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Milk Heating Using a Solar Cooker Coupled with Point-Focus Fresnel Lens

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ABSTRACT

Today, concerns regarding global warming resulting from fossil fuel usage and the depletion of these resources have led individuals to consider alternative, clean energy sources. Renewable energies such as solar energy are non-polluting, inexhaustible resources, serving as an excellent alternative to fossil fuels. Solar concentrate sunlight, directing it towards the solar oven. Utilizing renewable energy for cooking not only saves time and money but also ensures safety and security. The aim of this research is to construct and assess a solar oven equipped with a point Fresnel lens. The evaluations were conducted over a three-day period in March 2023. The maximum total thermal efficiency obtained for heating the milk for three days with different radiation intensity, wind speed and ambient temperature tested was 45%, 72.7% and 90%, respectively. The findings indicated that the solar oven could raise the milk temperature to 80℃ within one hour. The maximum attainable performance of this system was 90%.

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INTRODUCTION

Today, challenges such as global warming resulting from fossil fuel usage and the depletion of these resources have prompted a growing consideration towards the adoption of alternative, environmentally friendly energy sources. Renewable energies, notably solar power, stand as environmentally non-polluting, endless resources, offering an exceptional substitute for fossil fuels. Solar lenses serve the purpose of concentrating sunlight, allowing for its directed application toward solar ovens. The utilization of renewable energy sources for cooking not only saves time and money but also ensures safety and security.

Solar cooking devices were initially developed by an individual named Nicholas. His solar cooker consisted of an insulated box with a black plate, with glass pieces forming its lid. Sunlight entered the box through the glass and was absorbed by the black surface, raising the temperature inside the box to 88 ℃. The fundamental principle of a solar oven is to gather direct sunlight of the sun into a focal point, consequently increasing the temperature at that specific point. In a study, solar cookers (SC) were categorized into two types: direct and indirect (Omara et al., 2020). Many applications of direct (Coccia et al., 2021; Zhao, et al 2018) and indirect (Altouni et al., 2021; Bahadoran et al., 2022) solar applications have been developed during last decade. The direct type includes concentrators that focus light from the top of the lid of the container and the bottom of the container, and the indirect type includes flat plate collectors, vacuum tubes, and parabolic type. Direct type solar cooker includes box type and concentrated type. The most common type of direct solar cooker is a box that has an insulated box with a transparent glass cover. This box is usually integrated with reflectors that direct the sun's rays to the box, and in order to improve the absorption of solar radiation, the box was covered with black paint, which could raise the temperature of the box to 100 ℃, which allows Provides cooking and boiling. A concentrator-type solar cooker, focusing light from the top and bottom of the container, contains of a parabolic concentrator, a cooking pot at the center of the unit, and a base with a rotating system for aligning the reflector toward the sun. Indirect type solar cooker utilizes a collector to gather solar energy for cooking, using a heat transfer fluid to exchange energy between the collector and the gas stove. These cookers rely on collectors, among which are flat plate collectors, while vacuum tube belong to the parabolic type. Integrating a Fresnel lens with a parabolic mirror in a systematic approach can enhance the performance of the solar cooker. The geometry of their design is such that the optical focus of the lens resulting from the Fresnel lens is on the plate mirror and its final focus is under the target container. Their findings demonstrated that despite the low radiation intensity, this system successfully raised the temperature of 3 liters of water close to the boiling point (Coccia et al., 2021).

In a study, a Fresnel lens was employed as a solar cooker, concentrating light into a vacuum tube collector to heat the food. Their findings indicated that, at the radiation intensity of 712 W/m^2, the system achieved a maximum efficiency of 22% (Zhao, et al 2018). A study focused on investigating a solar concentrator utilizing a spot Fresnel lens. Expectations for this concentrator included achieving higher thermal efficiency at relatively elevated temperatures compared to flat plate and vacuum tube concentrators. The thermal efficiency of about 50% has been obtained at a fluid temperature of 90 ℃ (Altouni et al., 2021). In another research, they used a spot Fresnel lens to heat the salt water entering a desalination process. The obtained results showed that the theoretically expected value was not obtained. The reason for this is the losses caused by radiation. Also, the obtained results indicated the dependence of the heating ability of this concentrator on the flow rate of salt water. The incoming salt water, initially at 37°C and flowing at a rate of 250 ml/min, reached 76°C after passing through the solar concentrator absorber equipped with a Fresnel lens (Mahmoud et al., 2011). In another study, they theoretically and practically investigated the thermal performance of the solar concentrator using a point-type linear Fresnel lens. In this research, 8 types of cavity type receivers were used. The results indicate that the theoretical and practical results are consistent. It is also reported in this research that for a solar collector with a spot Fresnel lens, the geometric focusing ratio is more than 500 in order to achieve a better thermal efficiency (Xie et al., 2013). A sample of a parabolic cooker was tested for a refugee camp under disastrous conditions. This system was equipped with various reflective materials such as stainless steel, aluminum foil and melar tape (PVC tape). The results showed that after an hour and a half, the maximum water temperature reached 75.4 ℃ (Ahmed et al., 2020). A sample of a parabolic oven with a polished stainless-steel body was tested. By placing the target container in the focal distance, its maximum temperature should reach 53.6 ℃. The researchers came to the conclusion that in order to achieve a higher temperature, the diaphragm area should be 6 to 7 times larger than the design used to provide cooking in cold winter conditions (Noman et al., 2019).

