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PERFORMANCE EVALUATION OF A SOLAR ABSORPTION REFRIGERATOR FOR TOMATOES PRE-COOLING

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ABSTRACT: In this study, an ammonia-water absorption refrigerator (AWAR) with 50 L in capacity was operated by solar energy captured by two systems for conducting tomatoes pre-cooling process particularly in hot weather. The first system was a solar photovoltaic-thermal system which consisted of flat plate solar collector combined with the photovoltaic (PV) system, while, the second system included the solar photovoltaic (PV) system solely. This study aims to evaluate the performance of the solar absorption refrigerator with load and without load under Egyptian climatic conditions to investigate the capability of AWAR to perform tomatoes pre-cooling and reach the recommended range of tomatoes cold storage in the cooling cabinet (7-10°C) because tomatoes is perishable product. The obtained results indicated that using the solar photovoltaic-thermal absorption refrigerator (SPTAR) at hot water flow rate of 1.58 L/min and cooling load of 23 Kg of tomatoes (maximum capacity) gave the highest values of refrigeration system's coefficient of performance (COP_{ref}) of 0.30 and cooling cabinet temperature of 284 °K/11°C at the lowest temperature of evaporator (272°K/-1°C). Nevertheless, solar photovoltaic absorption refrigeration system (SPAR) gave lower COP_{ref} value of 0.27 and temperatures in the cooling cabinet of 295°K/22°C and evaporator temperature of 285°K/12°C at PV efficiency of 11% Hence, the integration of the flat plate solar collector with the PV system in SPTAR as heating system for the generator led to an enhancement in the performance of the AWAR at the maximum capacity of the refrigerator comparing to using the PV panels solely in SPAR system. Ultimately, using SPTAR system may reduce the operating times of the electric heater and consequently using less numbers of solar batteries for long operating time with low constructional cost.

Key words: Ammonia-water, absorption refrigerator, solar energy, tomatoes, pre-cooling, coefficient of performance.

INTRODUCTION

Solar energy is the most important type of renewable energy due to its cleanliness, inexhaustible and available intensively all over the year particularly in countries that located in the world's solar belt. **Tawfik (2018)** mentioned that Egypt has a high daily solar radiation intensity with a range of (5.5 – 7) kWh/m^2 from north to south and more than 270 of sunny days every year due to its outstanding location in the world Sunbelt which enables the country to exploit the solar energy in several applications that can serve the farm. **NREA (1998) and Vankeleom *et al.* (2004)** stated that about 90% of the Egyptian regions have an average total radiation greater than 2200 kWh/m^2/year. Solar energy can be utilized for many applications such as; drying, cooking, desalination or even cooling. Solar cooling systems one of the most potential method for preserving the agricultural products from deterioration especially in remote regions, insulated communities, deserts and within areas where electricity is not available. One of the most important solar cooling systems is solar absorption refrigeration system which

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can be operated by solar thermal or solar electrical energy. **Chidambaram *et al.* (2011)** indicated that reducing energy consumption and the negative environmental impacts caused by the conventional vapor compression air conditioning systems can be achieved by exploiting solar thermal energy or other renewable energy sources to operate vapor absorption chillers which required less electric power to operate. This system used friendly environmental mixtures as working fluid such as NH_3/H_2O mixture and H_2O/LiBr mixture. **Hassan and Mohamad (2012)** mentioned that working pair NH_3/H_2O was preferred to be used instead of working pair H_2O/LiBr in absorption systems to overcome the problems belong to the last one. **Chu and Majumdar (2012)** mentioned that ammonia– water mixtures as binary non-isotropic mixtures have a low boiling point and variable boiling temperatures during phase change process at constant pressure, thus, a good thermal match between the hot and cold streams can be occurred. Moreover, ammonia–water mixture can work at lower temperatures and can be exploited as working fluid in power generation cycles due to be suitable for utilizing low-and-mid temperature heat source, such as solar energy, industrial process heat, and waste heat from power plants. **Demirkaya *et al.* (2013)** compared ammonia absorption chiller to lithium-bromide absorption chiller and the results indicated that ammonia absorption refrigeration system has a wider range of operating temperatures about 60°C to 100° and it can be utilized for industrial applications when the evaporation temperatures are below 0°C. **Boudéhenn *et al.* (2012)** developed a 5kW solar-powered NH_3/H_2O absorption chiller with coefficient of performance (COP) of 0.65. The results showed that the efficiency was only 0.16 although their solution heat exchanger was designed to operate at an efficiency of 0.83. **Said *et al.* (2016)** presented that an experimental investigation of a solar thermal powered ammonia-water absorption refrigeration system. The results of the experiments indicated that the chiller COP was 0.69 and a cooling capacity of 10.1 kW at 114, 23 and - 2°C of the generator inlet, the condenser/absorber inlet and the evaporator outlet, respectively. Tomatoes is considered one of the most perishable products that can be deteriorated rapidly unless it was handled and kept under relatively low temperatures, during the period begins at the end of harvesting process until reaching to the markets or processing factories, particularly in hot weather. **Harderburg *et al.* (1986)** reported that the recommended range of tomatoes cold storage ranging from 7-10°C. So, it is necessary to determine the capability of a solar powered ammonia-water (NH_3/H_2O) absorption refrigerator (AWAR) for conducting tomatoes pre-cooling process to preserve it from decay, raise the quality as well as extend its shelf life.

