions. This is due to that the COP of using working solution in the system is 10 % greater than that of $NH_3$-$H_2O$.

AJIB et al. [10] for acetone-$ZnBr_2$ solution refrigeration units, it was found that the generator could be driven by temperature up to 55 °C at an evaporator temperature of 13 °C and condensing temperature 27 °C and the performance factor value cop changed during range (40-70) % .

From the previous presentation of scientific researches and references for the absorption refrigeration machines, noted that there is no clear comparison between the experimental and the theoretical study the absorption refrigeration machines used by the acetone-zinc bromide solution. Therefore, in our research we will make a comparison of the working pair solution mentioned above and the system is fabricated and tested at Babylon University site in Hila city-Iraq (32.4° latitude, 44.4° longitude).

## 2. Solution Properties

The working solution that is used in this work is acetone-$ZnBr_2$. To perform theoretical and experimental study on the absorption refrigerant system, the thermodynamic properties of the working solution as well as the system working conditions must be known. Properties such as temperature, pressure, density, concentration, and enthalpy are necessary in the experimental and theoretical work. For acetone-$ZnBr_2$ absorption refrigeration cycles, Acetone is the refrigerant, $ZnBr_2$ is absorbent. The thermodynamic properties at the generator output to absorber input as depicted in Fig. 1 are calculated. The acetone properties can be collected from data of ESS program, while other properties are conducted from binary mixture of acetone-$ZnBr_2$ solution and can be obtained from the following equations:

$$P_{acetone-ZnBr_2} = exp \sum_{i=0}^{2} \sum_{j=0}^{2} a_{ij} \, T^i \, x^j \tag{1}$$

$$h_{acetone-ZnBr_2} = exp \sum_{i=0}^{12} \sum_{j=0}^{4} a_{ij} \; T^i \, x^j \tag{2}$$

The temperature ($T$) is in (°C), and ($x$) in (kg zinc bromide/kg solution) % [11].

**Table 1** Coefficients for calculation of the vapor pressure of the solution acetone-zinc bromide with the Eq. 1.

| | | | | | |
|---|---|---|---|---|---|
| $a_{00}$ | -2.41 E+0 | $a_{10}$ | 5.35 E-2 | $a_{20}$ | -2.13 E-4 |
| $a_{01}$ | 1.72 E-2 | $a_{11}$ | -1.16 E-4 | $a_{21}$ | 3.66 E-6 |
| $a_{02}$ | -5.58 E-4 | $a_{12}$ | 2.38 E-6 | $a_{22}$ | -4.61 E-8 |

**Table 2** Coefficients for calculation of the specific enthalpy of the liquid solution of acetone-zinc bromide with the Eq. 2.

| | | | |
|---|---|---|---|
| $a_{00}$ | 176.64 E+0 | $a_{10}$ | -2.95 E+0 |
| $a_{01}$ | 1.892 E+0 | $a_{11}$ | -1.31 E-2 |
| $a_{02}$ | -1.616 E-4 | $a_{12}$ | 2.8735 E-5 |
| $a_{03}$ | 1.486 E-5 | $a_{13}$ | -5.02 E-7 |
| $a_{04}$ | -2.439 E-8 | $a_{14}$ | 1.755 E-9 |

## 3. Heat and Mass Transfer Calculations

The absorption cooling cycle is the best alternatives to vapor compression cycle. In the absorption cooling cycle, the collected heat from sun is not necessary to be converted into mechanical energy, while the conversion of collected heat conversion into mechanical energy is demanded. Fig. 1 shows a schematic diagram of a solar absorption cooling cycle. The cycle uses a various solution of two substances. One substance is separated from the solution in the form of a vapor that acts as a cooling medium. In the absorption cycle, three units are used: generator, absorber and mechanical pump, instead of the mechanical compressor used in a conventional compressed vapor cooling cycle. These units are added to the heat exchanger to improve cycle performance. The absorption cooling cycle operates at two different pressures.

