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Assessment of Solar Diffusion Absorption Refrigeration System to Store Crops

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Abstract: Food preservation is the technique to prevent food spoilage, food poisoning, and microbial or physical contamination in food. Food preservation includes cooling, heat, smoking, Salting, drying, and irradiation. Refrigeration plays a main role in preserving foods by providing creative ways to meet food spoilage. It is usually stored crops in commercial refrigerators throughout the year. It is used to keep vegetables and fruits fresh and edible, promoting maintaining the crops at a desired temperature, providing oxygen, and removing carbon dioxide thus circulating cool fresh air, preventing tuber desiccation, and keeping crop losses to a minimum. Recently, solar energy has received interest as an alternative energy source for refrigeration systems; especially in places where electricity is expensive or in short supply- with the use of solar energy, usage of conventional energy sources and its peak demand will be reduced. Therefore, the DAR is one of the types of absorption refrigeration systems. The present study investigates the assessment of solar diffusion absorption refrigeration systems to store crops

Keywords: Solar diffusion, Preservation of foods, respiration, storage process, and refrigeration

1. Introduction

The sector of agriculture in Egypt needs some requirements after post-harvest of fruit and vegetable crops. In addition, when food processing is ended to able it for marketing. One of these requirements is commercial refrigeration that represents important tool in food preservation methods. Refrigeration prevents bacteria and fungus or other microorganisms at desired temperature which can controlling the air movement indoor around these commodities. But, the main energy source of refrigeration systems is electricity. Electrical energy consumption becomes more and more huge with the world-wide economy developments. Moreover, Egypt has suffered of shortage of energy. Thus, solar energy as a renewable resource of energy for refrigeration system can be used. Solar energy is a clean energy source that has impact on the environment compared to conventional energy sources. In addition, the vapor compression system has harmful impact on ozone layer. Consequently, these reasons and others support using solar energy as a source for refrigeration systems. Absorption refrigeration system one of the systems can be operated using solar energy. Some types of this system; solar diffusion absorption system one of these methods that based on ammonia (refrigerant) and water (absorbent) as the working inert gas. Since, there are no moving parts in the unit, quiet and reliable. The relation between quantity of solar radiation intensity and cooling load with absorption refrigeration system evaluated by (Mustofa et al., 2021). Their results showed that the annual cooling load and maximum instantaneous cooling load are 463 Wh/m3 and 173 W/m2. Also, these results revealed that solar collector area of 900 m2, storage tank volume of 25 m3 and collector flow rate 5 kg/ h.m2 with annual fraction of 0.52. In addition, Mungyeko et al. (2023) the various types of absorption refrigeration systems. The main methodologies and techniques used, and the designs generators/or bubble pumps. They reported that some challenges facing diffusion absorption refrigeration systems are: low coefficient of performance (COP) and presented the future work to improve COP. According to Nasser et al. (2021) reported that renewable energy sources have become increasingly vital as a clean source of energy to avoid pollution and global warming. Also, they mentioned that renewable energy has commonly used in the third world it has been less widely employed in the Western world until lately. Solar radiation is the first important climate parameter to consider when determining whether place is

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suitable for applications of solar energy (Baudoin et al., 2013). The importance of using solar diffusion refrigeration system showed by Amjad et al. (2023), they reported that in the developing regions, the most important factor causing postharvest losses in fruit and vegetables in their bulk storage at production sites and them transpiration to long-distance markets in a non-refrigerant environment. Therefore, solar-powered cooling can play a vital role addressing the challenge food security through decentralized storage of horticultural commodities. Therefore, the type of this cooling supports green economic growth by processing technology or infrastructure varies greatly depending on the level of local skill and the level of development of the nation.

The objectives of this present study:

a. Describe the position of the sun on place question
b. Evaluate the cabinet temperature throughout 24 h
c. Compare between the temperature of refrigerat

2. Materials and Method

The position of the sun on place in question

The sun's position in the sky is a major factor in the effect of solar energy on a surfaces. It is essentially defines the direction of the sun's rays that are affected by: location on the earth's surface, time of the day and day of the year. These three quantities are conveniently specified by the many angles. Therefore, it is imperative to recognize that, before establishing and utilizing any solar energy system in application, the position of the sun on specific location must be studied and computed. The geometric relationships between a plane of any particular orientation relative to the earth at any time and incoming beam solar radiation can evidently be described in terms of several angles by (Duffie & Beckma, 2013).

