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Performance of Solar Adsorption Cooling System Using Methanol and Activated Carbon as a Working Pair

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Abstract

The need for renewable energy sources is higher than ever due to rising global warming, climate change, and ozone depletion. For refrigeration and air conditioning applications, adsorption refrigeration systems are viable alternatives cooling techniques. This study is a topic and part of the M.Sc. thesis. A field solar-powered ice maker unit was created, studied, tested, and evaluated on the 13th and 30th of May, 2022. Activated carbon and methanol pair was used to set up a refrigeration system in Baghdad (Al Dora). Experimental tests were carried out outdoors to determine the coefficient of performance COP and specific cooling power SCP of the system. The results showed that the lowest temperature obtained at the evaporative surface was (4 ^{o}C) and (3 ^{o}C) for the 13th and 30th of May, respectively, at the opening time of the valve between the evaporator and the generator at 9 pm. In addition, the amounts of methanol condensate were (0.340 kg) and (0.344 kg) for the 13th and 30th of May, respectively, while the maximum cycle coefficient of performance (COP) and specific cooling power SCP are about 0.57 and 0.14 kW/kg$_{a.c}$, respectively.

Keywords: Solar, Refrigeration, Methanol, Activated Carbon, Adsorption, Cooling

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تصميم ودراسة أداء نظام التبريد بالامتزاز الشمسي باستخدام الميثانول والكربون المنشط كزوج عمل

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الخلاصة

أصبحت الحاجة إلى مصادر الطاقة المتجددة أعلى من أي وقت مضى بسبب ارتفاع مستويات الاحتباس الحراري وتغير المناخ وثقب طبقة الأوزون .تعد أنظمة التبريد بالامتزاز تقنية تبريد بديلة قابلة للتطبيق وهي احدى تطبيقات تكييف وتبريد الهواء. موضوع هذه الدراسة هي جزء من رسالة ماجستير. تم إنشاء ودراسة واختبار وتقييم وحدة تصنيع تبريد حقلية تعمل بالطاقة الشمسية وتم تقييمها في يوم 13 و30 من شهر مايو لعام 2022. تم استخدام زوج من الكربون المنشط والميثانول لإنشاء نظام تبريد في بغداد منطقة (الدورة). لتحديد معامل الاداء COP للنظام و قدرة التبريد النوعية SCP، أجريت الاختبارات التجريبية في الهواء الطلق. اظهرت النتائج ان أدنى درجات حرارة تم الحصول عليها على سطح المبخر كانت (3 درجة مئوية) و(4 درجة مئوية) ليوم 13 و30 من شهر مايو عند وقت فتح الصمام بين المبخر والمولد 9 مساءً . بالأضافة الى ذلك كانت كتل الميثانول المتكثفة (0.340 كغم) و (0.344 كغم) ليومي 13 و 30 من شهر مايو .بينما يبلغ الحد الأقصى لمعامل الاداء COP وقدرة التبريد النوعية حوالي 0.57 و 0.14 (كيلو وات / كجم كاربون منشط) على التوالي.

الكلمات الرئيسية:الطاقة الشمسية، التثليج، الميثانول، الكربون المنشط ، الامتزاز ، التبريد

1. INTRODUCTION

Iraq suffers from a shortage of electrical energy, especially in the summer, and the temperature rises to more than 55°C, which means the availability of electrical energy for Iraq's greatest need for cooling due to the long summer period, which lasts for more than six months. The most important types of renewable energies widely available in Iraq are solar energy, through unconventional cooling technology, precisely, adsorption cooling systems. They verified and realized the viability of a solar adsorption refrigeration model; an adsorptive solar-powered ice maker was analyzed, planned, built, tested, and improved. Its response and the ratio of methanol to activated carbon were also examined. Results from an experiment using a refrigerator with a bed containing 3 kg of activated carbon and 870 g of methanol to produce 1 kg of ice showed that the refrigerator's response was 0.39, and its specific refrigeration power was 1.4 KW/Kg. The ideal (COP) and (SCP) were accomplished for refrigerators **(Farman et al., 2017).**

As a metal-dependent adsorptions model for ice making, ice slurry, cooling, and drinkable water, a nickel-based designation polymer using open material locations of organic structures with operating seawater couples was presented. According to the findings, ads generating chilled antifreeze produced the most ice at 8.9 tons per day per ton. Surrounding temperatures of 95 °C, - 1 °C, and 24 °C expanded along the number of periods, exchanging intervals, adsorption/desorption intervals, and saltiness **(Dakkama et al., 2017).** As a working pair, micro- and nano-activated carbon and methanol are applied in a solar-powered continuous adsorption chiller. The chiller utilized in this thesis contains

an adsorbent bed, condenser, evaporator, and compound parabolic collector. The results demonstrate that including nano-activated carbon of varying mass percentages can increase the level of adsorption; Consequently, the COP improved, and the adsorption capacity increased. The adsorbent bed received mass fractions of 4.7%, 11.1%, and 18.3% of nano-activated carbon at 30 °C and 34 °C, respectively. The COP increased by 11%, 21%, 33%, 17%, 23%, and 25% **(Hamrahi et al., 2018)**. A prototype with improved mass transfer for a solar adsorption refrigeration model. The original relied on an idealized tight-adsorption refrigeration period using powered carbon against methanol as the operating couple. The coefficient of performance (COP) was utilized to compute the model's efficiency and examine the operating hypothesis. The study found that the increased mass transfer and adsorption refrigeration system had a maximum capacity of 7 kg and COP of 0.142, respectively. Furthermore, they showed that when the energy of the info radiation was at the very least 14.7 MJ during a refrigeration period, the typical COP of the imaginative framework operated by 35.9% when contrasted using the typical COP of the regular mass exchange adsorption refrigeration framework **(Wang et al., 2018)**.
The modeling of thermodynamics and the (COP) of the intermittent cycle of the vapor adsorption refrigeration system with a single bed or two beds were reviewed. The concept of adsorption, the characteristics of adsorbent-adsorbate materials, and the vapor cycle of adsorption were all explored. They discovered that adsorption systems could be helpful for ice production, air conditioning, and refrigeration, as standalone or hybrid models, as well as for environmental preservation and energy conservation **(Singh and Dhingra, 2019)**. the investigation uncovered the optimally designed coefficients for a solar-powered adsorption cooling model for construction in hot, dry locations. The system comprises solar collectors, a fan coil unit, a cooling tower, an 8 kW water-silica gel adsorption chiller, and a hot and cold water tank. They used a computer simulation of the TRNSYS program to accomplish the objective of their study. They discovered that the 58 m2 solar collecting area, 5.5 m^3, and 1 m^3 hot and chilled water tanks were the system's best design features. The findings show that on the day of the design, the daily solar collection efficiency was 56%, producing 113.3 kWh of chilling power at a rate of 7.35 kW and 0.41 tons of CO_2 per day. Additionally, the system could operate for 110 minutes after the chiller was turned off, thanks to the cold water tank **(Reda et al., 2019)**.

