Role of agricultural engineering in environmental and sustainable development for the valley and delta areas: 1907 - 1921

MANUFACTURE AND PERFORMANCE EVALUATION OF SOLAR ABSORPTION REFRIGERATION UNIT FOR POTATO STORAGE

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ABSTRACT

Solar diffusion absorption refrigeration system, consisted of solar water heater (flat plate solar collectors), generator with bubble pump, condenser, evaporator and absorber, was locally manuactured to be used for potato storage. The temperature in cabinet, evaporator, generator, condenser and absorber were measured to evaluate the performance of the absorption refrigeration with load and without load. The solar and electrical consumption were measured under two conditions (electrical heater and solar water heater). Performance of the refrigeration system was evaluated by the coefficient of performance (COP).

The main results of this research work can be concluded and summarized as follows:- The absorption refrigeration system has the ability to refrigerate potato especially under fluid flow rate of 2l/ min with the use of 2.994 m^2 solar collector area. The values of COP ranged from 0.002 to 0.204 under different treatments. The electrical consumption for the cooling load of 200 kg potato was higher than other cooling loads under electrical heater. The electrical energy consumption with electrical heater ranged from 3.5 to 6.2 kW.hLday. Also, with load the cabient temperature was ranged from 4.5 to 8.5 °C, but withoutload it ranged from 2 to 13.5°C.

INTRODUCTION

Solar energy is used as a renewable source of energy for many applications. Solar refrigeration forms one of the most important applications of solar energy. Recently, solar energy has received interest as an alternative energy source for refrigeration systems,

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especially in places where electricity is expensive. Refrigeration term is defined as the process of removing heat from a substance. So, deterioration of vegetables and fruits can be reduced as temperature is lowered by refrigeration. **Abou Karima (1992)** designed and tested of a refrigeration system utilizing solar energy. He concluded that the intermittent absorption refrigeration system used ammonia- water as a working fluid by two methods for heating the working fluid in the generator, the first is the Kerosene burner and the second is the solar energy. The solar intermittent refrigerator can be used to keep fresh vegetables, which do not usually need temperature, less than zero. He added that as the generator and refrigeration cycle increases. Evaporator temperatures increases, the maximum coefficient of performance for the refrigeration increases. **Chen et al. (1996)** evaluated the diffusion-absorption refrigerator. Their results showed the effects of ambient temperature on diffusion-absorption refrigerator performance. As ambient temperature increases, the operating range shifts towards higher power. The nominal operating power (312 W) represented a choice by the manufacturer to maximize the cooling capacity at the upper limit of design ambient temperature. Therefore, at typical room temperature (15-25°C) the systems operates in the overpower range with a somewhat reduced COP. They tested the system at ambient temperature of 19-23°C and 32.2°C. The high ambient temperature tests were performed inside a test chamber able to maintain the vertical ambient temperature gradient with 0.9 per meter. Also they found that the cooling capacity is higher for elevated ambient temperature. This is mainly due to the fact that more ammonia is allowed to evaporate inside the evaporator at higher ambient under the same power input level. The overall effects of increasing the ambient temperature within design conditions are higher temperature lift, higher COP and higher cooling capacity. This is mainly due to two effects: less generator and rectifier heat loss, as the generator temperature is defined by the liquid concentration while the ambient temperature is higher; and the fact that less ammonia exits the evaporator, which results in higher cooling capacity.**Izquierdo et al. (2004)** studied and constructed double-stage LiBr–H_2O absorption cycle evaporating at 5°C and fed by solar energy from flat plate collectors to a single-stage one.

Martin Henning (2007) reported that From a thermodynamic point of view there are many processes conceivable for the transformation of solar radiation in cooling. Although the conversion of electricity by photovoltaics and the subsequent use of this electricity in a classical motor driven vapour compression chiller is a technically feasible concept, it is not further considered here. Reason is, that in industrialized countries, which have a well-developed electricity grid, the maximum use of photovoltaics is achieved by feeding the produced electricity into the public grid. From an economic point of view this is even more valid if the price for electricity generated by solar energy is higher than that of electricity from conventional sources. Also, he added that from the thermally driven technologies, which may use a solar thermal collector to provide heat to drive a cooling process, the technologies based on heat transformation are best developed.**Izquierdo et al (2008**) evaluated the performance of a 4.5-kW air-cooled chiller, single effect LiBr/H_2O absorption unit . Measurements were recorded over a 20-day period. The hot water inlet temperature in the generator varied throughout the day from 80 to 107 °C. The total energy supplied to the generator came to 1085.5 kWh and the heat removed in the evaporator to 534.5 kWh. The average COP for the period as a whole was 0.49. To avoid the above problems and evolve an energy-efficient and environmental friendly refrigeration system, the other refrigerants and refrigeration technologies are gaining more and more interests these years. Among them, absorption refrigeration technology is the most widely used one thanks to the following features: environmental friendly to safe ozone layer; heat driven, quiet and long life, but, DAR has a low efficiency. In Egypt, potato storage is carried out into wasys: in nawalla and cold storage. Although cold storage ways have been proposed, none have been wholly successful without excessive energy. For this reason, such care had to be taken to develop new modern systems depending on usage of solar energy. Therefore the objectives of this study are to:

1- Manufacture and utilize solar absorption refrigeration system for potato storage to reduce electrical consumption.
2- Optimize some operating parameters affecting the performance of the used system.

MATERIALS AND METHODS

Solar heat driven ammonia/water (NH_3/H_2O) diffusion-absorption cooling machine was designed and constructed in a private workshop, and installed on a roof of the house in Denosher village, El-Mehalla El-Kobra, ElGhrabia Governorate at latitude angle of (30.95°N and 31.09°E). The daily average total solar radiation flux incident on the horizontal , vertical and tilted surface were 4.066, 5. 623 and 6.335 $kW.h/m^2/day$ for the aveage day of November.

Materials

The solar diffusion absorption refrigeration system consists of two main parts. The first part is solar water heater (solar collector and generator). The second part is the refrigeration cycle (condenser, evaporator, absorber and cabient).

Solar water heater components

solar collectors

The two solar collectors boxes are rectangular in shape and made of aluminum bar 2 mm thick. The gross dimensions of the long solar collector boxes are 2.8 m long, 1.8 m wide, and 0.12 m deep, with a net upper surface area of 5.88 m^2 and the gross dimensions of the small solar collector 1.50 m long, 0.78 m wide, 0.12 m deep, with a net upper surface area 1.17 m^2.

Electrical generator

Coil heater gives 75 W and heat generator temperature reached up to 150°C which has length of about 10 cm.

Solar generator

Solar generator represents a heat exchanger which carries hot water inside it has a cuboid shape. The gross dimensions of this heat exchanger 8 * 11 *15 cm for width, height and length. This heat exchanger attached with bubble pump pipe where it receives hot water from solar collectors.

Refrigeration cycle components

The solar absorption refrigeration cycle represent diffusion absorption refrigeration as shown in Figure 1. This refrigeration cycle consisted of

Condenser: It consists of three bends of tube with 41 fins. The dimensions of each fin are 80*60*1 mm.

Evaporator: It consists of 2 tube bends has a 40 mm length and 16 mm outer diameter. These tubes are tube-in-tube geometry. Evaporator was connected with outlet condenser and inlet absorber.

Absorber: The absorber is made of 16 mm outer diameter iron pipe with 10 U-bends. The evaporator of this cycle is connected by a cabinet. The potato put in this cabinet to represent as a load. The fabricated cabinet was gross dimensions are 810 mm long, 500 mm wide, and 440 mm deep (0.1782 m^3).

Instrumentation

The global positioning system (GPS)

The GPS was used to identify the actual coordinates for the experimental work area. The accuracy of the used GPS was ± 5 meters.

Data-loggers

The components of two data loggers were eight channels for each other, keyboard, monitor, programmed card and controllers. The programmed card employed two programs(Visual Basic andMatlab). These channels employed to measure temperatures of the system such as : water temperature in solar generator, condenser, evaporator and absorber temperatures. Also, inside cabient temperature with and withoutload.

Pyranometer

It is used in weather stations and field experiments for the measurement of radiation in the wavelength range of 0.3 to 3.0 μ.A typical instrument has an output of approximately 0.5 mV per 100 W/m^2. The expected solar radiation was in the range of 0 -1100 W/m^2.

Methods

Experiments were carried out using solar absorption refrigeration system for potato storage to study the effect of some operating parameters on its performance.

- The stuided parameters

1- Two different sources of energy:
- Electrical refrigeration
- Solar refrigeration

2- Two different collector areas of 2 m^2 and 2.994 m^2.

3- Four different cooling capacities of 100, 150, and 200 kg of potato comparing with no load condition.

4- Three different fluid flow rates of 2, 7.5 and 12 l/min. This fluid is water as a fluid thruoghout the solar collector to heat.

