Case Studies in Thermal Engineering 22 (2020) 100749

Contents lists available at ScienceDirect

Case Studies in Thermal Engineering

journal homepage: http://www.elsevier.com/locate/csite

Using solar collector unit in a methanol-water vapor absorption cooling system under iraqi environmental conditions

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ARTICLE INFO

Keywords:
Methanol-water pair
Vapor absorption cooling system
Mass flow rate

ABSTRACT

Testing, designing and fabricating a friendly vapor absorption cooling system was the main purpose of the present study using water and methanol as a working fluid. Various Iraqi environmental conditions (Hilla City) are the operating conditions under which the test rig experiment was performed. The temperature of the heat source, condenser, absorber and evaporator, is the involved property in the test calculations. The system is tested during June and July 2019. The results show that the COP of the absorption cooling system ranged from 0.22 to 0.38 while the range of temperature drop in evaporator is (9.8 °C–15.8 °C). Condensation and absorption temperatures are under 45 °C while the maximum temperature of the driving water was 85 °C. The results also show that the generator temperature had a great effect on the system performance.

1. Introduction

Vapor compression refrigeration process in the Air conditioning system consumes about 70%–75% of the house hold electrical current leading to use more fossil fuel to generate the required electrical energy from fossil fuel power plants. Consequently, more CO_2 emissions dissipate form fuel burning in these plants which affects global warming negatively. Thus, using an alternative refrigeration process derived by renewable energy resources is required to reduce the negative impact of the fossil fuel power plants on climate change [1–3].

Recently, efforts are concentrated on using renewable energy resources to drive cooling system cycles especially solar energy as a result of its availability [4].

The independency of solar powered Refrigeration systems on any external power resources and electric grid makes this system very suitable to be operated in fields like an agricultural produce and medicines in addition to its compatibility with Iraq environmental conditions.

From technical point of view, electing an appropriate sorbent-refrigerant pair is necessary in the absorption refrigeration cycles. Literary, number of works were proposed. One of the proposed solutions was converting refrigerant vapor to liquid phase at similar low pressure process which was performed by using a suitable absorbent to absorb the refrigerant vapor where the affinity between the absorbent and the refrigerant molecules helps the mixing tendency between the substances [5].

Enhancing the COP values of the absorption-refrigeration system was the main target of the researchers literary. Several studies

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https://doi.org/10.1016/j.csite.2020.100749
Received 27 September 2019; Received in revised form 7 September 2020; Accepted 9 September 2020
Available online 12 September 2020
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Nomenclature:

A	Area
H	Enthalpy
M	Mass
P	Pressure
Q	Heat amount
T	Temperature
X	Concentration
U	Heat transfer coefficient

Subscripts

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

were investigated in the previous works experimentally and numerically. Utilizing solar bonds to empowers the intermittent absorption refrigerator with NH_3–H_2O solution was performed by FZ.

Sierra et al. [6]. It was shown that high generation temperature as 73 °C and low evaporation temperature as -2 °C can be obtained. The range of the obtained COP values was between 0.24 and 0.28.

M. Li et al. [7] investigated the performance of a 23 kW solar powered single-effect lithium bromide–water (LiBr–H2O) absorption cooling system. Furthermore, the space heating mode was also investigated, analyzed and discussed. The cooling system was driven by a parabolic trough collector of 56 m^2 aperture area and used for cooling a 102 m^2 meeting room. Research results revealed that the chiller's maximum instantaneous refrigeration coefficient (chiller efficiency) could be up to 0.6. Most of the time in sunny and clear sky days, the daily solar heat fraction ranges from 0.33 to 0.41 and the collectors field efficiency ranges from 0.35 to 0.45. At the same time, chiller efficiency was varied from 0.25 to 0.7 and the daily cooling COP was varied from 0.11 to 0.27 respectively.

Porumb et al. [8] investigated the effect of operating parameters such as solar hot water, cooling water and cold water temperatures on the COP of the LiBr–H2O absorption chiller where the results indicated that the numerical model can successfully determine the safe operating conditions of the chiller while considering crystallization.

TRNSYS simulation package was used to perform a simulation for a Li–Br absorption solar cooling system by S.A. Kalogirou et al. [9] by implementing a yearly meteorological data of a hot session. 15 m^2 of a compound parabolic collator sloped at 30, and 600 L of storage tank were employed in the kalogirous experiment. It was concluded that the mass producing absorption system can be feasible economically if the annual load of a typical house be replaced by 9000 KWh of collected solar energy.