A recurrent solar adsorption ice-maker prototype that uses water as the refrigerant and silica gel as the adsorbent has been demonstrated to utilize four polished stainless steel flat exterior reflectors for enhanced response. At a reduced heat of 7 °C, they discovered that a prototype without reflectors did not produce ice. On the other hand, a prototype with reflectors produced 0.5 kilograms of ice from a weight of 9 kilograms, and adding more water to the prototype drifted to improve the solar COP as well. The starting mass of the refrigerant's impact was also examined **(Souissi et al., 2019)**. Developing a solar adsorption refrigeration pipe (SARP) allowed for establishing a novel method using solar refrigeration technology. SARP stands for solar-assisted adsorption refrigeration pipe. Numerous experiments were conducted to determine how well the SARP cooled during the hotter months. According to the findings, the prototype performs well even at the lowest refrigeration, 2.9 °C, with a 1.5 °C average during the hotter seasons. The prototype's daily cooling capability and COP amounts, which were roughly 81.23 kJ also 0.067, might subsequently be increased with a higher device size. The prototype might also be utilized to keep output steady. Additionally, they demonstrated such an advanced model might be a possibility for the heated upkeep of rank manufacturing **(Hu et al., 2020)**. An examination was implemented in the Bali zone to investigate the efficacy of solar adsorption refrigerators that used powered carbon and methanol. This system had only one absorber within a double-glazed collector box with a 0.259 m2 powerful surface area. The 1-kilogram water evaporator for the cooling load was housed indoor a cooler package that measured 0.37 meters by 0.25 meters by 0.345 meters. The conclusion revealed that the refrigerator's cooling system and COP capacities were 47.5 kJ and 0.046, respectively, and that it could lower the water temperature to 18°C **(Sugiartha, 2020).** An investigation into renewable technology used a solar photovoltaic structure to generate the electric power needed to operate an absorption period to compare it to a commercial AC absorption refrigeration system. The outcomes illustrated that the AC and DC systems had COP values of 0.18 and 0.14, respectively. They also determined that the system had a basic payback period of 10.2 years **(Selvaraj and Victor, 2021**). Methanol with powered carbon is used in a solar adsorption ice factory designed to produce 1 ton of ice each day in the climate of Makkah. An analytical scheme with implementation was advanced to confirm the system's year-round response. They discovered that, against condenser and evaporator heats of 35°C and –5°C, sequence, the factory might provide up to a ton each day throughout the year. In addition, they discovered that the COP could reach 0.9, with ambient temperature having a greater influence than solar radiation. This indicated that the winter season offered the greatest response and ice production **(Alamoudi and Abdel-Dayem, 2021)**. The MIL-101/FLGwater working pair's adsorption cooling performance and heat transfer characteristics were investigated. The analysis revealed that MIL-101/20%FLG composite had a thermal conductivity that was 5.79–6.54 times greater than MIL-101. The MIL-101/FLGwater working pair's adsorption cooling response and heat transfer characteristics were investigated. The analysis revealed that MIL-101/20%FLG composite had a thermal conductivity of 5.79–6.54 times greater than MIL-101. The MIL-101/FLG adsorber formed heat transfer channels more easily and quickly after adding FLG. The MIL-101/FLG adsorber heated and cooled about 2.2 times faster than the MIL-101 adsorber. 70 and 90 °C desorption temperatures, respectively, The MIL-101/FLG-water working pair's (SCP) against (COP) were, respectively, 72.2-81.0 W/kg and 0.187-0.202, which were between 1.43 and 1.56 times greater than the MIL-101-water operating couple **(Yin et al., 2021)**.

Investigated how the cooling capacity of solar adsorption systems as a whole will be affected by adopting various adsorption and desorption durations. They used silica gel and water as the adsorbent and adsorbate combination in a cooling system that was developed and tested in accordance with Iraq's climate. Concerning predict the model's response, they created a mathematical scheme. They discovered that the system might work for adsorption and desorption at different times. Additionally, they discovered that the system performed roughly twice as well with equal time as it did with uneven time. Adsorption speed, adsorption ability, the heat transfer factor as a whole, and cooling model response were all taken into consideration **(Lattieff et al., 2021)**.They used thermodynamic model of adsorption refrigeration as well as the energy – exergy analysis which is done by using MATLAB R2019 platform . They also develop the balance equation for cooling system for this analysis. They founded that the value of the maximum COP was about 0.68 by the simulation study **(Baiju et al., 2022)** .

This work aims to study, design, develop, evaluate, and construct a solar adsorption refrigeration system, assess the cooling capacity of the solar adsorption refrigeration system, and evaluate the factors affecting the system's performance.