### *3.1. Assumptions*

1. The heat diffusion amount in the stream direction of the working solution is insignificant and therefore it is neglected.
2. The process of the system is assumed to be adiabatic. It means that the evaporator does not gain heat from the surrounding and generator does not eject heat to the surroundings.
3. The refrigerant is considered to be in the saturated vapor state at the evaporator exit.
4. The refrigerant is regarded to be in the phase of superheated vapor at the generator exit.
5. The amount of work done by pump at the input is negligible.
6. There is no pressure drop in the pipes.
7. The fluid temperature at the exit and the input of the two successive components in the system is the same.

### *3.2. Mass Flow Rate Calculations*

Mass flow rate in evaporator ($m_9$) = Load / (Change in enthalpy)
Mass flow rate for weak and strong solution

$$\dot{m}_4 \times X_{ws} = \dot{m}_3 \times X_{ss} \tag{3}$$

$$\dot{m}_3 = \dot{m}_4 + \dot{m}_7 \tag{4}$$

$$\dot{m}_1 = \dot{m}_2 = \dot{m}_3$$

$$\dot{m}_5 = \dot{m}_4 = \dot{m}_6 \tag{5}$$

$$\dot{m}_7 = \dot{m}_8 = \dot{m}_9 = \dot{m}_{10} \tag{6}$$

### *3.3. Heat Transfer Rate*

Heat transfer rate in evaporator and other components are calculated as follows [12].

#### *3.3.1. Evaporator*

The energy balance for evaporator is as follows:

$$Qe = m_7\,(h_{10} - h_9) \tag{7}$$

#### *3.3.2. Condenser*

The energy balance for the condenser is as follows:

$$Qc = m_7\,(h_7 - h_8) \tag{8}$$

$h_7$ : Enthalpy of superheated steam at saturation temperature of solution in generator and condenser pressure.
$h_8$ : Enthalpy of water (saturated liquid) at condenser pressure and saturated temperature.

#### *3.3.3. Generator*

The energy balance for the generator is as follows:

$$Qg = m_4\,h_4 + m_7\,h_7 - m_3\,h_3 \tag{9}$$

$h_4$ : Enthalpy of solution at exit of generator temperature and Xws concentration.
$h_3$ : Enthalpy of solution at inlet of generator temperature and Xss concentration.

#### *3.3.4. Absorber*

The energy balance for the absorber is as follows:

$$Qa = m_6\,h_6 + m_{10}\,h_{10} - m_1\,h_1 \tag{10}$$

$h_6$ : Enthalpy of solution at inlet of absorber temperature and Xws concentration.
$h_{10}$ : Enthalpy of saturated water vapor at evaporator pressure and its saturation temperature.
$h_1$ : Enthalpy of solution at exit of absorber temperature and Xss concentration.

#### *3.3.5. Coefficient of Performance (COP)*

The COP is calculated by dividing the absorbed heat by evaporator to the supplied heat by generator.

$$COP = \frac{Q_e}{Q_g} \tag{11}$$

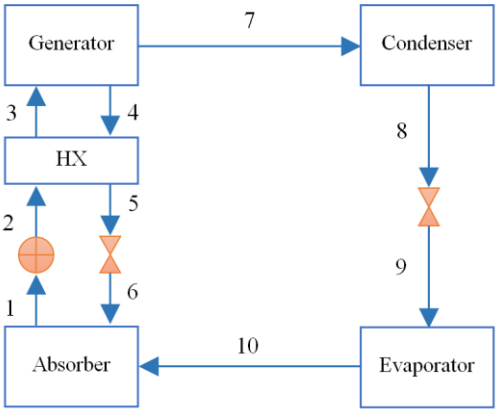

**Fig. 1** Schematic of a single cycle absorption system.

## 4. Experimental Rig

The system components are absorber, generator, condenser and evaporator, all were connected using copper pipes, and the heat exchanger is used with the system between the generator and the absorber, some of the connections made by welding and others by copper fittings.