This research evaluated the performance of a solar cooker equipped with a solar Fresnel lens specifically heating milk. The assessment spanned three working days in March, focusing on analyzing the impact of environmental factors such as solar light intensity, ambient temperature and wind speed on milk heating was evaluated.

MATERIALS AND METHODS

Figure 1 illustrates the Fresnel lens system developed within this research. The target container has a width of 20 cm. In order to focus the light of the lens on the entire surface of the target container, the distance between the surface of the Fresnel lens and its location should be obtained so that the focal point of the circular lens is the diameter of the desired container. According to the technical specifications of the lens, the focal length of the lens is about 150 cm and its length is 100 cm. According to the right triangle with chord length of 150 cm and side of 50 cm, the distance between the container and the lens was 146 cm. The height of the container can be calculated by considering the sun's angle of about 45 degrees and the chord length of 150 cm. Considering that the solar inclination angle does not change during the test. for tracking every 15 minutes, the tracking error is corrected manually; so that the focus of sunlight was on the target container. This test was done for heating the milk on the 16th, 22nd and 24th of March. Sunlight intensity was measured using the TES 1333R sensor, while the wind speed was monitored with a vane sensor named SMART SENSOR AR856. the temperature of the milk was recorded using the LODESTAR LD9817B multimeter at 5-minute intervals.

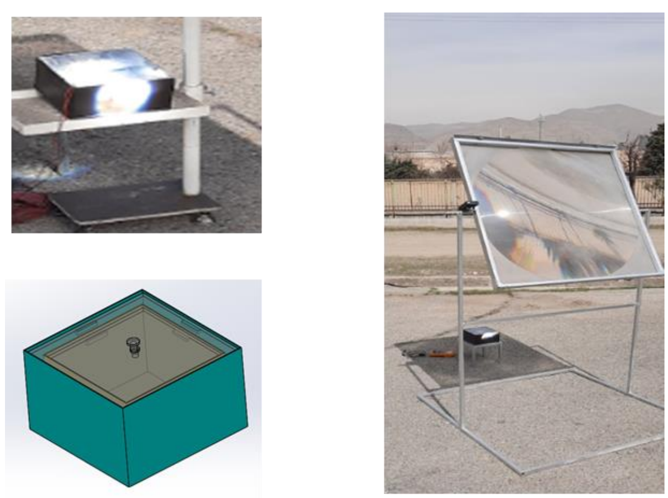

Figure 1. Solar cooker system for milk heating

Thermal efficiency of the system

The efficiency of the solar energy system is obtained by dividing the energy consumed by the total energy received according to equation (1).

$$\text{Thermal efficiency of the system} = \frac{Q1}{Q2} * 100 \qquad (1)$$

According to this relationship Q_2 which expresses the intensity of the sun's radiation and converting its unit from watts to joules, and then using formula number (2) Q_1 calculated the amount of energy received by the fluid, whose unit is joules. Now, by taking the average of both and dividing them by the sum (expressing the heat exchanged) and multiplying by 100, the thermal efficiency of the system will be obtained. The amount of energy absorbed by the liquid is calculated from the following formula.

$$Q_1 = mc\Delta T \qquad (2)$$

In this formula, Q_1 equals the exchanged energy, m is the weight in kg, C is the specific heat capacity of the liquid (unit) and ΔT is the temperature change. It should be noted that heat capacity is a physical quantity for a material and the amount of heat that is given to a certain amount of material will increase its temperature by one unit.