2. EXPERIMENTAL WORK

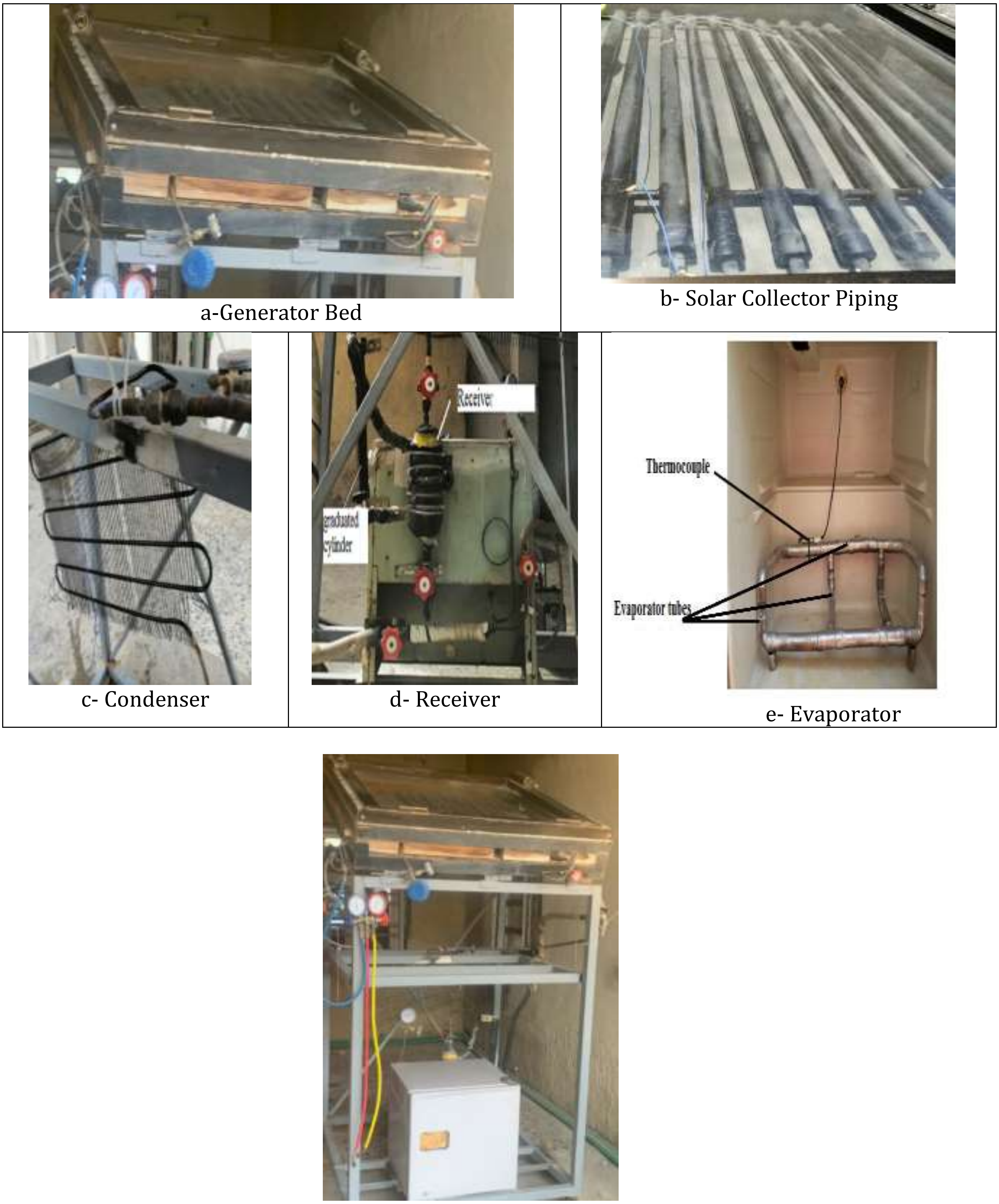
The field adsorption refrigerator was built in Baghdad (Al Dora) and tested on the 13th and 26th of May, 2022. The solar adsorption refrigerator comprises a bed, condenser, receiver, and evaporator. The generator (Bed) is the main part of the field unit. It acts as a compressor in the vapor compression unit. Its dimensions are (1m in width and 1m in length, and it consists of the following parts:

2.1 Structure

The structure consists of three parts. The first part is fixed with the overall structure of the field system, and it is made of iron; the network of pipes is fixed above it, and it is painted black to increase the ability of the black color to absorb the sun's rays. The second part (middle part) consists of a wooden base on which the glass cover rests above it. There is an insulating material underneath to prevent heat dissipation. The third part (upper part) consists of a glass cover made of an aluminum structure that can be opened outward to remove the heat from the solar collector during the night, as shown in **Fig. 1a**.

2.2 Solar Collector Piping Network

The piping network comprises a group of copper pipes. They are 11 copper tubes according to the area of the bed, every 800 mm in length and with a diameter of (25.4 mm). Carbon is put inside it, and the outer tube consists of another perforated tube; its diameter is (12.4mm), and its length is less than the length of the outer tube, which is (500 mm) to leave space for carbon expansion when methanol is added as shown in, **Fig. 1b**. A naturally Air cooled condenser was chosen for the following reasons: It was easy to manufacture and was economical. Finned steel coated with copper tubes of (4) mm diameter and (500) mm length, six tubes were set in parallel and soldered by headers of (5) mm diameter to form the condenser, as shown in **Fig. 1c**. The condenser fins were 124 fins/m. The Condenser lower header was inclined to the outlet by (5° with the horizontal) to allow drainage to help the liquid methanol flow to the receiver. A cylindrical copper vessel receiver (250 mm in length and 190 mm in diameter) accumulates the condenser's coming condensed methanol. This vessel (of 1 Liter capacity) is connected to a graduated cylinder to measure the amount of methanol. The receiver is connected to a valve to control the pressure as shown in **Fig. 1d**. A band of copper tubes and fittings sized to fit along the walls of the cold space constitutes the evaporator structure. The evaporator's dimensions depends on the size of the space to be cooled. Copper tubes with an outer diameter of 19mm and thickness (of 0.8) mm, and the cooler box were (0.084) m^3. The evaporator is shown in **Fig. 1e**, while the constructed experimental setup is shown in **Fig. 1f.**



a-Generator Bed

b- Solar Collector Piping

c- Condenser

d- Receiver

e- Evaporator

f- Experimental setup

Figure 1. Elements of solar adsorption refrigeration system.

3. EXPERIMENTAL PROCEDURES

The experimental study was carried out in one part. The system was vacuumed using (a vacuum pump) where the pressure was fixed to 4kp under atmospheric pressure. After that, the system was charged with methanol. The key variables studied in this work were generator temperature, condenser, and evaporator temperature, solar radiation, and amount of condensed methanol. Also, some tests were achieved with different ambient temperatures. The initial pressure and mass ratio of methanol to active carbon were constant for all tests. The adsorption bed was fixed vertically in all thermal performance tests, and then all its terminals were connected to their proper measuring instruments. Then the temperature was recorded with pressure after being allowed to reach steady-state conditions. The evaporator design is a band of copper tubing and fittings sized to fit along the cooler's walls. The evaporator's size will vary depending on the size of the used cold space. A building with copper tubes is functional and satisfying. However, at least ten minutes were given before any data was recorded. **Fig. 2** shows the schematic diagram of our field solar adsorption refrigerator, and **Fig. 3** depicts a Schematic diagram of the system cycle.