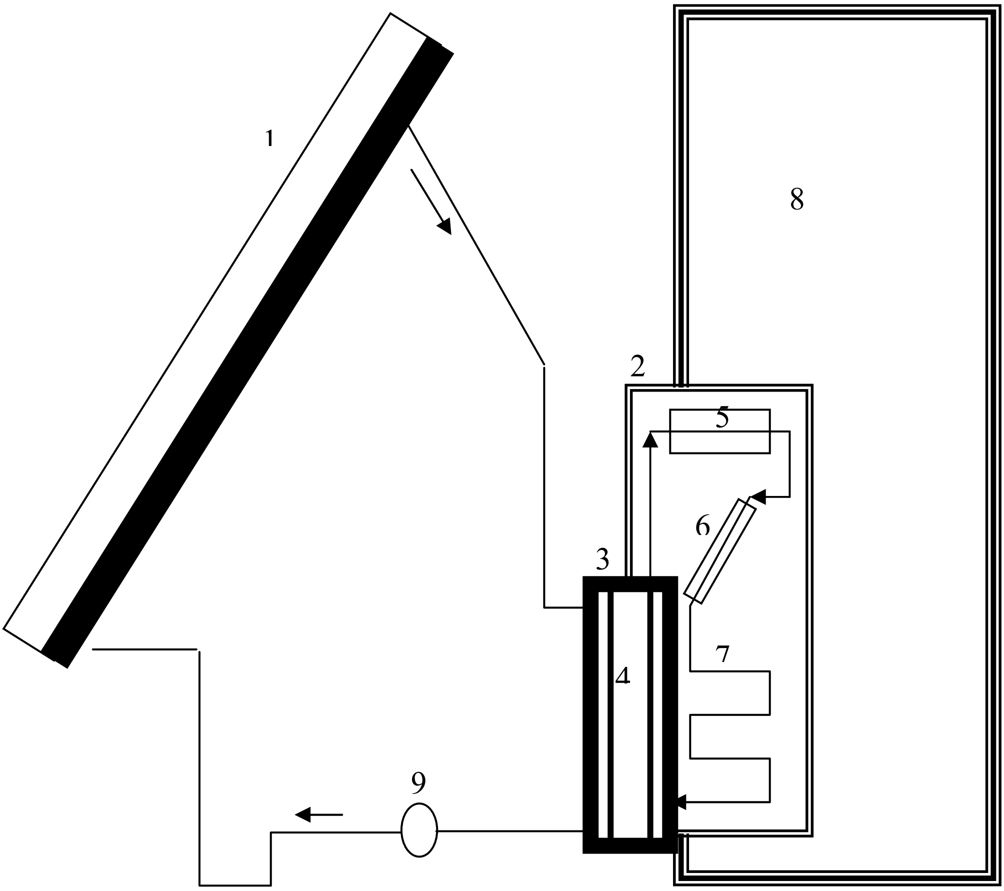

Fig. 1: Schematic diagram of solar energy collection system

No	1)	2)	3)	4)	5)	6)	7)	8)	9)
Component	solar collector	refrigeration cycle	solar generator	bubble pump	condenser	evaporator	absorber	cabient	pump

- Refrigeration system performance

The performance of the absorption refrigeration system is measured mainly by coefficient of performance (C.O.P). Coefficient of performance is a useful index of performance in solar cooling, where collector costs (and thus costs of heat of evaporator) are important. Here, where the solar energy is the source for heating the solution, the thermodynamic efficiency of the absorption refrigeration system is evaluated by means of the coefficient of performance (COP). The COP is defined as the unit of heat load in the evaporator per unit of heat load of the generator. It can be computed from the following equation:

$COP_{actual} = (Q_{ev} / Q_{ge})$

Q_{ge} = the heat of generator, kW

Q_{ev} = the heat of evaporator, kW

According to Kassem et al . (1993) in order to calculate the effective cooling produced, it is necessary first to measure the maximum and minimum temperatures of load (cooled potato) and Q_{ev} can be calculated from:

$Q_{ev} = W_P * C_{Pp} * (T_{max} - T_{min})$

Where:

Q_{ev} = The total cooling effect, kW

W_P = mass of potato to be cooled, Kg

C_{Pp} = specific heat of potato at constant pressure, KJ/Kg.