RESULTS AND DISCUSSION

Figure 1 shows the performance of the solar system and the amount of milk heating on March 16, 22, 24, 2023. The findings of March 16th indicate a decrease in solar radiation intensity. Initially, this decline was gradual and consistent during the early test hours. Simultaneously, the wind speed remained negligible with minimal variation. Consequently, the milk temperature increased by 41℃ within 30 minutes. To clarify, the initial milk temperature was 25.2 ℃ at 2:41 p.m., reaching 66.9 ℃ by 3:11 p.m. (depicted by curve number 1 in brown). Wind speed and ambient temperature are critical factors influencing the process. In this experiment, the wind speed has the least non-uniformity and the temperature of the environment has gradually decreased and there was no sudden drop during the work cycle compared to the previous experiments, so the light concentration by the absorber after 1:10 minutes, the volume of 4 L of milk to a temperature of the temperature reaches 70 ℃. The intensity of the sun's radiation at the beginning of the experiment had its highest value equal to 1139 W/m^2 and its lowest value equal to 925.6 W/m^2 at the end of the experiment. The average radiation intensity on this day is 1057.44 W/m^2. The results of March 22nd show that the milk temperature increase is a slow and slow process (blue curve number 2). The main cause of this behavior is the result of three factors. The first factor is the intensity of the sun's radiation which has a very slow increasing trend and has a direct impact on the work process the second factor which is the wind speed, has had a minimum increase, so that it has seen an increasing trend in all stages of the experiment, although on the one hand Another third factor is the ambient temperature, which has prevented the milk temperature from increasing due to its low temperature. In order to make more use of solar radiation in the target container, the focus of the concentrator light can be brought closer to a point state and the light distance to the container can be reduced, but this was not true in this case and it affected the quality of the milk. At 10:05 after a uniform cycle the intensity of the sun's radiation increased rapidly and reached 1272 W/m^2 and 5 minutes later the opposite wind speed reached its maximum speed of 3.8 m/s. Therefore, due to low radiation intensity, increasing wind speed and low ambient temperature, no significant increase has been reported in the test process.

As the results of March 24 (curve number 31 in orange color) show, the intensity of the sun's radiation has a minimal increasing and decreasing trend. At the onset of the test, the sunlight intensity was recorded at 1225 W/m^2 with the ambient temperature 21.9 ℃, ambient humidity 29% and a wind speed 0.16 m/s. The temperature of the valve at the beginning is 26 ℃. Over time, there was a gradual increase in sunlight intensity. On this day, the process of increasing the milk temperature was an increasing and then decreasing process, so that at the beginning of the test process, the intensity of the sun's radiation was 1225 W/m^2, and at 11:25 the intensity of the sun's radiation decreased and reached its lowest value 1187 W/m^2 has arrived. Due to the low wind speed, which was zero or close to zero most of the time, and due to the uniform ambient temperature, the temperature of the valve increased rapidly. It is noteworthy that in this test, after one hour the system was able to bring the volume of 4 liters of milk to a temperature of 81 °C. After that, due to the fact that the intensity of the radiation has decreased to the value of 1207 W/m^2, which is lower than the beginning of the testing process, the temperature of the tap was gradually reduced. The average radiation intensity on this day is equal to 1217 W/m^2.