These angles and their mathematical relationships can be studied and estimated as follows:

a. Latitude angle (¶)
b. Solar declination angle (¥): This angle can be calculated from the following equation:-

, degree&&&&& & .(1)

Where, n, is the day number from the first of January.

c. Solar hour angle (…): It can be estimated from the following equation:

…= (LAT- 12) ◊ 15 , degree&&& & & .(2)

Solar altitude angle (») This angle can be computed using the following equation:-

» = arcsin [cos(¶) cos (¥) cos (…) + sin (¶) sin (¥)], degree & ..(3)

d. Solar zenith angle (z): It can be calculated from the following equation:- z= arccos[cos(¶) cos (¥) cos (…) + sin (¶) sin (¥)], degree . .(4)

or z = 90 □»

e. Surface azimuth angle (≥): Which is the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due to south, east negative and west is positive (-180 d ≥ d 180).
f. Solar azimuth angle (≥s): This angle can be estimated from the following equation:-

≥s = arcsin [(cos(¥) sin (…) / cos (»)] , degree&&& & ..(5)

g. Solar- surface azimuth angle (≥ss): Which is the sum of surface azimuth angle (≥) and solar azimuth angle (≥s) throughout the day light. The magnitude of this angle is dependent upon the orientation of surface in question and the time of the day light.
h. Optimum tilt angle (≤o):
i. ≤o = arccos [cos (¶) cos (¥) cos (…) + sin (¶) sin (¥)] , degree && & ..(6)

For fixed solar collector according to Abdellatif et al. (2008):

≤o = ¶ □¥ , degree && &&& (7)

j. Solar incident angle (∏): Which is the angle between the beam on a surface and the normal to that surface. The incident angle of the sun is dependent upon the tilt angle of the surface in question and the mode of surface motion. For any inclined surface, the angle of incident, ∏, is a function of; solar altitude angle (»), solar-surface azimuth angle (≥ss) and the tilt angle of the surface in question (≤):

∏= arccos [cos (») cos (≥ss) sin (≤) + sin (») cos (≤)] , degree& && ...(8)

k. Number of bright sunshine hours (N) : This is the maximum possible daily of bright sunshine (i.e. the day length). It can be found from the following equation:-

N = acrcos [- tan (¶) tan (¥)] , hours& && . (9)

l. Time of sunrise (Ts): This is the starting time of the day light. It can be calculated from the following equation:-

Ts = 6 + arcsin [- tan (¶) tan (¥)] , hours&& ...(10)

2.1 Theory of Absoption Cooling

List of bullets can be used based on the following format:

a. First point
b. Second point
c. And others

The phenomenon of absorption is the mixture of a gas in a liquid, the two fluids presenting a strong affinity, to form a solution. This process is reversible. Therefore, absorption is the process in which material transferred from one phase to another. According to Saravanan & Maiya (1998) the working fluid in an absorption refrigeration system is a binary solution consisting of refrigerant and absorbent. In Figure 1, two evacuated vessels are connected to each other. The left vessel contains liquid refrigerant while the right vessel contains a binary solution of absorbent/refrigerant.

The solution in the right vessel will absorb refrigerant vapor from the left vessel causing pressure to reduce. While the refrigerant vapor is being absorbed, the temperature of the remaining refrigerant will reduce as a result of its vaporization. This causes a refrigeration effect to occur inside the left vessel. At the same time, solution inside the

right vessel becomes more dilute because of the higher content of refrigerant absorbed. This is called the ❑absorption process . Normally, the absorption process is an exothermic process; therefore, it must reject heat out to the surrounding in order to maintain its absorption capability.

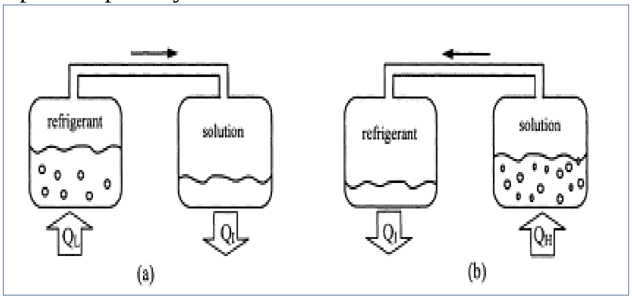

Figure 1. Absorption process (a) Refrigerant separation and (b) cooling effect

Also, they indicated that whenever the solution cannot continue with the absorption process because of saturation of the refrigerant, the refrigerant must be separated out from the diluted solution. Heat is normally the key for this separation process. It is applied to the right vessel in order to dry the refrigerant from the solution as shown in Figure 2. The refrigerant vapor will be condensed by transferring heat to the surroundings. With these processes, the refrigeration effect can be produced by using heat energy. However, the cooling effect cannot be produced continuously as the process cannot be done simultaneously. Therefore, an absorption refrigeration cycle is a combination of these two processes as shown in Figure 2. As the separation process occurs at a higher pressure than the absorption process, a circulation pump is required to circulate the solution. Coefficient of Performance of an absorption refrigeration system is obtained from;

$$\text{COP} = \frac{\text{cooling capacilty obtained at evaporator}}{\text{heat input for the generator} + \text{work input for the pump}}$$