T_{max}= initial temperature of the load (potato) at which the cooling process starts, ◦C

T_{min} = load of minimum temperature that can be reached, ◦C

$(COP)_{sys}$ can be defined as :

$(COP)_{sys} = \acute{\eta}_{coll} * COP_{actual}$

Where:

$\acute{\eta}_{coll}$ = Overall thermal efficiency of solar collector.

RESULTS AND DISCUSSION

The components of the refrigeration cycle have a great effect on the cycle coefficient of performance (COP). Therefore, the study of these components from temperature point of view is important. Also, the ambient temperature and solar radiation may have an affect on refrigeration cycle through natural heating load. Thus, a series of tests were carried out to evaluate the cycle performance under different cooling loads. Depending on COP and reduction of electricity the best of treatments were chosen.

Performance characteristics of the refrigeration cycle

Performance characteristics of the refrigeration cycle is described by the coefficient of performance (COP) and cooling capacity. It is a useful index of performance in solar cooling to evaluate the diffusion absorption refrigeration cycle with different conditions. Figures (2) through (4) indicate the relationship between the COP and different cooling loads under different fluid flow rates and two solar collector areas as a solar heaters and Figure (5) show this relationship under electrical heater. The values of COP_{sys} ranged from 0.002 to 0.204 under different treatments. This range indicates that the COP values are low because of the nature of refrigeration cycle. In other words, the efficiency of the diffusion absorption refrigeration is low because the carnot COP is low due to the low temperature heat input and the circulation of the auxiliary gas adds additional cooling load on the evaporator. These figures show that the COP_{sys} values with no load were less than the COP values of other loads. The COP_{sys} values of no load are sharply low throughout where these values ranged from 0.002 to 0.009 in all treatments. But, the value of COP_{sys} was 0.132 for the treatment of fluid flow rate of 12 l/min with 2.994 m^2 solar collector area. The lower values of COP_{sys} with no load referred to increase the heat input in the generator and decrease the heat load in the evaporator. Meanwhile, the exception case which had a rise of COP_{sys} with no load was attributed to decrease in the heat input in the generator and heat load in the evaporator. Also, these figures show that values of COP_{sys} under 2m^2 solar collector area is higher than the values of COP_{sys} under 2.994 m^2 solar collector area. These values ranged from 0.003 to 0.204 and from 0.002 to 0.111 for 2m^2 and 2.994 m^2, respectively. The previous result is attributed to the heat generator input in the long scale area of solar collector resulting in a decrease of value from heat load in the evaporator. A cooling load of 200kg had a higher values of COP_{sys} than other loads under different solar energy treatments, except for fluid flow rate of 7.5 l/min and 2.994m^2 solar collector area.

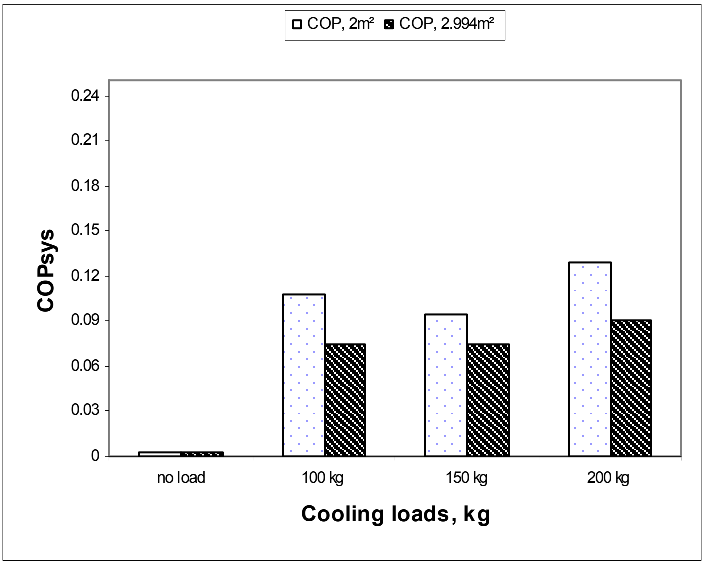

Fig.2: The COP_{sys} values with different cooling loads under fluid flow rate of 2 l/min and two solar collector areas.