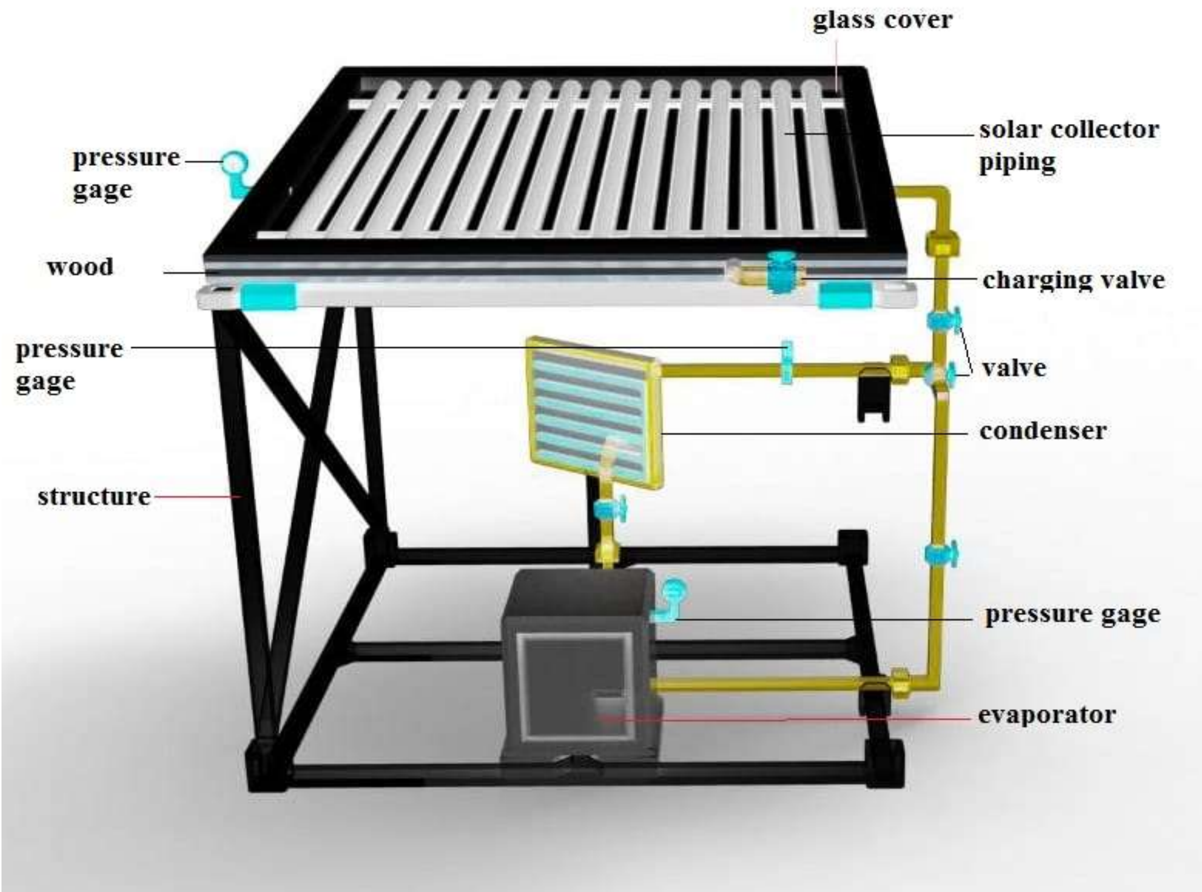


Figure 2. Schematic diagram of the field solar adsorption refrigerator.

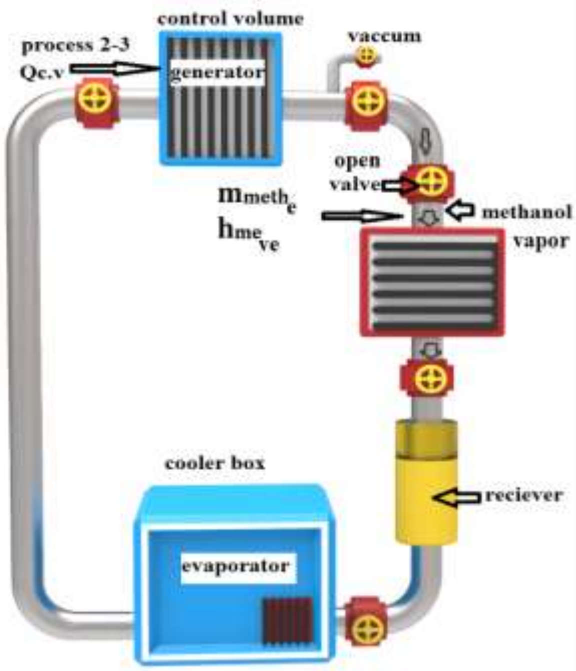


Figure 3. Schematic diagram of the system cycle

A Bourdon pressure gauge was used to measure the system pressure. The range of the pressure gauge was 0 kPa to -100 kPa absolute. Three gauges were used since the unit was submitted to uniform pressure covering all the unit parts shown in **Fig. 4a**.
Seven thermocouples of K-type were used to measure the temperatures in and out of the generator, in and out of the condenser, the refrigerant in the evaporator and on its surface, water in a cooler box, and ambient temperature. The thermocouples were connected through a selector switch to a digital thermometer of K-type (range of temperature (−60 to 1200) °C). Through the selector switch, Applent AT4532 is shown in **Fig. 4b**. The device of solar power meter TM-750 is used to directly measure the intensity of incident solar radiation in units of Btu/ (ft^2) (W/m^2) shown in **Fig. 4c**. Also, the volume of condensate methanol was measured by a glass picker of 1 Liter volume.

a- Pressure Gauges b- Applent AT4532 c- solar power meter

Figure 4. Instrumentations and Measurements.