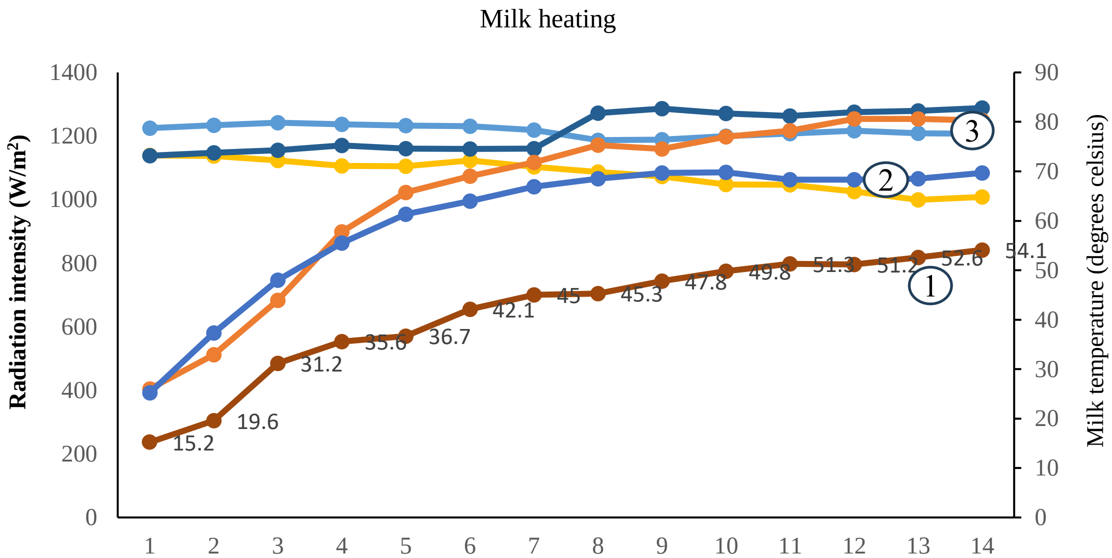

Figure 1. Evaluation of the solar lens system in milk heating on March 16, 22, 24, 1401

In research with a similar system, the temperature of 3 liters of water increased from 40 degrees to 90 °Cin 30 minutes. Their experiments were conducted in July, when there is a higher average intensity [2]. The changes shown in Figure 2 have been tested with the highest intensity of solar radiation and the increase of the ambient temperature as well as the low wind speed in the time period, the thermal efficiency of the entire system has increased. The maximum total thermal efficiency obtained for heating the milk for three days with different radiation intensity, wind speed and ambient temperature tested was 45%, 72.7% and 90%, respectively. The maximum interval related to March 22nd with negligible wind speed and close to zero and high ambient temperature compared to other days and the light concentration of the collector was obtained to a point state and around 11 o'clock. In one research, it was shown that efficiency increased by increasing the amount of water in the container, so that their efficiency increased from 15 to 41 percent when the capacity of the target container increased from one liter to 4 liters (El-Sebaii & Ibrahim 2005). The higher efficiency of the present research experiments can be attributed to the insulation of the target container and the reduction of heat losses.

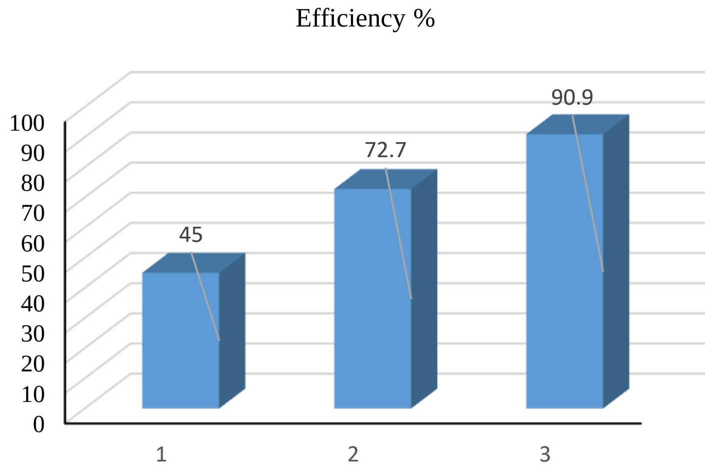

Figure 2. Checking the efficiency of the milk heating system on March 16, 22, and 24, 1401

CONCLUSION

The purpose of this research is to provide milk heating using a solar oven equipped with a spot Fresnel lens. The results show that the evaluation of the solar lens system for milk heating in the winter season had a positive performance and was able to heat the target container well in the mentioned time frame. According to the issues raised about milk heating with the system, the following results can be extracted from this research:

1) In this research, the evaluation of the solar system in milk heating was done with regard to the spot Fresnel lens. The results showed that at the end of winter when there is low solar radiation intensity, this solar system was able to raise the milk temperature to 80 ℃ after one hour.

2) Due to the fact that this experiment was conducted in March on different days and hours, the results show that the maximum intensity of radiation is at 11 am.

3) Wind speed and ambient temperature are the two main factors affecting the milk temperature. Considering that the intensity of the sun's radiation was almost the same in both experiments, two different procedures can be observed. This confirms the results obtained in the previous section.

4) Due to its lower heat capacity, milk is heated earlier, and therefore its heating speed is much higher than that of water in the previous tests.

5) As can be seen from the above graphs, the performance of the system is lower in the early hours of the day, and when it reaches noon, when the sun's rays fall perpendicularly on the lens, it increases, and after noon, the performance of the system decreases again. We can see that, of course, the slope of the decrease in the afternoon is greater than the slope of the increase in the morning.

To increase the efficiency and efficiency of the designed solar system, phase change materials can be used to increase the ability to heat or store the temperature of the heating material during the night or when solar energy is not available, in addition to storing additional heat during the day.

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