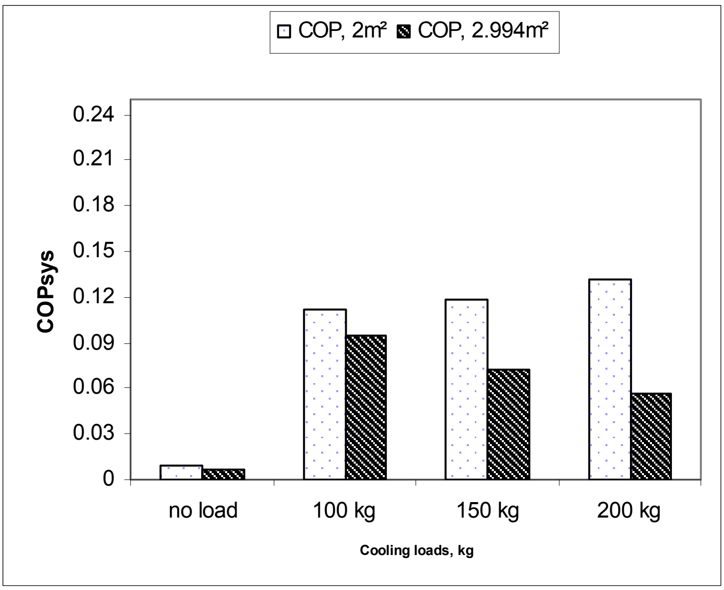

Fig.3: The COP_{sys} values with different cooling loads under fluid flow rate of 7.5 l/min and two solar collector areas.

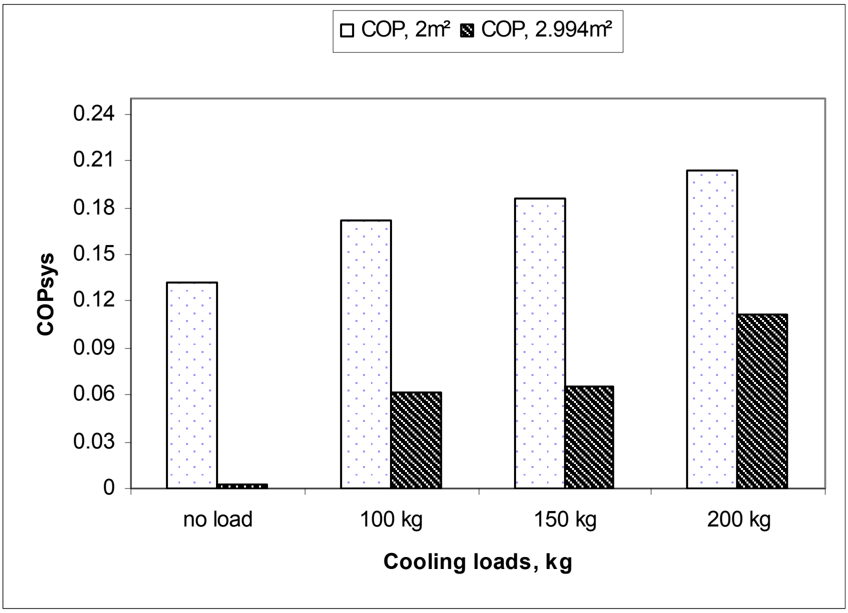

Fig. 4: The COP_{sys} values with different cooling loads under fluid flow rate of 12 l/min and two solar collector areas.

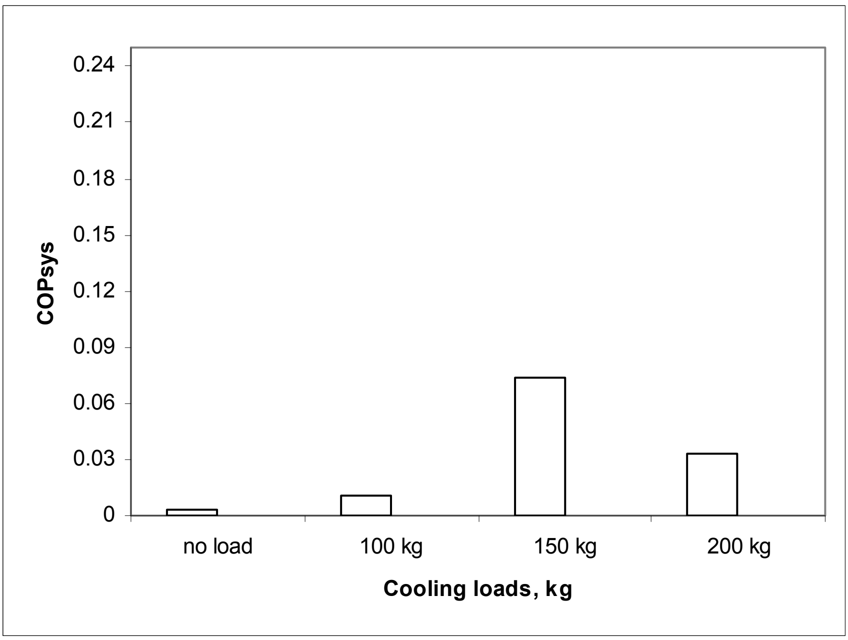

Fig. 5: The COP_{sys} values with different cooling loads under electrical heater