Figs. 2 and 3 show the Schematic diagram and photographic of the absorption cooling system. The parabolic trough collector considered in the current work consists of two main components reflector and receiver. Reflector consisted of a stainless steel sheet (mirror) fabricated as a parabolic trough with an aperture area of 2.1 m$^2$. The receiver consists of a helical copper tube coil installed in a transparent evacuated tube. The size and dimensions of the different components of the system depend on the cooling capacity required (cooling load) and the thermodynamics properties of the working fluid pair. The purpose of this work is to obtain a cooling effect by using a solar absorption system. A continuous solar absorption cooling system is designed and fabricated to achieve this purpose. The operation and performance of the system is tested using one pair of working fluid, namely Acetone-zinc bromide. Acetone is the refrigerant, zinc bromide is the sorbent. The solar absorption cooling system consists of many components.

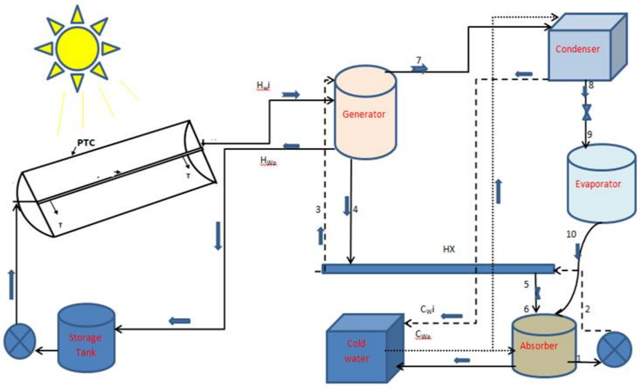

**Fig. 2** Schematic Diagram of Solar Absorption Cooling System.

**Fig. 3** Fabrication of Solar Absorption Refrigeration System.

## 5. Procedures for Absorption Test

The detailed steps of test procedures are as follows:

- All the 24 points thermocouples, as well as points for water coolant and environment temperature (Type K), are connected by plugs and connectors to the data logger watchdog weather station to measure solar radiation, as shown in Fig. 3.
- The two pressure transmitter (model: QP-83A) are connected to the data logger (as well as pressure gauges).
- The pressure of refrigerant, (acetone vapor) at evaporator is equal to 9.4 kPa. The pressure of the acetone vapor at condenser is 56.5 kPa. Assuming the same pressure of condenser and generator.
- The whole system is evacuated (generator, absorber, condenser, evaporator, heat exchanger and piping system) by a vacuum pump to the minimum possible vacuum pressure.
- The acetone-zinc bromide solution for the experiment is charged to the unit by the charging valve. The solution concentration is 60 %.
- The experiment starts at morning at a sunshine time. The axis of the orientation is into horizontal, and the angles of tracking are setting (tilt angle $\beta$, module azimuth angle $\gamma$). The tilt angle is calculated for each mouth. The module azimuth angle also measured in winter and summer season (90° in winter and 75° in summer) measured from North.
- During the day, the acetone-zinc bromide solution in the generator is gained the heat from the hot water at the collector until reach saturation temperature when acetone starts evaporate. Due to the increase of the temperature and consequently of the pressure of the solution in the generator, the acetone vapor flows to the condenser, where condenses by cooling water in, and then it passed to the evaporator through the capillary tube where the cooling effect occurs.
- After the saturated acetone vaporized in the evaporator, the vapor goes back, to the absorber where absorbed by the strong solution and pumped to the generator. The chemical pump is linked to the electrical control system (Twin Timer). The electrical system provides the power to the chemical pump at the specific time.