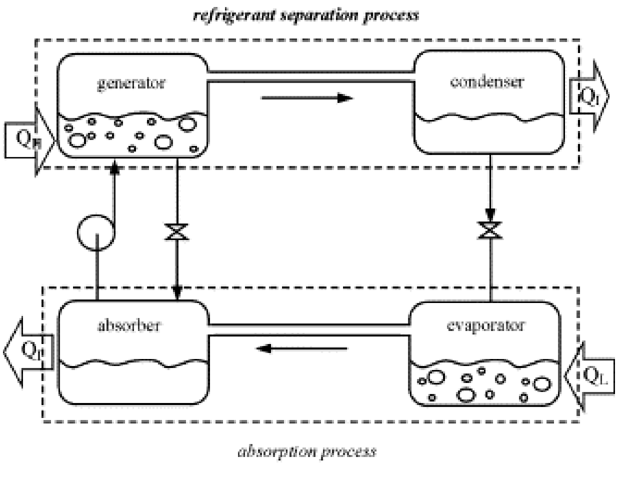

Figure 2. A continuous absorption refrigeration cycle

The work input for the pump is negligible relative to the heat input at the generator; therefore, the pump work is often neglected for the purposes of analysis.

3. Theory of Solar Diffusion Absorption Refrigeration

There are four working fluid loops in the solar diffusion absorption refrigeration system. They are the water, ammonia, gas, and solution loops. Hot water loop between the heat exchanger around generator and solar collectors. Where the hot water which heated by thermal solar collectors supplied the generator by heat to operate the bubble pump. Therefore, the water loop forms the main loop of the solar diffusion refrigeration cycle. Meanwhile, the ammonia loop represents the heart of the diffusion refrigeration cycle. In this loop, ammonia vaporizes when it receives heat in the generator and evaporator, and liquefies when it rejects heat to the ambient in the condenser and absorber. The gas loop driven by the density gradient due to concentration gradient. The gas containing the auxiliary gas (hydrogen) and ammonia vapor circulates between the evaporator and absorber. In the gas loop, hydrogen serves as a pressure equalizer as well as ammonia carrier. The solution loop is a liquid flow loop driven by a bubble-pump as small diameter tube inside the generator containing liquid absorbent. As heat input to the generator through solar water heaters, vapor bubbles are formed. The vapor bubbles push the liquid absorbent upward providing the driving potential for the solution loop scirculating between the generator and absorber.

4. Results and Discussion

The position of the sun at any given time at question place is given by the solar declination angle, solar hour angle, solar altitude angle, solar zenith angle solar azimuth angle, optimum tilt angle, and solar incident angle At latitude angle of 30.95 °N and 31.09◦E, the sunrise time for average day of November is 6 am and 47 min am. The monthly average of maximum possible daily hours of bright sunshine (the day length) for November is 10.4 hours. The monthly average solar declination angle for November is -18.9°. The hourly averages of solar altitude angle, solar zenith angle, solar azimuth angle, optimum tilt angle, and solar incident angle from sunrise to sunset for November were computed and listed in Table 1. This table shows that the solar altitude angle increases gradually with solar time from sunrise until it reaches the maximum value at noon. It then decreases gradually till it attains the minimum value at sunset. Also, the table illustrates that the solar altitude angle at noon decreases from 36.78° to 11.60° on November. Zenith angle has a reverse relationship with solar altitude angle. The solar azimuth angle increases gradually with solar time from sunrise (-64.51°) until it reaches the maximum value at sunset (59.17°). The solar incident angle (θ) decreases gradually with solar time from sunrise (67.67°) until it reaches at noon. The minimum value of solar incident angle (θ) is 2.69° at noon; this means that the rays of the sun are perpendicular nearly to the surface. Therefore, the amount of solar radiation incident at this value of solar incident angle(θ) at noon will be the maximum value. Increasing the solar incident angle (θ) from afternoon until it reaches the maximum value at sunset (59.07°). The solar water heater which was used in this research work is fixed orientated facing to the south direction and fixed tilt angle of solar collector. The fixed system with tilt angle and orientation caused changing the values of the solar incident angle (θ).