So, this study aims to evaluate the performance of the AWAR under two solar energy systems for heating up the generator of the absorption refrigerator and optimizing some operational parameters affect its performance.

MATERIALS AND METHODS

The solar ammonia-water (NH_3/H_2O) absorption refrigerator was developed in a private workshop, and installed at Mashtoul El Souk City, Sharkia Governorate, Egypt (Lat. 30° 21′ 38" N , Long. 31° 22′ 39" E) during July and August 2017.

Materials

Two solar systems as heat sources were used to operate the absorption refrigerator. The first one was called the solar photovoltaic-thermal system that represents an integration system between a solar flat plate collector and the solar photovoltaic (SP) system, while the second one included only the photovoltaic (SP) system as shown in Fig. 1.

Solar Heating Systems

The solar photovoltaic-thermal system consisted of solar thermal (ST) system and solar photovoltaic (SP) system. The (ST) system included the solar flat plate collector, centrifugal pump and heat exchanger. Meanwhile, the (SP) system consists of PV panel, solar battery, charging controller and inverter which were connected to an electric heater allocated at the generator of AWAR.

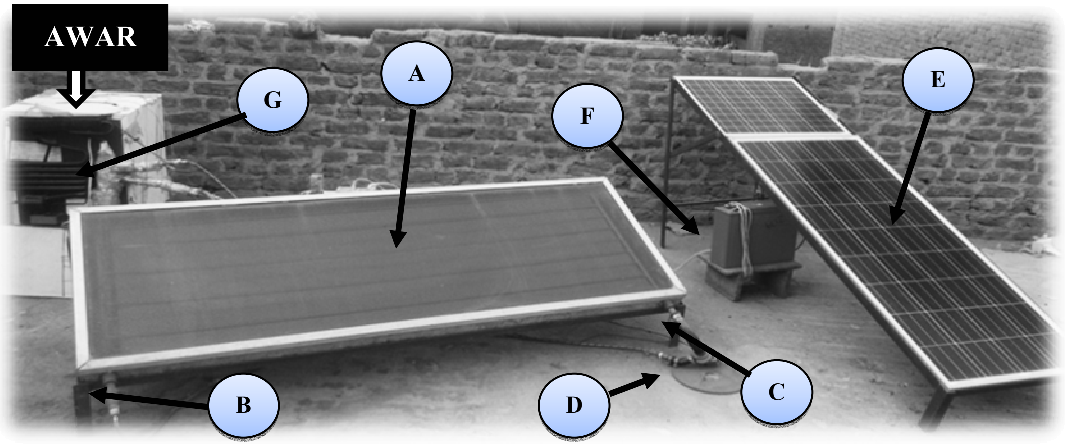


Fig. 1. The solar ammonia-water absorption refrigerator

A) Flat plate solar collector, B) Water inlet port, C) Water outlet port, D) Centrifugal pump, E) PV panel, F) Solar battery, G) Generator.

Solar Thermal (ST) System

The flat plate solar collector

The solar flat plate collector box was made of iron sheet 2 mm with rectangular shape and dimensions of 2020, 760 and 150 mm for length, width and depth, respectively with net upper rated surface area of 1.372 m^2. It consisted of an aluminum absorber plate, Copper pipes with diameters of 4.7625 mm (3/16 inch), a clear glass cover with surface area of 2020 mm × 760 mm and thickness of 6 mm using an insulation layer of glass wool with thickness of 50 mm.

Centrifugal pump

The centrifugal pump with power of 40 W was installed at the output of the solar flat plate collector to circulate the hot water from the solar collector to the heat exchanger continuously in a closed system.

Heat exchanger

It was constructed from copper pipes and fittings (elbows) which were connected together by welding to give a continuous serpentine shape. The diameter and length of copper pipes were 12.7 mm (1/2 inch) and 150 mm, respectively. It was coiled in direct contact with generator pipe of the refrigerator in the vertical plane.

Solar Photovoltaic (SP) System

Photovoltaic solar panel and the solar battery

Two polycrystalline photovoltaic (PV) solar modules with maximum power of 150 W and 50 W with surface area of 1.00 m^2 and 0.382 m^2, respectively were used. The two PV panels were connected in a serial connection so that the total maximum output power reached up to 200 W theoretically. Regarding the solar battery, a deep-cycle battery was used with nominal capacity of 100 Ah and 12 VDC.

Battery charging controller and the inverter

It was used a battery charging controller with rated voltage of 12V/24V and maximum current output of 10 A, whilst, 300 W inverter was used with input and output voltages of 12 VDC and 220 VAC, respectively.

Electric heater

Coil copper heater with approximate power of 80 W and length of 10 cm. It can raise the temperature of the AWAR generator up to 150°C.

Solar photovoltaic (SP) system

This system had the same previous solar photovoltaic design but with using an additional solar battery instead of the flat plate solar collector, so that the system could be operated for consecutive seven operating hours.

Refrigerator components

The absorption refrigerator consists mainly of generator, separator, condenser, evaporator, absorber, cooling cabinet and pump.

Generator

It consists of the heat exchanger and the electric heater generator for the (SPT) system. But for the (SP) system, it was only the electric heater. It could heat the ammonia-water solution to reach up to the temperature that converted the solution into a vapour form.