(a) (b)

**Fig. 4** (a) the Temperature Recording Data Logger. (b) Watchdog 2000 Series weather Stations.

## 6. Results and Discussion

### *6.1 Experimental results*

The measured hourly total solar radiation for 11th September for the year 2019 as a sample of measured data shown in Fig. 5. The incident radiation shows at Hilla city in Iraq. The latitude and the longitude of the city are 32.4° and 44.4° respectively. It is noted that the intensity of solar radiation is higher at noon because the sun becomes vertical, as vertical radiation penetrates shorter and thicker distance from the atmosphere, which is why it is less prone to loss by absorption, reflection and diffusion by atmospheric gases, water vapor, clouds and suspended materials. The measured maximum solar radiation is on 11th September at 12:20 corresponding 778 $W/m^2$. The maximum ambient temperature at this day is 43.5 °C.

Fig. 6 shows the measured ambient air temperature at 11th September 2019 as a sample of the measured data. The data of the ambient temperature shows that at Hilla city in Iraq. The latitude and the longitude of the city are 32.4° and 44.4° respectively. The ambient temperature increases with time from sunrise to noon due to increase of the solar radiation. The maximum ambient temperature was 43.5 °C at 1:00.

Fig. 7 shows acetone vapor temperature increases with increment of the solar radiation at 11-September. The maximum temperature reaches to over 74 °C during the day. The higher temperatures are observed occurs between 11:30 am and 12:30 pm. A noticeable increase in the outlet vapor temperature is found during the early hours of the day. The outlet vapor temperature has its maximum value during noon due to the fact that the values of solar radiation are greatest during this time compared to other hours of the day. After that, the outlet vapor temperature decreased because of the increase in the incident angle which causes decreasing in the solar radiation incident on the module.

Fig. 8 shows the variation of evaporator temperature with daytime for the 11-September note that the process of evaporation gradually decreases until it reaches its minimum value at noon when the intensity of solar radiation increases and lead to raising the temperature of hot water in the generator, which leads to the amount of vaporized refrigerant fluid increases and therefore increase in cooling rate.

### *6.2. Theoretical results*

Coefficient of performance and circulation ratio (mass flow rate of strong solution / mass flow rate of refrigerant) with generator temperature is presented in Fig. 9. The figure shows that as the generator temperature increases the COP increasing which the circulation ratio decreases because the quantity of acetone evaporated increases with increasing maximum generation temperature, and this is because the cooling effect for a given generator temperature increases more than the increase of the heat load of the generator for the same temperature. As for circulation ratio by definition, increasing the amount of evaporated cooling fluid will be to decrease circulation ratio.

Fig. 10 demonstrates the influence of the condenser temperature on the COP and circulation ratio. It can be noticed from this figure that the increase in condenser temperature leads to decrease the COP and increase the circulation ratio. The high temperature of condenser lead to the exchange of heat between the cooled water and steam is a little, and thus the process of condensation is incomplete. This leads to a low coefficient of performance, also, the drop in concentration of the strong solution and the increase in concentration of weak solution lead to increase circulation ratio. If the condenser temperature increases, COP values decrease.

Coefficient of performance and circulation ratio with evaporator temperature is shown in Fig. 11. It can be interpreted from this figure that the increase in the evaporator temperature lead to increase in the COP and decrease in circulation ratio. Therefore, this may be attributed to the fact that as the evaporator temperature is raised, the cooling capacity per unit mass of refrigerant increases.

Coefficient of performance and circulation ratio with absorber temperature is illustrated Fig. 12. It can be concluded from this figure that the increase in the absorber temperature cause decrease in COP and an increase in circulation ration because when the temperature of absorber increases the mass of refrigerant absorbed is reduced and hence the strong solution becomes lese strong and this leads to an increase in the circulation ratio.

Figs. 13 and 14 show the effect of the generator and condenser temperatures on the heat transfer from generator, condenser, absorber and evaporator. The figures show increases the generator temperature with the heat amount for all units increases. This increase in cooling load is due to the increase of the evaporated acetone and the pressure of the system, but increases condenser temperature the heat amount for all units decreases. When the temperature of condenser increases the absorption process inside absorber is incomplete. Increasing in the temperature of the absorber unit refers to increase the temperature of the solution of Acetone -zinc bromide inside the absorption unit and thus affects the absorption process between the evaporator and the absorber. The amount of solution that goes into the generator has a strong solution, and thus the amount of heat transfer to the solution is small, which affects the process of evaporation.