4. COEFFICIENT OF PERFORMANCE (COP) AND SPECIFIC COOLING POWER (SCP)

The (COP) of a cycle is defined as the ratio of the amount of energy extracted from the cooled body to the energy transferred to the cycle to accomplish this effect. So the net COP of the cycle is:-

$$COP\ gross\ cycle\ = \frac{Qe}{Q_c} \qquad (1)$$

$$Q_e = m_w \times c_w \times \Delta T + m.h_f \qquad (2)$$

Q_c=heat for copper + heat of active carbon +heat of an adsorbed methanol + heat of adsorbed methanol

$$Q_c = (m_m\, c_{pm} + m_{a.c}c_{p_{a.c}} + \dot{m}\, c_{p_{meth.}})(T_d - T_a) + (m_a - m_d)\Delta H \qquad (3)$$

$$\dot{m} = \frac{\left(\int_{ta}^{td} mdt\right)}{(T_d - T_a)} \qquad (4)$$

$$\dot{m} = \frac{\left(m_a(T_b - T_a) + m_d(T_d - T_b)\right)}{(T_d - T_a\ )} \qquad (5)$$

Specific cooling power measures the cooling output per unit mass of adsorbent per unit time, indicating the system size. The compactness of the system is indicated by higher scp outcomes.

$$SCP = \frac{\text{cooling effect}}{cycle\ time\ per\ unit\ adsorbent\ weight}$$

$$\mathrm{SCP} = \frac{\mathrm{Q_e}}{\mathrm{m_{a.c}t_{cycle}}} \qquad (6)$$

where:

c_{pm} –Specific heat of copper (kJ/kg.K)
$c_{p_{a.c}}$ –Specific heat of activated carbon, (kJ/kg.K)
$c_{p_{meth.}}$–Specific heat of methanol, (kJ/kg.K)
c_w– Specific heat of water, (kJ/kg.K)
h_f –Latent enthalpy of the liquid-to-vapor phase transformation, (kJ/kg)
m_w – Mass of water, (kg)
m– Mass of ice, (kg)
m_a– Mass of methanol added to the system, (kg)
m_d– Mass of methanol after condensation, (kg)
$\dot{m}$– Mass flow rate, (kg /s)
m_m–Mass of copper, (kg)
$m_{a.c.}$– Mass of active carbon, (kg)
COP–Coefficient of performance
SCP–Specific cooling power, (kW/kg)
SR–Solar radiation, (w/m^2)
t_{cycle}–Cycle time (min)
T_e –The evaporated temperature of methanol in the evaporator (°C)
T_a –Ambient temperature, (°C)
T_d – Peak (high level) temperature of the generator, (°C)
T_b–The temperature of the bed, (°C)

T_{ic}–inlet condenser temperature, (°C)
T_{oc} –outlet condenser temperature, (°C)
Qe–Cooling effect, (kJ)
Q_c–The heat of adsorption of activated carbon in the solar collector, (kJ)
ΔH –Heat of adsorption, (kJ/kg)

4. RESULTS AND DISCUSSIONS

The experiments are carried out throughout the day on the 13th and 26th of May, 2022. Results of the solar adsorption cooling system's performance included field experiments by using methanol and activated carbon as a working pair. Firstly, solar radiation is used for heating the bed generator for an adsorption coaxial cylindrical tube bed. The dimensions of the tubes were (0.8 m in length) and (0.001 m in thickness). Each tube of the bed is filled with 2.266 kg as a physical adsorbent (generator).
In comparison, the mass of the working fluid (refrigerant) is approximately 0.755 kg of pure methanol, which is one-third of the amount of activated carbon because it is the best amount obtained in previous studies **(Farman, 2013)**. The methanol and activated carbon were chosen as a working pair because the methanol works on low pressure, less than atmospheric pressure, which is suitable for this field unit. The biggest advantage of this pair is that it can work at low temperatures (60-70 ^{o}C), which a flat plate collector can obtain.
On the other hand, the initial unit pressure was chosen to maintain an evaporator temperature of about 0^{o}C. The amount of activated carbon and methanol were fixed and are equal to (2.266 kg) and (0.775 kg) respectively, for all tests that had been made. Both temperatures and pressure of the generator and the mass of methanol condensate, temperature of condenser and evaporator, and ambient temperature and solar radiation were noted and recorded with time.
Figs. 5 and **6** show the performance of the field adsorption unit with time and show variation, inlet and outlet condenser, and generator temperature. **Fig. 5** shows the effect of temperature with time on the 13th of May, while the **Fig. 6**, on the 30th of May, from the **Fig. 5** it is noted that T_g increased in the sunshine and reached its maximum value (of 97.8) °C at midday while reached its maximum value (of 115) °C at midday in **Fig. 6**. Then it decreased, and it can be noted a sudden increase in the generator bed temperature for both situations because of the evaporation of methanol. The adsorption process is exothermic, which rejects heat from the bed generator, leading to an increase in the temperature of the bed generator. T_{ic} decreased and reached its minimum value of 26 °C then at 6 am in **Fig. 5**. In comparison, T_{in} decreased and reached its minimum value of 28 °C and then at 6 am in **Fig. 6**, and then increased and it is reached its maximum value at midday and then decreased to reach to approximate value at the end of the day for both situations.

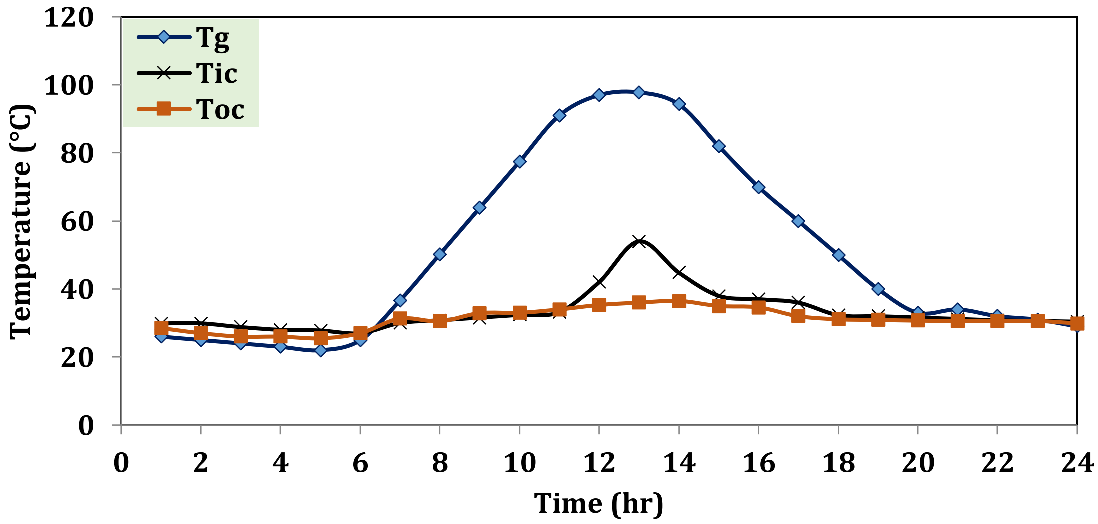


Figure 5. The variation, inlet, outlet condenser, and generator on the 13th of May.