Separator

The component that extracted the pure ammonia vapour from rich solution to prevent water from reaching the condenser.

Condenser

It consists of three bends of tube with 51 fins. The dimensions of each fin are 80, 60 and 1 mm for length, width and thickness, respectively.

Evaporator

It consists of two tube bends with a 40 mm length and 16 mm outer diameter. These tubes are tube-in-tube geometry. This evaporator connected to outlet condenser and inlet absorber.

Absorber

The absorber of 16 mm outer diameter iron pipe with 10 U-bends was used. It can absorb the refrigerant vapour by its poor solution in the absorbent, forming a rich solution of the refrigerant in the absorbent.

Cooling cabinet

It was used to carry out tomatoes pre-cooling process with rated storage volume of 50 L.

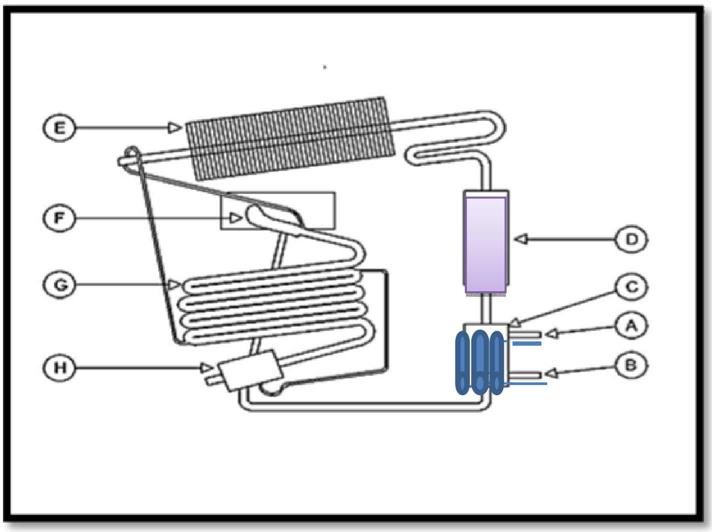
Instruments

Solarimeter

It is a digital device to measure the total incident solar radiation (Model : TES-132, TENMARS, Taiwan) with measuring range of 0-2000 W/m^2, resolution 0.1 W/m^2 and accuracy ± 10 W/m^2.

Digital thermometer

It is a portable digital device (Model: Omron E5C4-R, Japan) provided with probes, a convenient digital display with resolution of 1°C and temperature range from 0 to 399°C. It was used to measure the temperature at seven different points by using K-type thermocouples with thermal range of (-100 to 1300°C). These thermocouples were fixed at the generator, evaporator, absorber, cooling cabinet, ambient, inlet and outlet of the flat plate solar collector.



Part	Part name
A	Heat Exchanger (coil) inlet
B	Heat Exchanger (coil) outlet
C	Generator
D	Separator
E	Condenser
F	Evaporator
G	Absorber
H	Reservoir

Fig. 2. The ammonia-water absorption refrigerator (AWAR) componets

Methods

The performance of the AWAR was investigated under two heating systems, the Solar Photovoltaic-Thermal Absorption Refrigerator (SPTAR) system and the Solar photovoltaic Absorption Refrigerator (SPAR) system. The performance evaluation including the values of refrigeration coefficient of performance (COP_{ref}) and its capability to reach up the recommended temperature range of tomatoes cold storage of (7-10°C) at the cooling cabinet.

The evaluation period of every treatment through the (SPTAR) and the (SPAR) systems was consecutive 8 days, and then the hourly average of these days was determined.

The performance evaluation of the AWAR was carried out under the following conditions:

1. Two different solar heating systems were used:

a- Solar photovoltaic-thermal absorption refrigeration system (SPTAR).

b- Solar photovoltaic absorption refrigeration system (SPAR).

2. Three different flow rates of flat plate solar collector of 0.46, 0.77 and 1.58 L/min were used to determine the proper flow rate of the hot water (For SPTAR only).
3. Three different cooling loads of 11, 16 and 23 Kg of tomatoes corresponding to 50, 75 and 100 % of the cooling cabinet capacity besides the no load condition.

Measurements

Performance of the flat plate solar collector

The available solar energy

It can be expressed as the incident solar radiation heat rate on the surface of the solar collector which can be estimated given by the following equation **(Duffie and Beckman, 1980)**:

$$Q_A = GA_c$$

Where:

Q_A = available solar energy (W).

G = the intensity of solar radiation (W/m^2).

A_c = collector surface area (m^2).

The useful heat gained

It represents the energy produced by the solar collector *i.e.,* the amount of heat stored in the hot water flowing through the solar collector which can be calculated by **Kargarsharifabad *et al.* (2014)** as the following equation::

$$Q_C = m\, C_p\, (T_{out} - T_{in})$$

Where:

Q_C = the useful heat gained (W).

m = mass flow rate (Kg/sec.).

C_p = specific heat of water (J/Kg.°K).

T_{out} = hot water outlet temperature (°K).

T_{in} = hot water inlet temperature (°K).

The overall thermal efficiency of solar collector

It can be defined as the useful heat gained divided by the available solar energy as the equation given by **(Kalogirou, 2013)**:

$$\eta_{thermal} = \frac{Q_c}{Q_A} \times 100$$

$\eta_{thermal}$ = The collector thermal efficiency (%).