Fig. 15 shows a comparison between the theoretical and experimental a coefficient of performance for solar powered absorption cooling system for acetone-zinc bromide pair. The comparison is achieved for different days of September. The experimental value of COP is between 0.12 to 0.487, while for the theoretical one, it is between 0.2 to 0.62. The percentage of error is 18 % between the experimental and theoretical and this difference is the result of several reasons, including the difficulty of fixing the temperature of the condenser and absorber during the process as well as the solar radiation variable every second.

Fig. 16 shows the experimental COP for the present study satisfies the results of another researcher such as Ameer [7], Hamza [13] and Mezher [14], who built and tested a purpose designed solar diffusion absorption refrigerator. The differences in results with researchers due to different operating conditions as well as working pairs. The COP of Hamza [13] is lower than other researcher because the system is intermittent solar absorption system and a small quantity of ammonia.

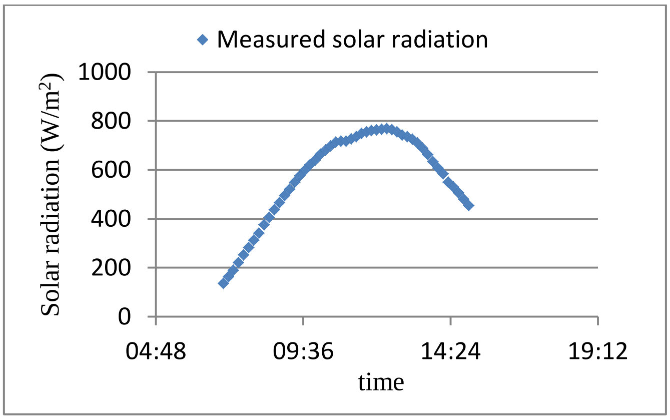

**Fig. 5** Measured total solar radiation at 11$^{ts}$ September -2019.

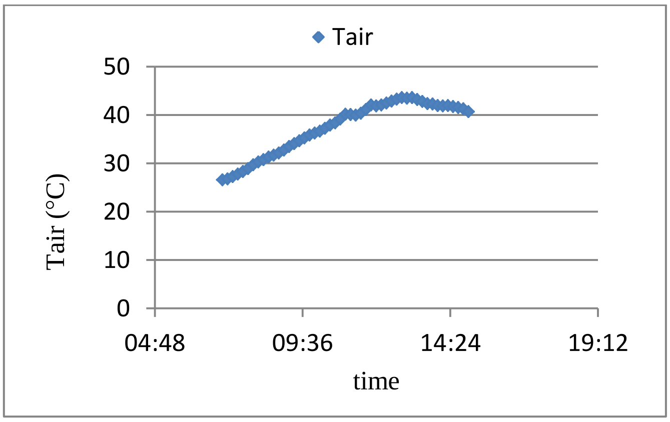

**Fig. 6** Measured temperature of air at 11$^{ts}$ September-2019.

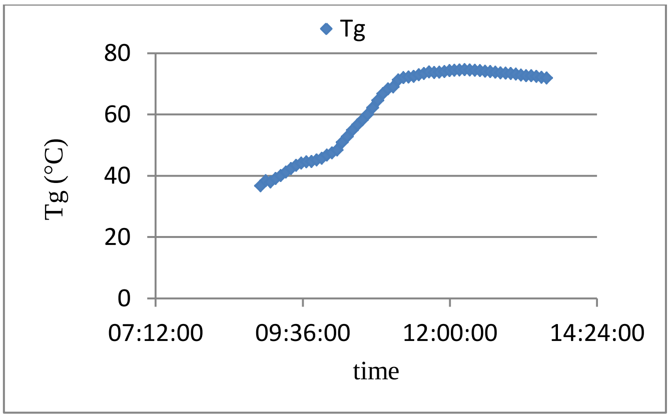

**Fig. 7** Measured variation temperature of generator with time for (Ac-ZnBr$_2$ 60 %) at 11$^{th}$ of September 2019.

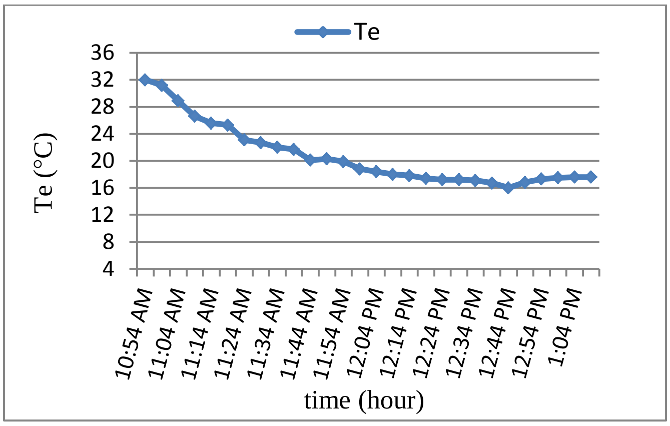

**Fig. 8** Measured variation temperature of evaporator with time for (Ac-ZnBr$_2$ 60 %) at 11th of September 2019.

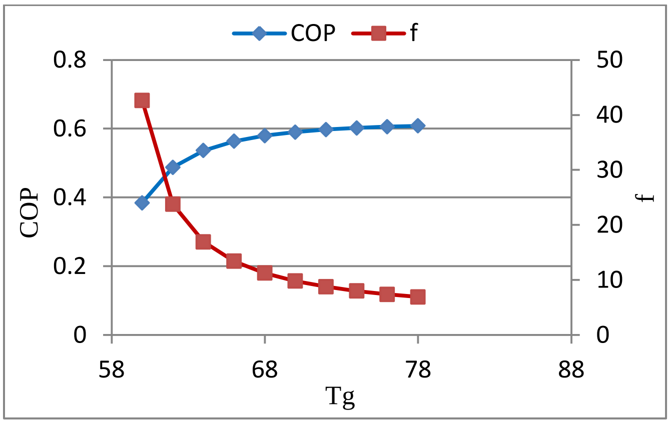

**Fig. 9** COP of the absorption cooling system and the circulation ratio with generator temperature at ($T_a$ = 30, $T_c$ = 30 and $T_e$ = 0).

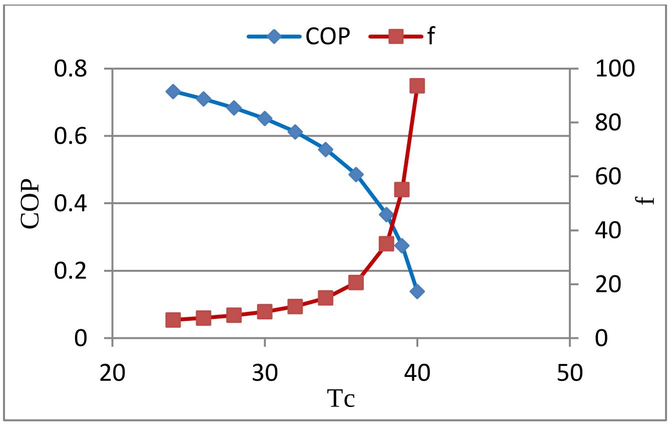

**Fig. 10** COP of the absorption cooling system and the circulation ratio with condenser temperature at (Tg = 70, Ta = 30 and Te = 0).