But, in opposite the solar water heater which moved to track the sun's rays from sunrise to sunset. Therefore this heater was orientated and tilted so that at any time the angle of incidence of the surface of the solar heater and the sun's rays could be set at zero. Also, when the solar heater tracking the sun's rays from sunrise to sunset, the solar azimuth angle equal zero at all times. For a tracking solar panel continuously orientated to face the sun, this means at all times from sunrise to sunset, the rays of the sun are perpendicular to the surface, and consequently the angle of incidence equal zero at all times. In this research because the angle of incidence of the sun's rays on solar collector is continuously changing through the day time, it is essential that the changes in the various parameters with angle of incidence be taken into account. These parameters such as: Effective transmittances of solar collector cover system, effective absorptance of the absorber plate of collector and the amount of solar radiation flux incident on tilted solar collector. This coordinates controlling of the amount of solar radiation which flux incident on the surfaces. The nature of surface may differ from tilted, horizontal and vertical; consequently, the angle of incidence is change. Also, the amount of solar radiation differs from type of surface to another. To determine the optimum tilt angle by equation (7) give 49.85° (where latitude angle = 30.95° and declination angle = -18.90°). The optimum tilt angle in fixed system which receive the maximum amount of solar radiation flux incident on tilted surfaces.

Table 1. Hourly average solar altitude angle(ψ), solar zenith angle (z), solar azimuth angle (γs), optimum tilt angle (βo), and solar incident angle (θ) from sunrise to sunset on November.

Angle / Time	**Ψ**	**z**	**γ_s**	**β_o**	**Θ**
07:00	**4.64**	**85.35**	**-64.51**	**49.85**	**67.67**
08:00	**15.60**	**74.39**	**-55.60**	**49.85**	**53.78**
09:00	**24.84**	**65.16**	**-44.73**	**49.85**	**39.76**
10:00	**31.72**	**58.27**	**-31.19**	**49.85**	**25.65**
11:00	**35.80**	**54.19**	**-14.76**	**49.85**	**11.49**
12:00	**36.78**	**53.21**	**3.50**	**49.85**	**2.69**
13:00	**34.61**	**55.38**	**21.30**	**49.85**	**16.86**
14:00	**29.42**	**60.58**	**36.67**	**49.85**	**31.01**
15:00	**21.57**	**68.42**	**49.13**	**49.85**	**45.09**
16:00	**11.60**	**78.39**	**59.17**	**49.85**	**59.07**

4.1 Utilization of Absorption Refrigeration System for Storing Potato

During this experimental research used the absorption refrigeration system is used as a new direction to store crops to avoid increasing electrical consumption in ordinary refrigeration stores. Before putting potato in the absorption refrigeration cycle, the cycle should be tested using electrical power. The seven positions of thermostat settings are selected to know the thermal characteristics during the operation (Figure 2). This figure showed that the maximum temperatures were 16, 14 °C at the first position of thermostat position at without and with potato load, respectively. Also, the minimum temperatures were 6, 4 ° C at the seventh position of thermostat without and with load, respectively. This result means that the range of inside air temperature in the refrigerating unit ranged from 4 to 10 °C at the third to the seventh thermostat position settings. This range is corresponding to the recommended storage temperature for potatoes for different usage according to (Srikhirin et al., 2001). The range of the obtained temperature is considered evidence that the absorption refrigeration system has the ability to be used for potato storage. Figure (3) represents the relationship between the generator, outside and inside temperatures for the higher outside air temperature than other days during storage period. The hourly average outside air temperature was 33.23 and 25.1 °C during day and night time.

The temperature inside refrigerating unit increased from sunrise until it 1 AM. The increasing of inside temperature for this time because of increasing natural heating load at this day. The natural heating load depends upon the sol air temperature, outside dry air temperature, absortivity of material surface, solar radiation flux incident on the refrigerator as a vertical surface and convection heat transfer coefficient. When the refrigerating unit extraction of the natural heating load the inside temperature decreased, and then increased after sunrise. Also, the hourly average generator temperature had higher values during day time than night time. The previous results revealed due to the higher the natural heating load the higher generator temperature. The previous data provided that absorption refrigeration system has ability to decrease temperature inside refrigerator unit from potato temperature ranges. Also, the absorption refrigeration system can operate under high natural heating load and outside air temperature.