The Solar Photovoltaic (SP) System

The useful solar electric heat produced by the photovoltaic (PV) system

The maximum electric current produced on the generator can be calculated as the following equation:

$$Q_{SP} = \eta_{PV} \times A_{PV} \times G$$

Where:

Q_{SP} = the useful electrical power produced by the PV system (W).

η_{PV} = the PV system efficiency (%).

A_{PV} = PV-panels area (1.37 m^2).

The PV system efficiency (η-PV)

It can be calculated by the following equation:

$$\eta_{PV} = \eta_{panel-max} \times \eta_{beat} \times \eta_{inv}$$

Where:

$\eta_{Panel-max}$ = the PV panels efficiency (14.36%).

η_{beat} = the battery efficiency (85%).

η_{inv} = inverter efficiency (90%).

The battery and inverter efficiencies were assumed according to **Abd El-Shafy (2009)**, whereas the actual PV efficiency was calculated as follows:

$$\eta_{thermal} = \frac{\text{Max. power outpout of panle}}{\text{PV panel area} \times \text{incident solar radiation}\left(\text{ie,}\frac{1000\ \text{W}}{\text{m}^2}\right)} \times 100$$

Hence, the SP system efficiency in this study would be about 11%.

Performance of the absorption refrigerator

Coefficient of performance (COP) is considered as crucial indicator for the performance of the SPTAR and SPAR systems.

COP of the refrigerator under cooling loads

It can be calculated for SPTAR and SPAR systems with different cooling loads by the relation given by **(Rodríguez-Muñoz and Belman-Flores, 2014):**

$$COP_{ref} = \frac{Q_{ev}}{Q_{ge}}$$

Q_{ev} = the cooling effect/the extracted heat by the evaporator (W).

Q_{ge} = the heat of generator (W).

The cooling effect represents the field heat that can be calculated by the equation of **(Mansouri *et al.*, 2017)** as follows:

$$Q_{ev} = \frac{m_f\, C_p(T_i - T_o)}{\tau}$$

Where:

m_f = Mass of tomatoes (Kg).

C_p = Tomatoes specific heat (3980 J/Kg.°K)

T_i = Tomatoes initial temperature at the beginning of cooling process (°K).

T_o = Tomatoes temperature at the end of cooling process (°K).

τ = The operation time (7 hr.) of the solar photovoltaic refrigeration system (sec).

By consideration that:

For (SPAR) system Q_{ge} can be determined as the following equation:

$$Q_{ge} = Q_{SP}$$

While for (SPTAR) system Q_{ge} can be estimated as the following equation:

$$Q_{ge} = Q_{SP} + Q_C$$

RESULTS AND DISCUSSION

The Effect of Flow Rate on the Thermal Performance of the Solar Collector

It is well known that hot water flow rate of the solar flat plate collector (FPC) as well as the incident solar radiation (ISR) on its area have great influence on the useful heat gained (Q_C). So, it is necessary to determine the optimum hot water flow rate which can achieve the highest values of the heat gained and consequently obtain the highest thermal efficiency (η_{th}) that depends basically on the useful heat gained by the solar collector. Fig. 3 depicted that, there is a directly proportional relationship between hot water flow rate and generated useful heat gained. *i.e.,* the increase of the flow rate values increased the thermal heat gained. So, the greatest values of the useful heat gained energy could be recorded at the maximum value of hot water flow rate all over the seven operating hours. This increase due to the capability of the solar collector to maintain the temperature difference between the inlet and the outlet hot water at the high mass flow of water and consequently the highest values of thermal efficiency also could be achieved when the solar radiation is not at its highest values as shown in Fig. 4. This means that the solar collector has a good heat transfer rate. The obtained results showed that the increased of hot water flow rate from 0.46 to 1.58 L/min was companied with a remarkable increase in the daily average values of useful heat gained from 135.46 to 625.08 W and the collector daily thermal efficiency from 13.83 to 60.11% under daily average values of solar radiation in the range of 661.18-757.88 W/m^2 during the experiment period.

It is obvious that the hot water flow rate of 1.58 L/min gave the highest value for each of useful heat gained and collector thermal efficiency.

Thermal Analysis of the Solar Absorption Refrigerator

Definitely, it is very important to measure the temperatures of the solar absorption refrigerator cycle components including the generator, absorber, evaporator, cooling cabinet and the

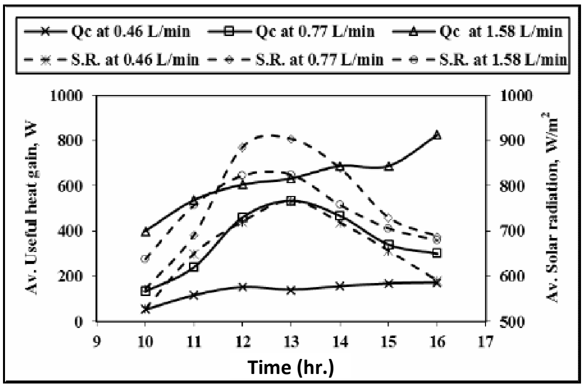


Fig. 3. The effect of hot water flow rate and the hourly average values of incident solar radiation on the hourly average values of useful heat gained of the solar collector during the experiment period