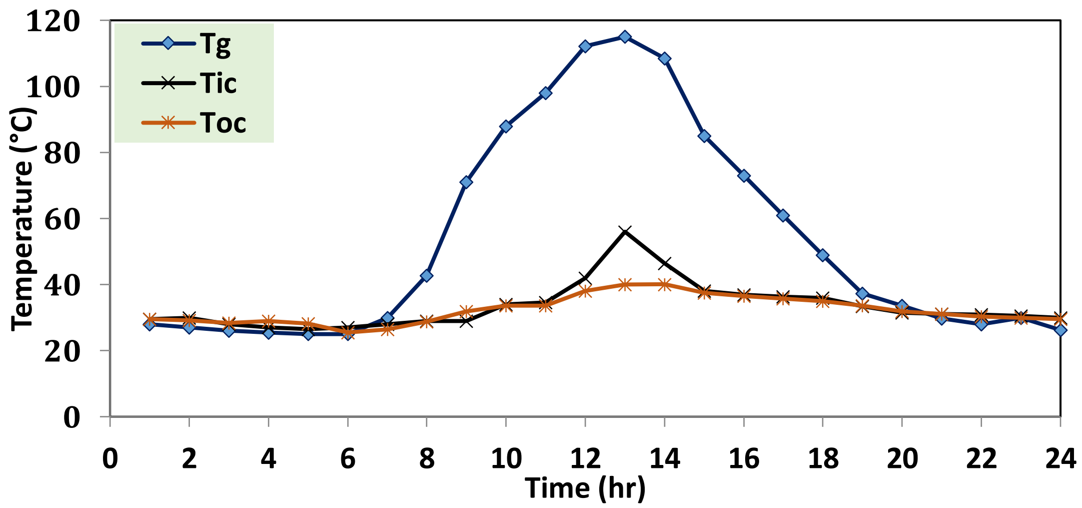


Figure 6. The variation, inlet, outlet condenser, and generator temperature 30th of May.

Figs. 7 and **8** represent the change in the evaporator temperature and solar radiation over time. **Fig. 7** shows the effect of temperature with time on May 13, while **Fig. 8** on May 30. From **Fig. 7**, it can be noted that the solar radiation (SR) starts with an approximate value and then increases at 6 am and reaches its maximum value at midday which is equal to 850(W/m^2), and then decreases until it reaches zero at sunset at 6 pm, as shown in **Fig. 7**, while **Fig. 8** depicts that the maximum value at midday which is equal to 1050 (W/m^2) and then decreases until it reaches zero at sunset at 6 pm. In addition, **Figs. 7** and **8** illustrate the change of evaporator temperature with the time that the system was stable, and temperature (5 and 4°C) in the evaporator was obtained and lasted for (6 hr) for **Fig. 7**, while the minimum temperature obtained in the evaporator for **Fig. 8** is 3 °C lasting for (6 hr.), this gives greater time for methanol to withdraw the latent heat of the water in this experiment; 1 kg of cooling water was obtained for both figures

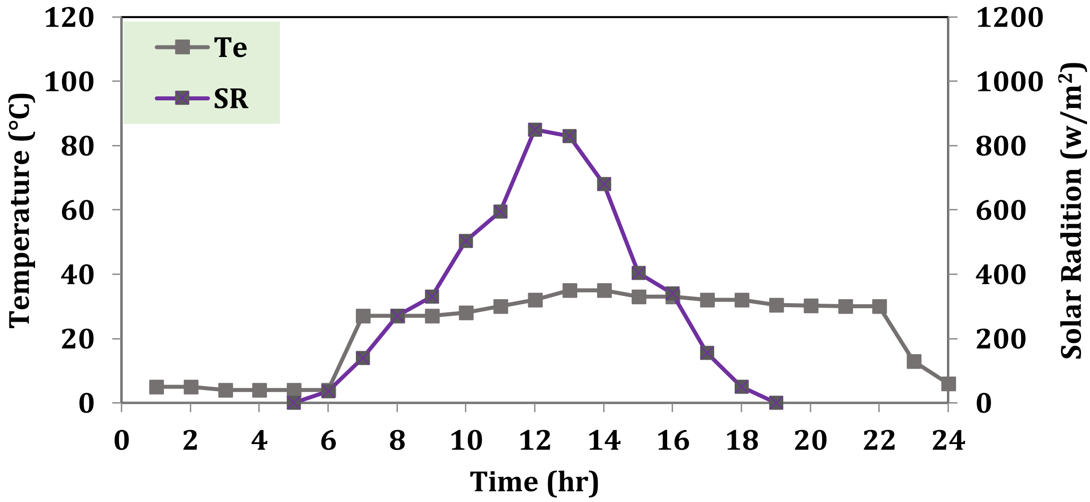


Figure 7. History of evaporator temperature and solar radiation on 13th of May.

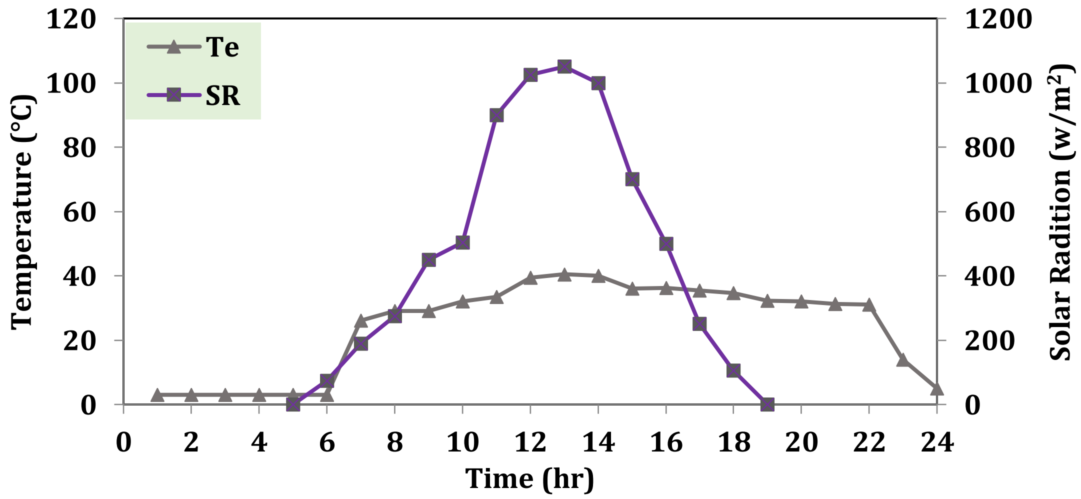


Figure 8. The variation, evaporator temperature, and solar radiation on the 30th of May.