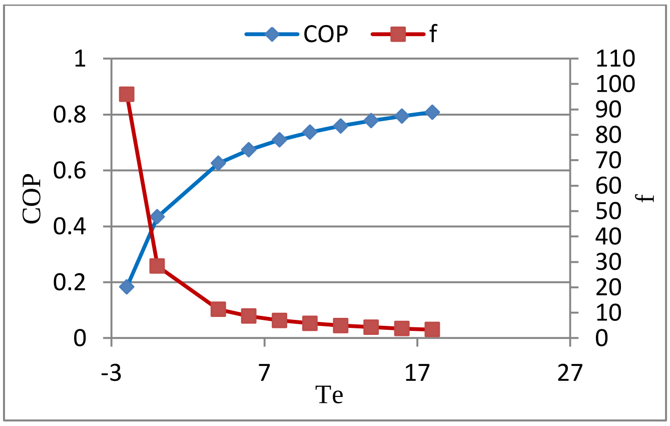

**Fig. 11** COP of the absorption cooling system and the circulation ratio with evaporator temperature at ($T_g$ = 70, $T_c$ = 30 and $T_a$ = 30).

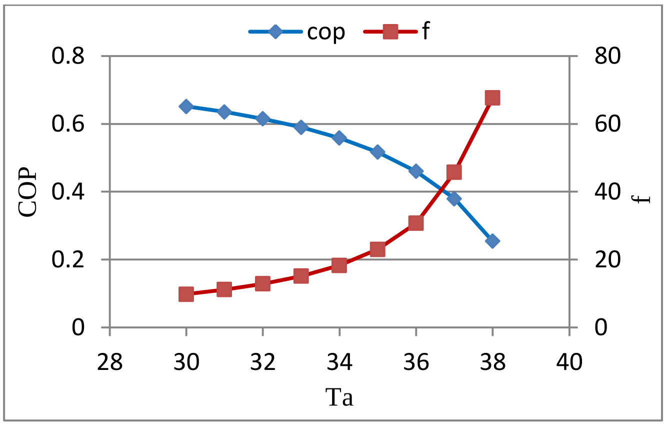

**Fig. 12** COP of the absorption cooling system and the circulation ratio with absorber temperature at ($T_g$ = 70, $T_c$ = 30 and $T_e$ = 0).