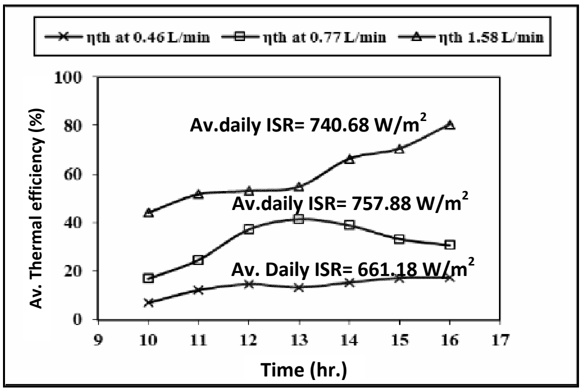


Fig. 4. The hourly average thermal efficiency of the solar collector under different flow rates

ambient temperature under the different values of the incident solar radiation for SPTAR system using the optimum hot water flow rate of 1.58 L/min and SPAR system to determine the most efficient system that can achieve the lowest temperature range in the refrigerator cabinet. The measurements were performed under no load condition comparing to cooling loads of 11, 16 and 23 Kg of tomatoes for the SPTAR and the SPAR systems.

Temperatures of the AWAR Components for SPTAR and SPAR Systems Under no Cooling Load Condition

Generally, the evaporator (T_{ev}) and cabinet (T_{cab}) temperatures affected by the generator temperature (T_{ge}). The excessive or partial heating of the refrigerator generator as well as the high ambient temperature will reduce the capability of the fridge to extract the heat from the product that allocated in the cooling cabinet and consequently the performance of refrigerator will be retarded. Hence, it is very essential to reach the appropriate temperature at the generator to allow the dissolved ammonia in the aqua-ammonia solution to rise up as bubbles toward the separator while the water take its own pass into the weak water-ammonia tube, so the refrigeration effect could take place and the performance will be more stable. Figs. 5 and 6 indicated that, after the first operating hour the average hourly evaporator temperature for the SPTAR and SPAR system were 281.5°K (8.5°C) and 277°K (4°C) and this means high cabinet temperature and then low performance. By the time, the evaporator temperature of SPAR system reached its highest value of 264.6°K (-8.4°C) corresponding to cabinet temperature of 283°K (10°C) at time of 13:00, while the evaporator temperature of SPTAR system reached its highest value of 259.63 °K (-13.38°C) corresponding cabinet temperature of 279.88°K (6.88°C) at time of 15:00.It is obvious that, the evaporator temperature of the SPTAR system has a good cooling performance under a similar incident radiation- as displayed in Figs 5,6- but this lag to reach its highest value comparing to the SPAR system due to the using of the hot water solar collector to rise up the generator temperature before operating of the heater to reach the appropriate temperature for the generator. At time of 16:00 (The end of the working day), the performance of both systems would retarded where the temperatures of evaporator and cabinet were 270.79°K (-2.21°C) and 289.4°K(16.4°C) for SPAR system, whereas the temperatures of evaporator and cabinet were 261°K (-12°C) and 280.75°K (7.75°C) for SPTAR system.

Since the vapor of ammonia and hydrogen mix leaves the evaporator and enters the absorber at high temperature and low pressure, thus the absorber temperature was higher than the ambient temperature, so high temperature difference between the absorber and ambient means good performance for the refrigerator. Ultimately, the SPTAR system gave a good method to be heating system for the AWAR.

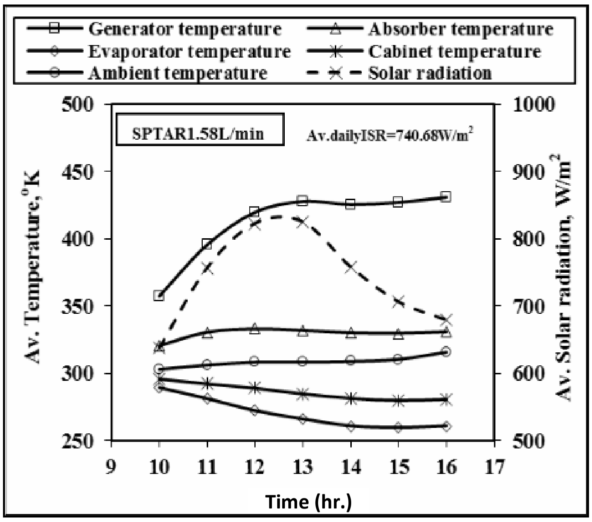


Fig. 5. The solar absorption refrigerator cycle without load for SPTAR system

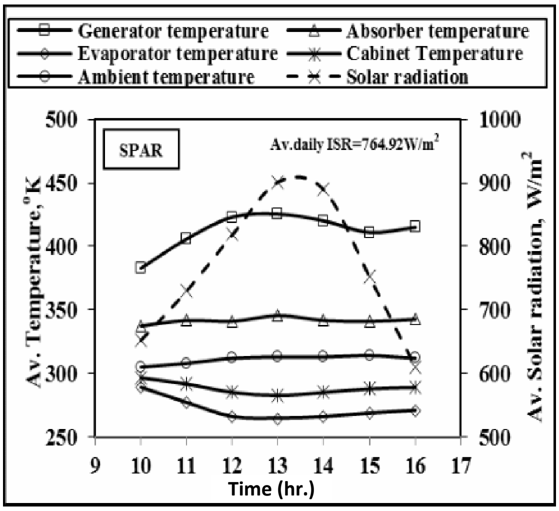


Fig. 6. The solar absorption refrigerator cycle without load for SPAR system

Temperatures of the AWAR Components for SPTAR and SPAR Systems Under Different Cooling Loads