Jasim et al. [10] developed a computer model to emulate three different working fluids; ammonia-water, ammonia-lithium nitrate and ammonia-sodium thiocyanate. Polynomial equations were implemented in the model to calculate the thermodynamic properties. The comparison in the temperatures between the three cycles and the generator, evaporator, and condenser shows that the ammonia-water cycle has lower performances than the other two cycles.

Testing, designing and fabricating an environmental friendly vapor absorption refrigeration system of unit capacity was performed by Bajpai [11], using ammonia-water as the working fluids. The system was designed and tested for various operating conditions using hot water as heat source and flat solar collector, the produced COP for this system was 0.58.

Xu et al. [12] developed a new technology on the solar powered absorption refrigeration storage system and used a dynamic model and numerical simulation. They found that COP equals to 0.75 when the condenser is cooled by air and COP equals to 0.7555 when is cooled by water. They also found that the required area was 66 m^2 and solar density was 368.5 MJ/m^2.

Moreno et al. [13]. also used CPC unit in Mexico with ternary solution ($NH_3/LiNO_3/H_2O$). The (COP) was 0.098 which obtained at an evaporator temperature of -11 °C. They found that the period of refrigeration is 8 h and the (COP) increases by 24% more than the binary solution ($NH_3/LiNO_3$) in the CPC unit.

Mamdouh El Haj et al. [14]. studied a lithium bromide absorption chiller operated with a geothermal heat source and analyzed it thermodynamically. The focus was on the effect of the solution on the heat exchanger performance, in particular, the effect of the medium fluid temperature and mass flow rate on the COP of the chiller. Preliminary results showed that as the pressure in geothermal water vapor separator increased from 0.23 to 0.45 MPa, the absorption chiller cooling load increased by 28% while the COP decreased by only less than 1.4% at the same condenser pressure.

Agrouaz et al. [15] investigated the performance of solar absorption chiller under the Moroccan weather conditions by conducting energy analysis. The conclusion revealed that some parameters such as inclination angle of the solar collector, collector surface field, and evaporator and generator flow rates have important role to enhance the system performance.

The main objective of the present work focuses on studying the performance of solar absorption refrigeration system using methanol-water as a working pair. The reason behind using such a working pair is that the required energy to regenerate the solvent is low considerably for methanol in addition to its low boiling point at the atmospheric pressure, low viscosity, less poisoning comparing with ammonia-water pair, no solid formation under its operation conditions, low cost and its positive on global warming [16,17]. In this study, a solar absorption refrigeration unit is constructed. The system is operated mainly with PTC to deliver heat to the generator during the months of April to August (2019) 6 h per day period.

2. Experimental apparatus and method

In this work, a solar powered absorption cooling system was fabricated and tested. Methanol – water pair was used as a working pair (see Table 1). All the required parameters for the design of the solar powered absorption cooling system were calculated individually for each component. The parabolic trough collector considered in the current work consists of two main components; Reflector and Receiver. Reflector consists of a stainless steel sheet (mirror) fabricated as a trough parabola shape with an aperture area of 2.1 m^2. While the receiver consists of a helical copper tube coil in a transparent evacuated tube. The assembly was fixed along the focal line of the parabola. The helical coil was coated by a black paint to increase the absorptivity. The outer diameter for the copper tube was 12.7 mm and the thickness was 1 mm. The concentric glass cover helps reducing the radiation and the convection losses. The fabricated parabolic trough solar collector (PTSC) unit is shown in Fig. 1 The design, working, and testing of the system was carried out at Babylon University, Babylon province, Iraq, under the Iraqi outdoor conditions.

The size and the dimension of the system components are dependent on the required cooling capacity (cooling load) and the thermodynamics properties of the working fluid pair. The components of the solar absorption cooling system are: Parabolic Trough Solar Collector, Generator, Condenser, Evaporator, Absorber, Heat Exchanger, Capillary Tube, Storage Tank and Pumps. The mass, energy and heat balance was performed for each component as below [18]:

Mass balance:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \tag{1}$$

$$\dot{m}_3 = \dot{m}_4 + \dot{m}_7 \tag{2}$$

$$\dot{m}_1 = \dot{m}_2 = \dot{m}_3; \ \dot{m}_5 = \dot{m}_4 = \dot{m}_6 \tag{3}$$

$$\dot{m}_7 = \dot{m}_8 = \dot{m}_9 = \dot{m}_{10} \tag{4}$$

Balance of the methanol-water concentrations:

$$\sum \dot{m}_{in} \times X_{weak} = \sum \dot{m}_{out} \times X_{strong} \tag{5}$$

$$\dot{m}_4 \times X_{ws} = \dot{m}_3 \times X_{ss} \tag{6}$$

Energy conservation:

$$\dot{Q} - \dot{W} = \sum \dot{m}_{out} \times h_{out} - \sum \dot{m}_{in} \times h_{in} \tag{7}$$

$$Qe = m_7 (h_{10} - h_9) \tag{8}$$

$$Qc = m_7 (h_7 - h_8) \tag{9}$$

$$Qg = m_4h_4 + m_7h_7 - m_3h_3 \tag{10}$$

$$Qa = m_6h_6 + m_{10}h_{10} - m_1h_1 \tag{11}$$

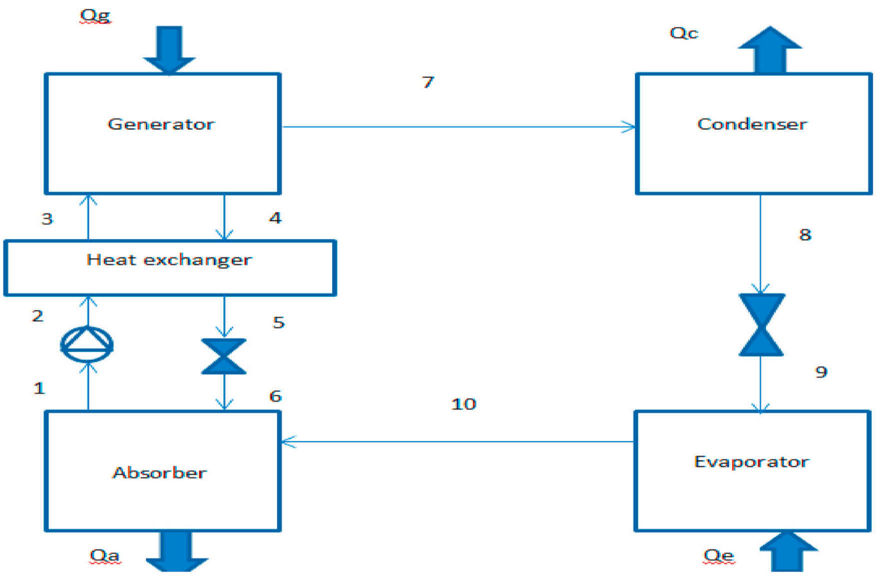
Heat transfer equation:

$$Q = U \times A \times \Delta T_{LMTD} \tag{12}$$

Table 1
Physical properties of Methanol and Water [16,19].

	Methanol	Water
Formula	CH_3OH	H_2O
Molar mass	32.04 g/mol	18.015 g/mol
Density	0.792 g/cm3	0.999 g/cm3
Normal boiling point	64.7 °C	99.98 °C
Normal melting point	−97.6 °C	0 °C
Enthalpy change of vaporization	1104 J/g	2257 J/g

(a) The Fabricated Solar Absorption Refrigeration System



(b) Schematic of a Single cycle Absorption System

Fig. 1. a. The Fabricated Solar Absorption Refrigeration System. Fig. 1b. Schematic of a Single cycle Absorption System.

$$\Delta T_{(LMTD)x} = \frac{(T_x - T_o) - (T_x - T_i)}{\ln\left(\frac{T_x - T_o}{T_x - T_i}\right)} \quad (13)$$

where x represents the component in which equation (13) would be applied whether evaporator, condenser, generator or absorber.

The COP was based on the heat removed from the evaporator and the heat delivered to generator [18].

$$COP = \frac{Q_e}{Q_g} \quad (14)$$

3. Procedures for absorption test

The procedure of the absorption test was classified into three consequent steps. The first step was performed by setting the whole system. I this context, the whole system (generator, absorber, condenser, evaporator, heat exchanger and piping system) was evacuated into the minimum possible vacuum pressure (0.75 bar–0.82 bar) by using a vacuum pump. The instrumentation system and measurements were set on the test rig in the second step. In this stage, 24 thermocouples were set on the system and distributed to calculate the coolant and the environmental temperatures where 23 thermocouples were set to the coolant and one to calculate the surrounding conditions. The used thermocouples were K type and connected to a data logger to process the values. In addition, two pressure transmitters model (QP-83 A) were used to measure the pressure and connected to a data logger and gauge pressure to post process the pressure data. After setting the test rig and the instrumentation system properly, the absorption test and experiment was started as the next consequent step. In this step, 16 L of water-Methanol solution was injected to the unit first through a charging valve at three different concentrations; 40%, 50%, and 60%. The experiment starts at morning through the sunshine time. The axis of the orientation was the horizontal axis where the angles of tracking were set properly (tilt angle β, module azimuth angle γ). The tilt angle was measured in summer and winter season (43°in winter and 21°in summer). The azimuth angle was measured in winter and summer season too (90° in winter and 75° in summer) form the North.