The system performs when the pressure evaporator is equal to 4 kPa for two situations, as shown in **Figs. 9** and **10** for different days. The pressure generator and mass of methanol condensate with time; it can be noted from this **Fig. 9** that methanol begins to condense at ten in the morning Baghdad time, then the temperature of the methanol convergence temperature ambient, which is equal to (77.4 ° C). In contrast, the pressure of the bed generator equals (27 kPa), and the ambient temperature equals 33.4 °C. **Fig. 10** shows that the temperature generator equals (88.5) ° C.

In contrast, the pressure of the bed generator equals (29 kPa) and the temperature of the ambient equals (36) °C. Then the generator pressure reaches its maximum value (73) kPa at midday and then decreases to reach the operating pressure of 4kpa. Also, the figure depicts that the amount of methanol condensate increased, maximum at 0.340 kg (0.430 lit) around five in the afternoon for **Fig. 9**. While the maximum amount of methanol condensed in **Fig. 10** is 0.344 kg (0.435 lit) around five in the afternoon. Then the condensation process was stopped because of the low methanol amount in the bed.

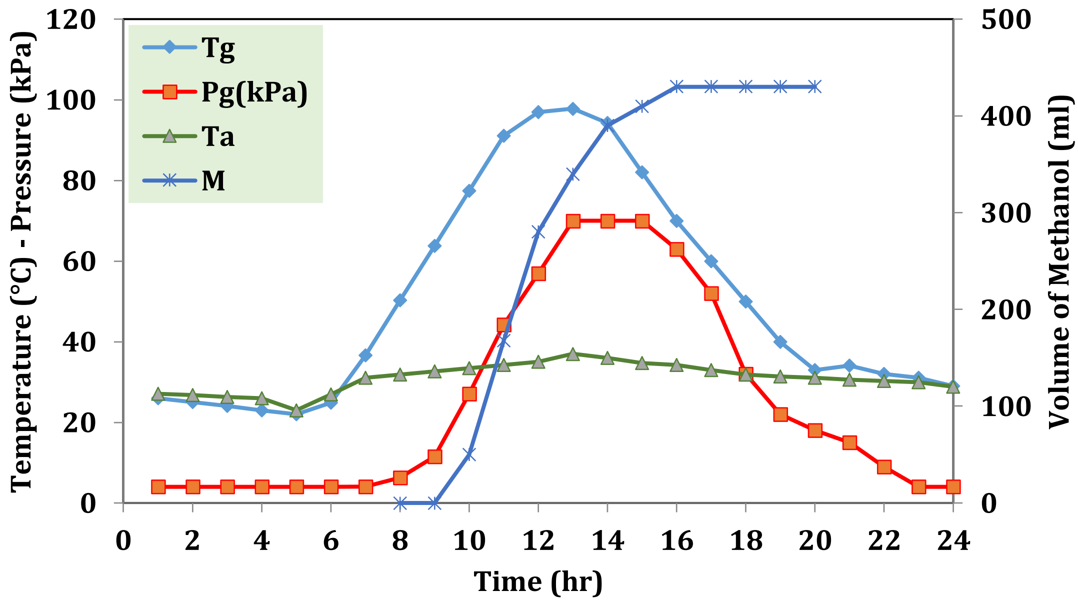


Figure 9. Transient variation of ambient generator temperature, pressure, and methanol concentration on the 13th of May.

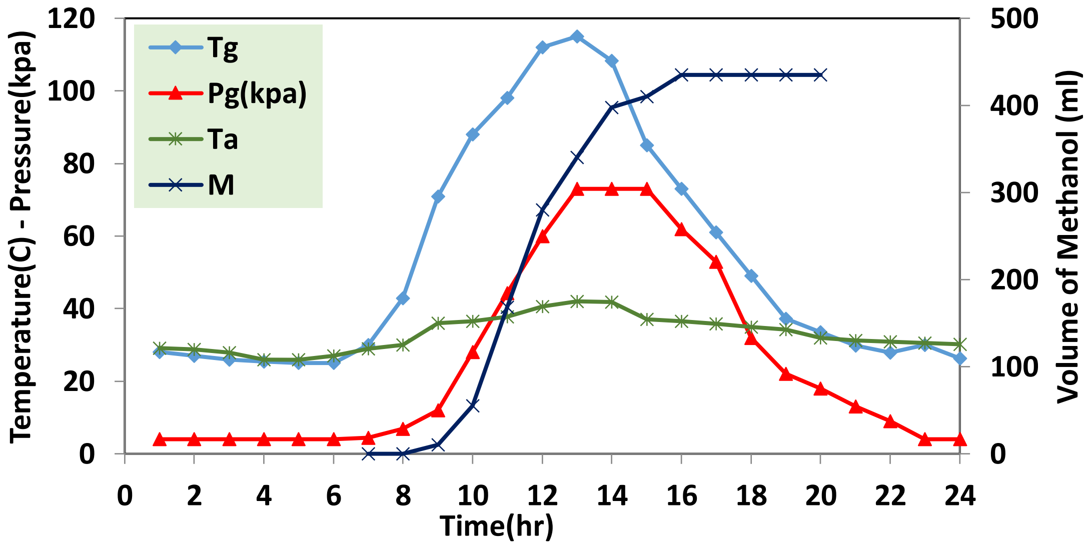


Figure 10. Transient variation of ambient, generator temperature, pressure, and methanol concentration on the 30th of May.

This work aims to study the system's performance with different temperatures using activated carbon and methanol as a working pair and the incident solar radiation on the bed. In contrast, the other study found the COP and SCP using heated water. So the comparison between the results of COP this study and the previous study plotted in **Fig. 11,** a study was selected for comparison **(Farman et al., 2017)** which studied the performance of the system with 0.870 kg methanol and 3kg activated carbon, while in the present study using 0.755kg methanol and 2.266kg activated carbon. From **Fig. 11**, the value of COP for the presented study was (0.56) while the value of the COP for **(Farman et al., 2017)** was (0.39).