In this study, the performance of the AWAR was investigated through the temperature distribution within the fridge under the SPAR and SPTAR systems as heating systems using different cooling loads of tomatoes to select the proper system for heating up the generator of the refrigerator with noting that all experimental days had very close values of the daily average solar radiation to each other. Three different cooling loads represented in three different masses of tomatoes of 11, 16 and 23 kg corresponding 50, 75 and 100% of the refrigerator capacity were used to determine practically the heating system that can give a temperature in the cooling cabinet within or close to the recommended cold storage temperature for tomatoes (7-10°C). As shown in Figs. 7, 8, 9, 10, 11 and 12, the average hourly evaporator temperatures declined from the beginning of experiments at time of 10:00 until reaching its lowest values at time of 16:00 for both heating systems under all cooling loads. For the SPAR system, the average hourly evaporator temperatures were 283°K (10°C), 284°K (11°C) and 285°K (12°C) corresponding to average hourly cabinet temperatures of 292°K (19°C), 295°K (22°C) and 295°K (22°C) for cooling loads of 11,16 and 23 kg of tomatoes, respectively.

For SPTAR system, the lowest average hourly evaporator temperatures were 271°K (-2°C), 271°K (-2°C) and 272°K (-1°C) corresponding to average hourly cabinet temperatures of 279°K (6°C), 282°K (9°C) and 284°K (11°C) for cooling loads of 11,16 and 23 kg of tomatoes, respectively.

It is obvious that the SPTAR gave the lowest temperatures for evaporator and cabinet temperatures under all cooling loads due to the continues flow of the hot water around the generator of refrigerator in the interval time of the heater pulses (On and Off time) and consequently the generator temperature doesn’t reduced greatly from the recommended temperature all the time but the contrary can be occurred when the heater used solely as in the SPAR system. Lastly, it can be recommended to use The AWAR with The SPTAR system under the maximum capacity to be more economic, especially the aim of this investigation is conducting the tomatoes pre-cooling process not for long term cold storing.

The AWAR’s Coefficient of Performance Under two Heating Systems

Foremost, the system’s coefficient of performance (COP_{ref}) is an important indicator for the performance of the solar absorption refrigeration cycle under different heating systems. Fig. 13 depicted the relationship between the COP_{ref} for the SPAR and SPTAR

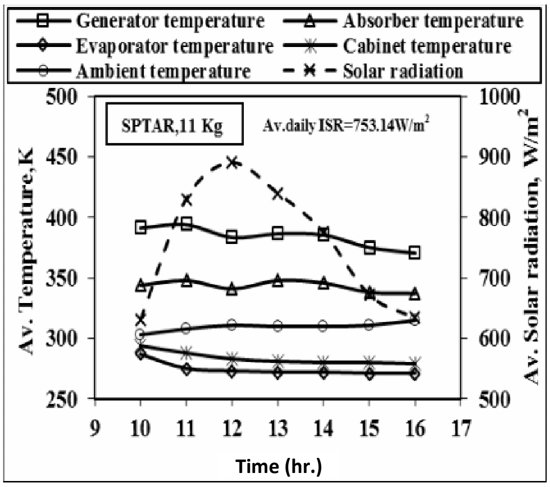


Fig. 7. The SPTAR system under cooling load of 11 Kg of tomatoes at hot water flow rate of 1.58 L/min.

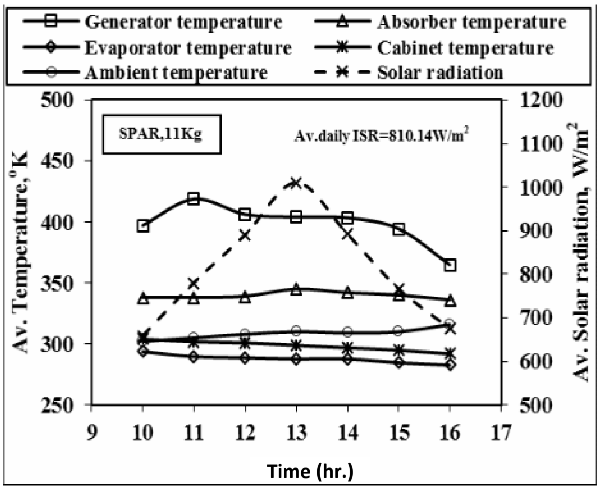


Fig. 8. The SPAR system under cooling load of 11 Kg of tomatoes.

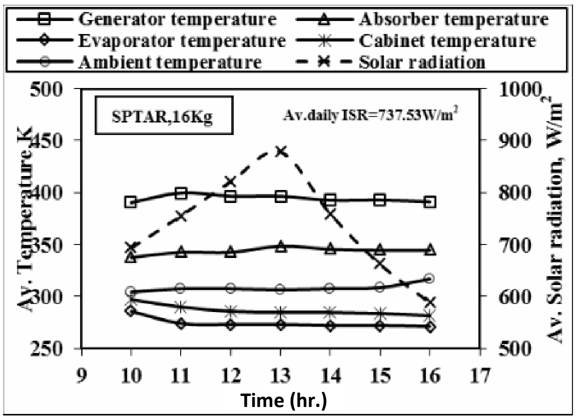


Fig. 9. The SPTAR system under cooling load of 16 Kg of tomatoes at hot water flow rate of 1.58 L/min.