The higher value of COP_{sys} with 200 kg potato load is referred to the increase in the generator heat input and increase the heat load in the evaporator. The exception case for 7.5 l/min and 2.994m² solar collector area referred to increase in the input generator heat comparing to the heat load in the evaporator. The higher values of COP_{sys} for 200 kg cooling load under fluid flow rate of 12 l/min with 2 and 2.994 m² solar collector areas were 0.204 and 0.111, respectively.

Electrical consumption with solar and electrical refrigeration cycles

The theory of diffusion absorption refrigeration depends upon adding heat to the bubble pump to operate the refrigeration cycle and then produce cooling effect. This heat can be added by electrical heater or solar water heater. The electrical consumption in solar water heater case is by pump which moves the water between solar collectors and solar heat exchanger. Electrical consumption with electrical heater was higher than electrical consumption with different solar energy treatments as shown in Figure (6). Also, Figure (7) indicates the electrical reduction by the solar water heater treatments. The electrical consumption for the cooling load of 200 kg potato was higher than other cooling loads under electrical heater. The electrical energy consumption with electrical heater ranged from 3.5 to 6.2 kW.h / day. Meanwhile, the electrical consumption with solar water heater ranged from 0.8 to 2.5 kW.h / day. The minimum values of electrical consumption with solar heater were 0.8 kW.h /day under 2.994 m² of solar collector area with fluid flow rates of 2 , 7.5 l/min and cooling load of 200 kg potato. Also, the same value is given by 2.994 m² solar collector area and without load. The higher electrical consumption value was 2.5 kWh/day under 2 m² solar collector area and fluid flow rate of 2 l/min without load in the refrigeration unit. The higher electrical reduction was 87.09% under 2.994 m² of solar collector area with fluid flow rates of 2 and 7.5 l/min when the cooling load was 200 kg potato. The lower electrical reduction was 42.85 % under 2.994m² solar collector area with fluid flow rate of 2 l/min without load in the refrigeration unit.

Thermal behaviour of the refrigeration cycle The observations on the obtained results of the two processes of refrigerator during generation and refrigeration periods are represented in Figures8 and 9.

A: Electrical heater

B : 2.994 m² solar collector area + fluid flow rate of 2 l/min

C: 2.994 m² solar collector area + fluid flow rate of 7.5 l/min

D : 2.994 m² solar collector area + fluid flow rate of 12 l/min

E: 2 m² solar collector area + fluid flow rate of 2 l/min

F: 2m² solar collector area + fluid flow rate of 7.5 l/min

G : 2 m² solar collector area + fluid flow rate of 12 l/min

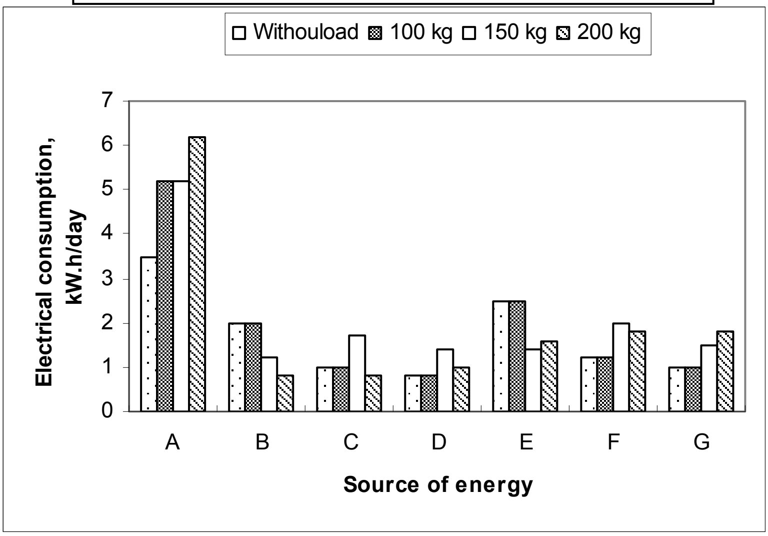

Fig. 6: The electrical consumption and source of energy under different cooling load conditions.