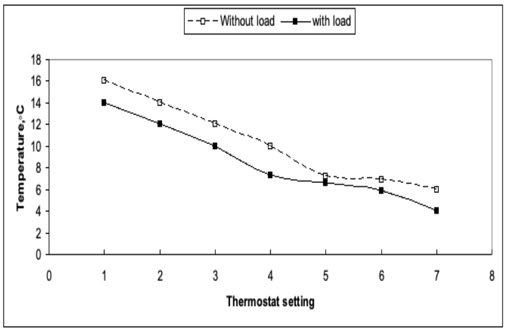

Figure 3. Air temperature inside refrigerating unit with and without load under different thermostat setting levels.

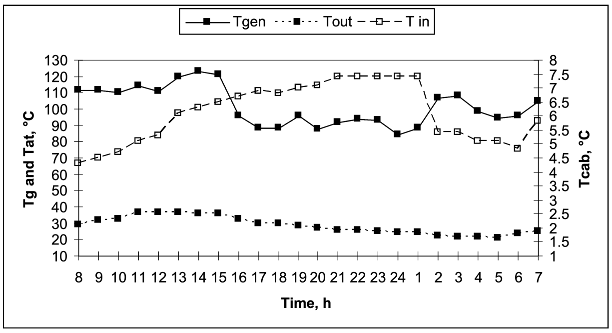

Figure 4. Generator (Tg), ambient air (Ta) and air inside cabinet (Tin) temperatures

The cabinet temperatures were less than the ambient temperature for all treatments. The previous results mean that the sufficient cooling by refrigeration cycle with solar and electrical power could be obtained regardless the allowable limited of potato temperature. The obtained results are agreement with that published by [10].

a. The condenser temperatures were less than the absorber temperatures for all treatments. Because the ammonia which entering the absorber took a gas phase after converting from liquid to gas phase in evaporator. The heat transfer process was happened in the evaporator where the ammonia liquid was converted to the gas phase when it extracted the heat from cabinet as acceptable by (Wang, 2012).

b. In the treatments which were operated by solar energy as a heat source, the evaporator temperature range was from 0.2 to 4 °C. Meanwhile, the treatments which were operated by electrical energy as a heat source, the evaporator temperature was ranged from 0.08 to 1.5 °C.
c. Also, the cabinet temperature in the treatments which were operated by electrical energy was ranged from 2 to 10 °C during day time. Meanwhile the cabinet temperature in the treatments which were operated by solar energy was ranged from 2 to 16 °C.
d. 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. These results agreement with (Kaushik et al., 2024).

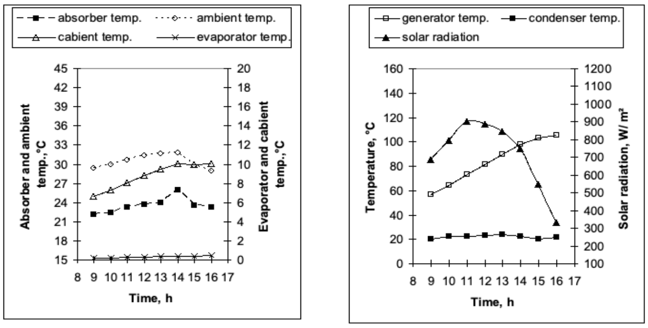

Figure 5. Observations on the solar refrigeration cycle during generation and refrigeration for fluid flow rate of 2l/min under condition of 15 kg potato load with 2 m² solar collector area

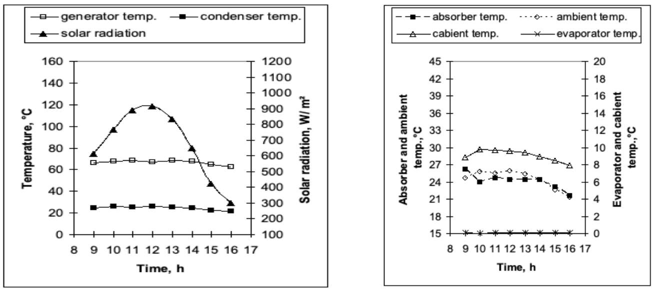

Figure 6. Observations on electrical refrigeration cycle during generation and refrigeration under condition of 15 kg potato load.

5. Conclusion

This research work is mainly aimed to study the solar energy as a heat source for diffusion refrigeration cycle. The cabinet temperatures were less than the ambient temperature for all treatments. The results mean that the sufficient cooling by refrigeration cycle with solar and electrical power could be obtained regardless the allowable limited of potato temperature.

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Conflict of Interest
The authors declare no conflict of interest.

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