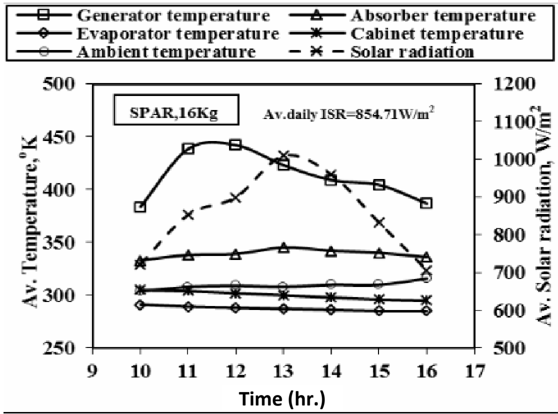


Fig. 10. The SPAR system under cooling load of 16 Kg of tomatoes

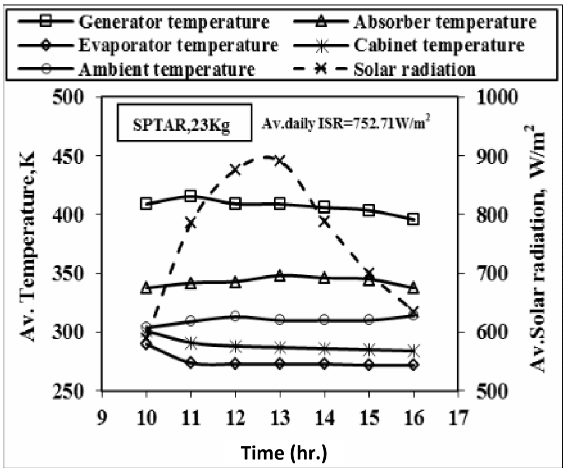


Fig. 11. The SPTAR system under cooling load of 23 Kg of tomatoes at hot water flow rate of 1.58 L/min.

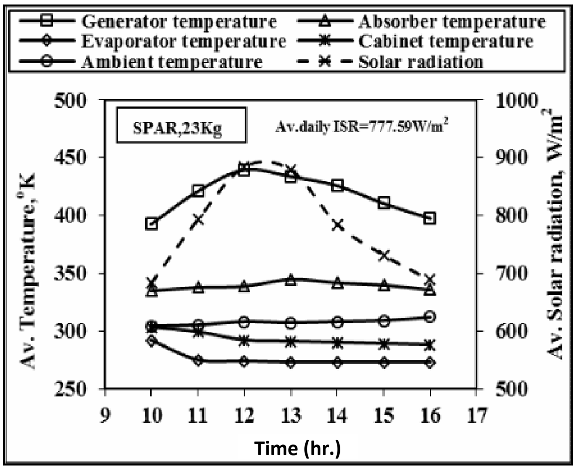


Fig. 12. The SPAR system under cooling load of 23 Kg of tomatoes

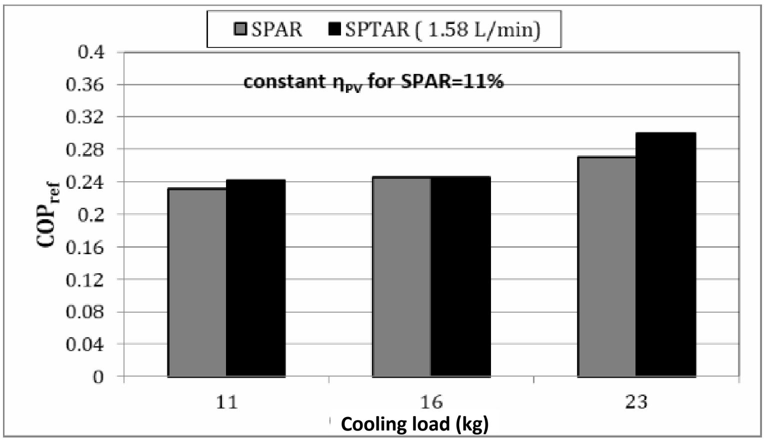


Fig. 13. COP_{ref} for SPAR and (SPTAR) systems using different cooling loads of tomatoes

systems using different cooling loads of tomatoes. Generally, the COP_{ref} mainly depends upon the refrigeration coefficient of performance COP_{ref} and the total efficiency (η_{total}) for the heating system. The total efficiency is represented in the sum of thermal efficiency of the solar collector and The PV efficiency for SPTAR and the PV efficiency solely for the SPAR system. In this investigation, the PV efficiency can be described as a constant value of 11% under the all operating conditions and it is affected greatly by the amount of the battery charge, while the thermal efficiency of the solar flat plate collector affected by the incident solar radiation (ISR).