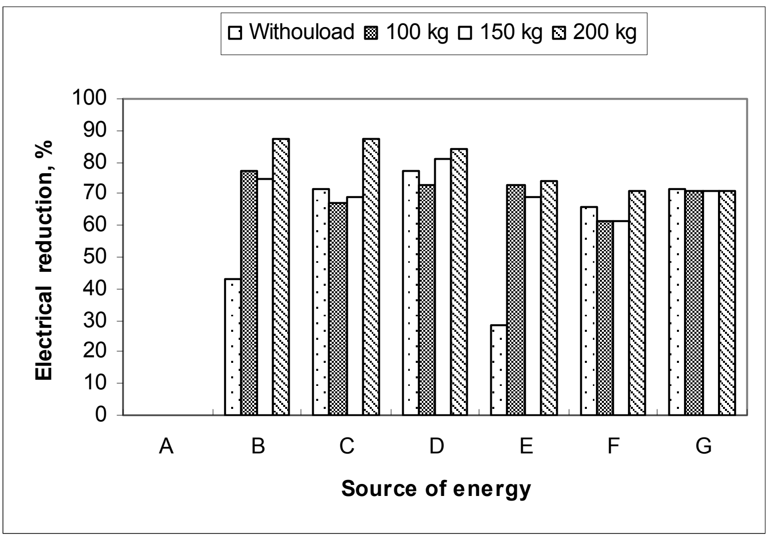

Figure (7): The electrical reduction and source of energy under different cooling load conditions.

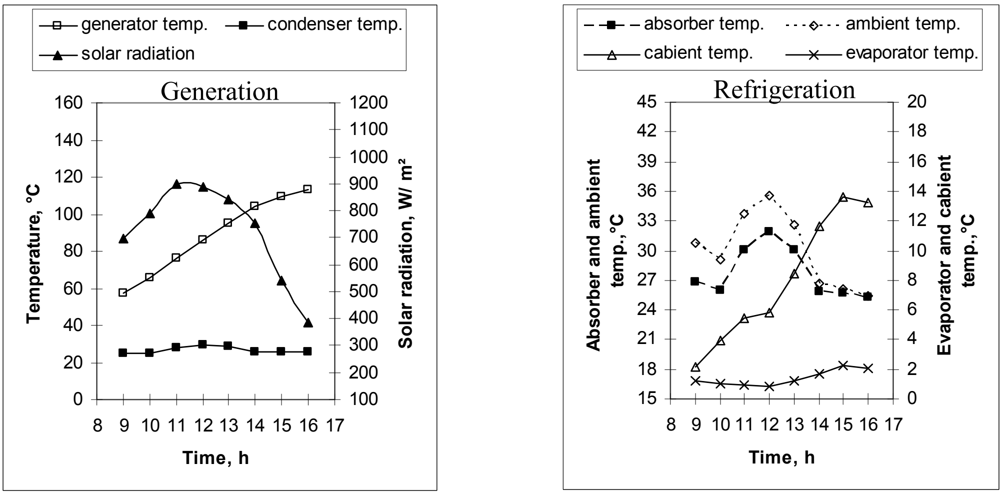

Fig. 8: Observations on the solar refrigeration cycle during generation and refrigeration for fluid flow rate of 2 l/min under condition of withouload with 2 m^2 solar collector areas.

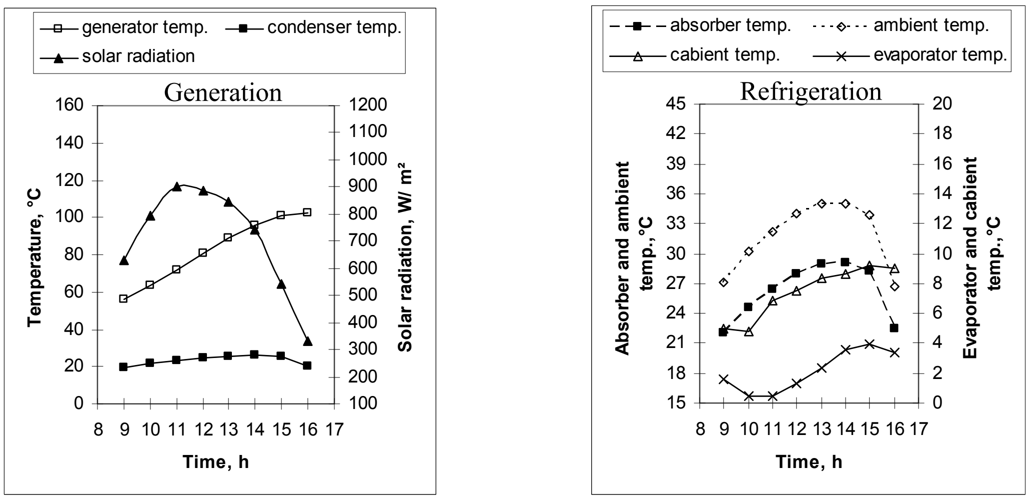

Fig. 9: Observations on the solar refrigeration cycle during generation and refrigeration for fluid flow rate of 2 l/min under condition of 200 kg potato load with 2 m^2 solar collector areas.