During the day, the water-methanol solution in the generator is heated by the hot water from the collector until reaching the saturation temperature where methanol starts to evaporate. Due to increase in the temperature and consequently the pressure of the solution in the generator, the methanol vapor flows to the condenser where cooling water condenses it, and then, it passes to the evaporator through the capillary tube where the cooling effect occurs.

After the vaporization of the saturated methanol in the evaporator, the vapor charges to the absorber to be absorbed by the strong solution and pumped to the generator. A chemical pump was linked to an electrical control system (Twin Timer). The electrical system provides the power to the chemical pump at a specific time.

4. Results and discussion

The experiments of the present test rig were made between April to July 2019 where solar energy reaches the optimum value. Fig. 2 show that the variation of generator temperatures for the selected days (12th June and 17th July) during the year 2019. The temperature of generator increases until it approaches the maximum value and then decreases because the flow keeps charging as a continuous system. The maximum temperature of generator reaches over 83 °C during the 17th of July. The difference between the results of the 17th of July and June is due to absorbing lower solar radiation in June than July. In addition, tilt angles and temperature of the ambient air are different between the two months. As well, the above mentioned difference is due to the decrease in the angle of declination. Figs. 3 and 4 show the variation of evaporator temperature throughout the day for the selected days (12th June and 17th July) during the year 2019. It is noted that the evaporator temperature gradually decreases until it reaches its minimum value at noon when the intensity of solar radiation increases causing a raise in the temperature of hot water in the generator and leading to increase the evaporation of the refrigerant. Fig. 5 show the variation of temperature drop in the evaporator at different solution concentrations (40%, 50%, and 60%) in June 2019. It is observed that the maximum temperature drop in the evaporator is obtained at the highest concentration due to producing large amount of methanol vapor. The range of temperature drop in the evaporator is (9.8 °C–15.8 °C). High concentration used, more methanol vapor released as well as a great pressure variation existed between the condenser and

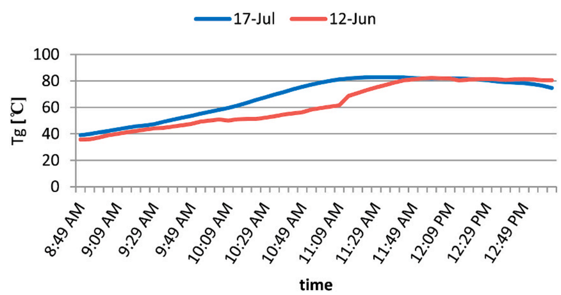


Fig. 2. Measured variation temperature of generator with. Time at 12th of June & 17th of July -2019.

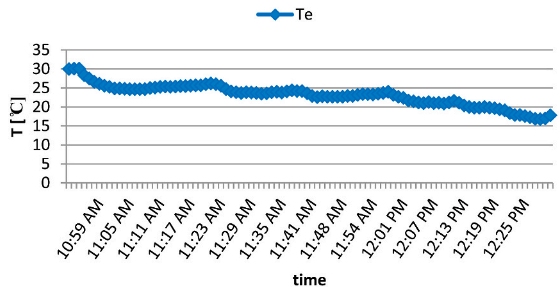


Fig. 3. Measured variation temperature of evaporator with. Time at June 12, 2019.

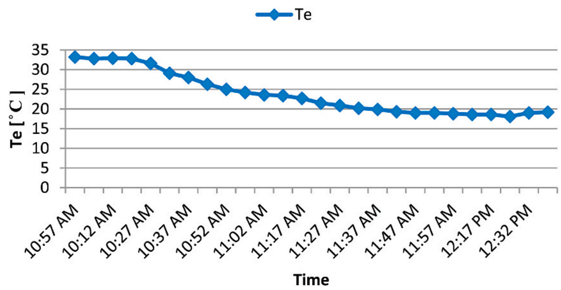


Fig. 4. Measured variation temperature of evaporator with. Time at July 17, 2019.