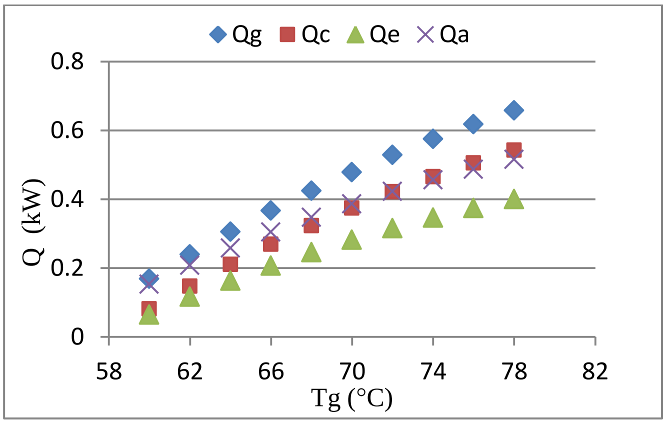

**Fig. 13** Heat amount with generator temperatures.

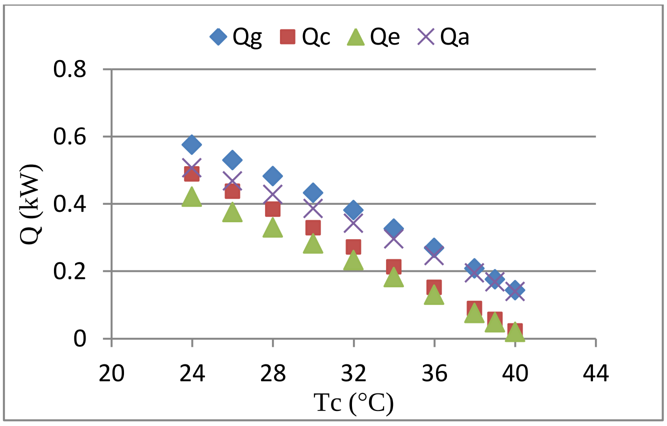

**Fig. 14** Heat amount with condenser temperatures.

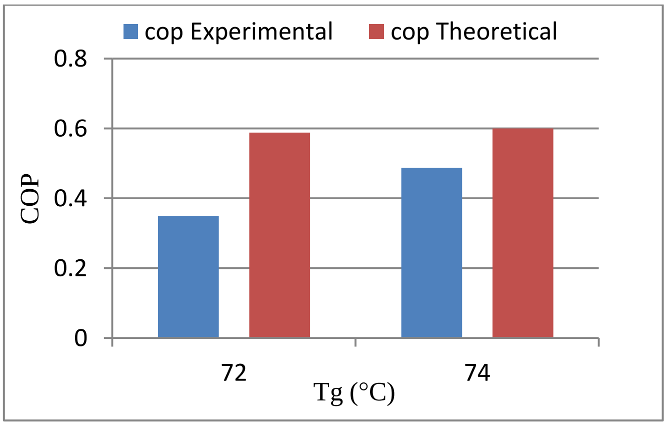

**Fig. 15** Comparison between experimental, theoretical with generator temperature for (Acetone-Zinc Bromide).

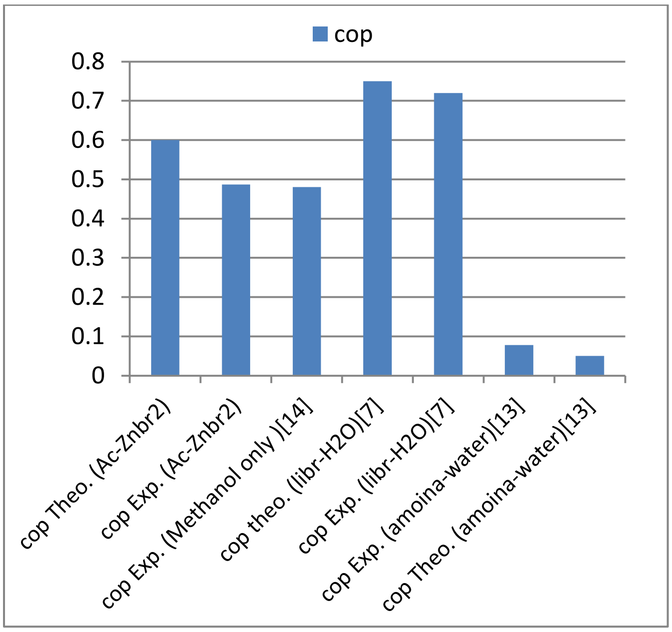

**Fig. 16** Comparison between experimental COP for methanol-water and references [7], [13] and [14].

## 7. Conclusions

The drawn conclusions from this study are listed below:

1. The system uses clean energy that produces no waste gas that affects or increase the global warming.
2. The generator temperature (74 °C) is recorded at noon because of higher solar radiation (778 W/m$^2$) and ambient temperature is 43.5 °C.
3. The continues absorption cooling system using Zinc Bromide-Acetone pair as a working fluid with the high, released amount of (Acetone) vapor is possible to satisfy the home requirement in any region area.
4. The parabolic tough concentrator (PTC) is efficient for solar powered absorption refrigeration system working in conditions as Iraq weather conditions.
5. Modeling of energy balance in absorption cooling system gives a reasonable results compared with the experimental results.
6. The maximum COP obtained experimentally is (0.487) for the absorption cooling system using (Acetone-ZnBr$_2$).
7. COP increases with increasing the generator temperature.

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## Nomenclature

a : Coefficient Constant.
h : Enthalpy.
f : Circulation Ratio.
m : Mass.
P : Pressure.
Q : Heat Amount.
T : Temperature.
X : Concentration.

## Subscripts

1, 2, 3….. , 10 Position as mentioned absorption cycle in Fig. 1.
ss : Strong solution.
ws: Weak solution.
e : Evaporator.
c : Condenser.
a : Absorber.
g : Generator.