- The cabinet temperatures were less than the ambient temperature, the previous results mean that the sufficient cooling by refrigeration cycle with solar and electrical power could be obtained regardless the allowable limited potato temperature.
- The condenser temperatures were less than the absorber. Because the ammonia which enters the absorber took a gas phase after converting

from liquid to gas phase in evaporator. The heat transfer process happened in the evaporator, where the ammonia liquid was converted to the gas phase when it extracted the heat from cabinet.

- In the treatments which were operated by solar energy as a heat source, the evaporator temperature range was from 0 to 4 °C with parallel with 200kg load.Meanwhile, the treatment which was operated withoutload, the evaporator temperature ranged from 0 to 2°C.
- Also, with load, the cabinet temperature range was 4.5 to 8.5 °C, but withoutload it ranged from 2 to 13.5°C. In the solar energy refrigerator, the evaporator temperature increased with the solar time until it reached the maximum value at noon, and after then decreased with solar time.
- The cabinet temperature was affected by the evaporator temperature, thus the thermal behavior in the cabinet was often in parallel with them.

CONCLUSION

1- Sufficient cooling by refrigeration cycle with solar and electrical power could be obtained regardless of the allowable limited of potato temperature (4-10°C).
2- In the treatments which were operated by solar energy as a heat source, the evaporator temperature ranged from 0.2 to 4 °C. Meanwhile, in the treatments which were operated by electrical energy as a heat source, the evaporator temperature ranged from
3- The difference between electrical and solar energy may be referred to the heat transfer between the bubble pump and both of electrical and solar heater.

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الملخص العربى

تصنيع وتقييم أداء وحدة تبريد شمسي بالامتصاص لتخزين محصول البطاطس

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أن استخدام الطاقة الشمسية في عملية التبريد في المناطق البعيدة والمستصلحة حديثا والتي لم يتم إمدادها بعد بالطاقة الكهربية يمكن استخدامها حيث التبريد ضروري لحفظ منتجات المزرعة أو لتكييف عنابر الإنتاج الحيواني و الداجني خاصة أن هذه المناطق تتمتع بطاقة شمسية ذات كثافة عالية. كما و أن في القري و المدن التي يتم فيها تخزين الحاصلات الزراعية في ثلاجات تبريد تعمل بالفريون فإنها تكون عرضة لاستهلاك كهربي عالي و كذلك التعرض لأحمال كهربية متذبذبة خاصة أثناء فصل الصيف مما يؤدي إلي زيادة تكاليف استهلاك التخزين و تعرض الموتورات إلي التلف و العطل بسبب الأحمال الحرارية العالية. لذلك فإن دائرة التبريد الشمسي بالامتصاص والتي تعمل بنظام الثلاث موائع (أمونيا-ماء-هيدروجين) كمثال لاستخدام الطاقة الشمسية كمصدر حراري مع دائرة التبريد بالامتصاص يعتبر من أنسب طرق التبريد بالطاقة الشمسية حيث أنه يحافظ علي البيئة لعدم وجود مركبات الفلوروكلوروكربون ، عدم التعرض لذبذبة في الأحمال الكهربية ، قلة الاستهلاك الكهربي و قلة عمليات الصيانة. وكانت أهم النتائج المتحصل عليها :

1- إمكانية استخدام نظام التبريد بالامتصاص لتخزين محصول البطاطس حيث تراوحت درجة الحرارة خلال ساعات التشغيل نهارا ما بين 4 إلي 10 °م وهو المدي المناسب لتخزين البطاطس تحت درجة حرارة مبخر ما بين 0.2 إلي 4 °م لمعاملات الطاقة الشمسية بينما تراوحت بين 0 إلي 1.5 °م للمعاملات الكهربية.

2- تراوحت قيم معامل أداء نظام التبريد الشمسي بين 0.002 إلي 0.204 .

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