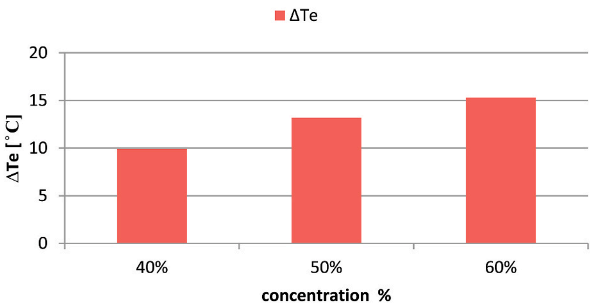


Fig. 5. Measured variation maximum temperature drop of evaporator with Variable concentration for June 2019.

evaporator. Fig. 6 illustrates the relationship between the instantaneous coefficient of performance and the temperature of the generator for June and July. It can be seen that the COP increases by increasing the temperature in the generator. It is noted that the performance coefficient reaches its maximum value at 0.34 when the temperature approaches 83 °C on July while the performance coefficient is slightly lower than that on June. This is because of the intensity of solar radiation in June month lower than July month. The reason behind increasing the coefficient of performance at the higher temperature of generator is to increase the evaporation rate of methanol vapor in generator unit. Fig. 7 shows the effect of solution concentration on COP of the system for the day of June. This figure shows that the coefficient of performance increases by increasing the concentrations. It is noted that high performance is obtained at high concentration due to producing large amount of methanol vapor. The range of COP is 0.22–0.38. The high concentration gives more released methanol as well as a great pressure variation between the condenser and evaporator since the coefficient of performance of the refrigeration system increases with increasing the pressure variation between the condenser and evaporator (or generator).

5. Conclusion

An experimental study was performed in the present work using methanol as a refrigerant in an absorption-refrigeration cooling system. It can be concluded that the studied system is viable technically and environmentally where this system is more efficient as a result of using a renewable energy source and doesn't affect the Ozone layer causing less negative impact on global warming. Thermally, higher temperature drop would be obtained from the studied system at higher concentration as a consequence of producing higher amount of refrigerator vapor where the drop ranged from (9.8 °C–15.8 °C) concluding that the system is more efficient

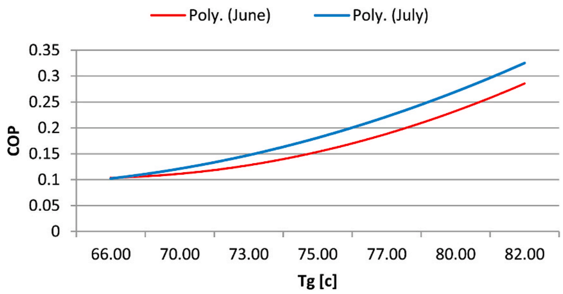


Fig. 6. Experimental COP with generator temperature of June and July 2019.

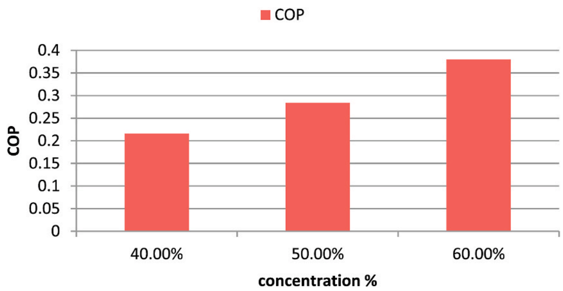


Fig. 7. Experimental maximum COP with variable concentration of June 2019.

thermally. Furthermore, generator temperature increases, COP and cooling ratio increase as a result where the maximum generator temperature reaches 85 °C while the maximum COP reaches 38%. Overall, the above mentioned conclusions assure that the solar absorption cooling system highly promises in the hot climate weather regions.

CRediT authorship contribution statement

Nabeel A. Ghyadh: Conceptualization, Methodology, Formal analysis, Software, Investigation, Data curation. **Salman H. Hammadi:** Supervision, Project administration, Methodology, Writing - review & editing. **Haroun A.K. Shahad:** Supervision, Project administration, Methodology, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements-

Special thanks to the University of Basra/College of Engineering/Department of Mechanic. In addition, the author is very thankful to University of Babylon/College of Engineering/Department of Mechanics for their permission to work inside their property. An appreciation sent to Mr. Hussein for his help through test.

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