Fig. 13 illustrated that, there is no significant difference in the COP_{ref} values for the SPAR or SPTAR systems by increasing the cooling load from 11 to 16 Kg of tomatoes in the cooling cabinet. The obtained results indicated that increase of the cooling load from 11 to 16 kg, the COP_{ref} values increased from 0.231 to 0.245 for SPAR system and from 0.242 to 0.245 for SPTAR. Nevertheless, the further increase in the cooling load up to 23 kg of tomatoes (The maximum capacity of the refrigerator) the COP_{ref} values were 0.270 and 0.300 for the SPAR and SPTAR system, respectively. This means that the extracted heat by the evaporator increased with the increase of the heat that produced on the generator by the integration system between the solar collector and the PV. Hence, it can be concluded that the using of SPTAR system helped the AWAR to conducting the pre-cooling process for the tomatoes in a good performance during the 7 hours of the working day even at the highest cooling load. Ultimately, it is recommended to use the integration system of the solar collector and PV as heating system to operate the AWAR system because this system reduced the operating time of the heater resulting in low consumption rate of the stored electric energy in the solar battery and consequently long operating period for the one battery with low constructional cost.

Conclusion

It is recommended to operate the ammonia-water absorption refrigerator (AWAR) by using the solar photovoltaic-thermal absorption refrigerator (SPTAR) system that represents the integration of the flat solar collector with the PV system as heating system at the hot water flow rate of 1.58 L/min while the highest collector thermal efficiency of 60.11% was achieved.

Regarding the no load condition, the average values of the evaporator temperature ranged from to -2.82°C to 2.91°C for all hot water flow rates under the SPTAR system, while it was 1.19°C for the solar photovoltaic absorption refrigerator (SPAR) system. This means a potential performance for the AWAR by using the SPTAR. Concerning the cooling load, the pre-cooling of tomatoes by the SPTAR system at the hot water flow rate of 1.58 L/min led to achieve temperature range of 6-11°C in the cooling cabinet during 7 hours of working with evaporator temperature range from -2 to -1°C comparing to the SPAR system which gave temperature range from 19 to 22°C in the cabinet and 10 to 12°C for evaporator temperature. For the cooling load, using the SPTAR under cooling load of 23 kg (Max. capacity) of tomatoes achieved the highest values of refrigerator coefficient of performance (COP_{ref}) of 0.30 cooling cabinet temperature of 284°K/ 11°C with the lowest temperature of evaporator (272°K/-1°C), but the contrary occurred by using SPAR under the same conditions.

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تقييـــم أداء ثلاجـــة تبـريد شـــمسـى بالامتصـــاص للتبـريـــد المبدئـــى لمحصـــول الطمـاطـم

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في هذه الدراسة تم استخدام ثلاجة تعمل بدورة الإمتصاص باستخدام محلول (الأمونيا- الماء) بسعة تصل إلى ٥٠ لتر وذلك بواسطة نظامين للطاقة الشمسية لإجراء عملية التبريد المبدئى للطماطم وخاصة في الأجواء الحارة، النظام الأول هو عبارة عن نظام الطاقة الشمسية الكهروضوئية الحرارية وهو نظام تكاملي يجمع بين المجمع الشمسي المسطح ونظام الألواح الشمسية الكهروضوئية، بينما النظام الثاني هو نظام الألواح الشمسية الكهروضوئية فقط، تهدف هذه الدراسة إلي تقييم أداء الثلاجة فى حالة وجود وعدم وجود أحمال تبريد مختلفة وذلك لمحصول الطماطم نظراً لأنه من أكثر المحاصيل قابلية للفساد وذلك تحت ظروف الإشعاع الشمسي فى مصر للتحقق من قدرة ثلاجة التبريد الشمسية من إنجاز عملية التبريد المبدئي للطماطم و الوصول إلي المدى الموصى به من درجات الحرارة اللازمة للتخزين البارد للطماطم (من ٧-١٠م°)، حيث أشارت النتائج المتحصل عليها إلى أن استخدام المجمع الشمسى المسطح عند معدل تدفق للماء الساخن قدره ١,٥٨ لتر/دقيقة المتكامل مع نظام الطاقة الشمسية الكهروضوئية في تشغيل ثلاجة التبريد الشمسى بالامتصاص عند حمولة التبريد ٢٣ كجم من الطماطم (أقصى سعة للثلاجة) قد حقق أعلى قيمة لمعامل أداء للثلاجة والذي بلغ ٠,٣٠ مع قيم أقل لدرجات حرارة المبخر وكابينة التبريد حيث بلغا ٢٧٢ كلفن (-١م°) و٢٨٤ كلفن (١١م°) على التوالي، بينما استخدام نظام الألواح الشمسية الكهروضوئية فقط لتشغيل ثلاجة التبريد الشمسي بالامتصاص فقد أعطت قيمة أقل لمعامل الأداء للثلاجة وهو ٠,٢٧٠ عند كفاءة مقدارها ١١% مع قيم درجة حرارة المبخر ودرجة حرارة كابينة التبريد بلغت ٢٨٥ كلفن (١٢م°) و٢٩٥ كلفن (٢٢م°) على الترتيب، ومن هنا فإن النظام التكاملي بين المجمع الشمسي المسطح و الألواح الشمسية الكهروضوئية كنظام لتسخين المولد أدي إلى تحسين أداء ثلاجة التبريد الشمسى بالامتصاص بالمقارنة بنظام الألواح الشمسية الكهروضوئية فقط حيث قد يؤدي هذا إلى تخفيض أوقات تشغيل السخان الكهربي علي مولد الثلاجة وبالتالي يمكن استخدام عدد من البطاريات أقل لتشغيل فترات أطول ومن ثم تخفيض نفقات الإنشاء.

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