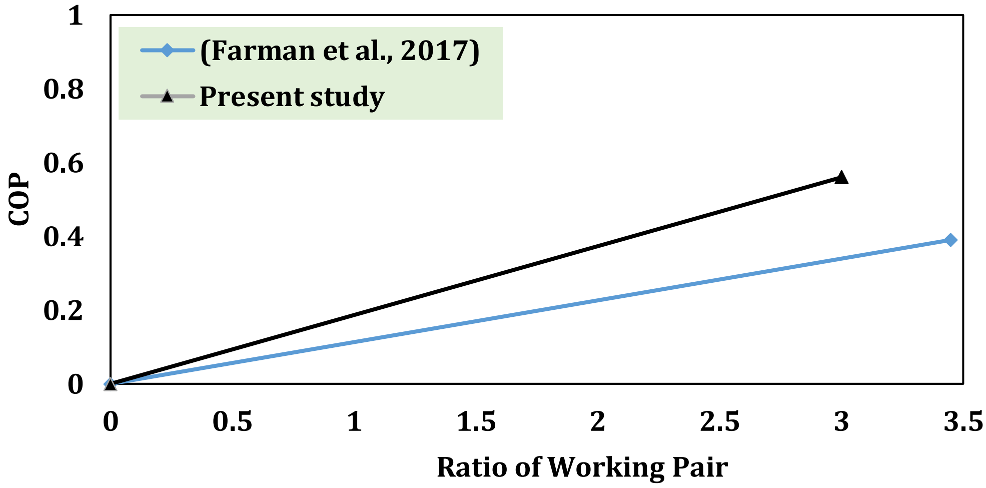


Figure 11. Comparison of coefficient of performance for two studies using solar radiation on a bed and heated water.

5. CONCLUSIONS

This study involved an experimental test, and a field adoration refrigeration design for the cooling system was manufactured and tested. Different experimental tests were carried out on different days at different temperatures. The main conclusions can be summarized as follows:

1. When the ambient temperature was 43°C, the maximum temperature measured from the bed was 115 °C. Although the ambient temperature increased, it didn't go above this degree.
2. The maximum value of COP and SCP were 0.57 and 0.14 $kW/kg_{a.c}$, respectively.
3. At the opening time of the valve between the evaporator and the generator (9 pm), the lowest temperature obtained at the evaporative surface was (4 °C). The maximum amount of methanol condensate was (0.340 kg) at 13th of May, while the lowest temperature obtained at the evaporative surface was (3 °C). The maximum amount of methanol condensate was (0.344 kg) on the 30th of May.
4. Solar adsorption ice makers can be used in Baghdad because of Iraq's large amount of solar radiation all year.

REFERENCES

Alamoudi, H.A., and Abdel-Dayem, A.M., 2021. Design Optimization and Simulation of an Ice Plant Working by Solar Adsorption Technology. *European Journal of Energy Research*, *1*(4), pp. 13–22. Doi:10.24018/ejenergy.2021.1.4.22

Baiju, V., Asif Sha, A., Shajahan, C.A., and Chindhu, V.G., 2022. Energy and exergy based assessment of a two-bed solar adsorption cooling system. *International Journal of Refrigeration*, *141*, pp. 90–101. Doi:10.1016/J.IJREFRIG.2022.06.001

Dakkama, H.J., Youssef, P. G., Al-Dadah, R. K., and Mahmoud, S., 2017). Adsorption ice-making and water desalination system using metal-organic frameworks/water pair. *Energy Conversion and Management*, *142*, pp. 53–61. Doi:10.1016/j.enconman.2017.03.036

Farman, N.F., Hadi, N.H., Abdulmajid, B.A., 2017. Performance of the Solar Adsorption Refrigeration System under Various Conditions and Parameters for Iraq Climate. *1st IJRTESS – 2017 7th Scientific Engineering and 1st International Conference "Recent Trends in Engineering Science and Sustainability" 17-18 May*, pp. 425-430.

Farman, N.F., Hadi, N.H. and Abdulmajid, B.A., 2013. Performance of the Solar Adsorption Refrigeration System under Various Conditions and Parameters for Iraq Climate (Doctoral dissertation, College of Engineering, University of Baghdad).

Hamrahi, S.E., Goudarzi, K., and Yaghoubi, M., 2018. Experimental study of the performance of a continuous solar adsorption chiller using Nano-activated carbon/methanol as working pair. *Solar Energy*, 173, pp. 920–927. Doi:10.1016/j.solener.2018.08.030

Hu, T., Liu, J., and Wang, T., 2020. Development of a New Solar-Assisted Refrigeration Pipe for Potential Permafrost Protection. *Journal of Cold Regions Engineering*, *34*(3), 06020001. Doi:10.1061/(asce)cr.1943-5495.0000222

Lattieff, F. A., Atiya, M. A., Mahdi, J. M., Majdi, H.S., Talebizadehsardari, P., and Yaïci, W., 2021. Performance analysis of a solar cooling system with equal and unequal adsorption/ desorption operating time. *Energies*, 14(20). Doi:10.3390/en14206749

Reda, A. M., Ali, A. H. H., Morsy, M. G., and Taha, I. S., 2019. Optimization and performance of a small scale adsorption cooling system fully powered by solar energy for hot arid areas. *SN Applied Sciences, 1(9)*, pp. 1–14. Doi:10.1007/s42452-019-1150-8

Selvaraj, D. A., and Victor, K., 2021. Design and Performance of Solar PV Integrated Domestic Vapor Absorption Refrigeration System. *International Journal of Photoenergy*, 2021, P. 6655113. Doi:10.1155/2021/6655113

Singh, S., and Dhingra, S., 2019. Thermal performance of a vapour adsorption refrigeration system: An overview. *Journal of Physics: Conference Series*, *1240*(1). Doi:10.1088/1742-6596/1240/1/012024

Souissi, M., Guidara, Z., and Maalej, A., 2019. Experimental study on a new solar refrigerator with intermittent adsorption cycle. *Energy for Sustainable Development*, *49*, pp. 89–99. Doi:10.1016/j.esd.2019.01.006

Sugiartha, N., 2020. Experimentation of an Activated Carbon/Methanol Solar Refrigerator. *Logic : Jurnal Rancang Bangun Dan Teknologi*, *20*(2), pp. 129–134. Doi:10.31940/logic.v20i2.1822

Wang, Y., Li, M., Ji, X., Yu, Q., Li, G., and Ma, X., 2018. Experimental study of the effect of enhanced mass transfer on the performance improvement of a solar-driven adsorption refrigeration system. *Applied Energy*, 224, pp. 417–425. Doi:10.1016/j.apenergy.2018.05.017

Yin, Y., Shao, J., Zhang, L., Cui, Q., and Wang, H., 2021. Experimental study on heat transfer and adsorption cooling performance of mil-101/few layer graphene composite. *Energies*, *14*(16). Doi:10.3390/en14164970