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Old Satellite Dish as a Solar Cooker in Iran

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Abstract

In this study, a portable concentrating solar cooker was designed, fabricated and tested. A 90 cm standard old satellite dish was used as a concentrator. This standard satellite dish is available for all. So, it can motivate using solar energy in routine life. Temperature rise more than 40 °C in one kilogram of water observed only in fifteen minutes. It proves that the cooker is good enough for cooking and baking or being used as a water heater. A series of experiments were performed to study its performance. Based on those experiments, the solar cooker optical efficiency was estimated about 39.1%. Energy and exergy study were also performed. Results showed that its first law efficiency was about 32.6% and second law efficiency was 2.55%. These figures may prove its proficiency beside its simplicity.

Key words

Solar cooker, Exergy, Optical efficiency, Concentrating cooker.

1. Introduction

Abundant solar energy is a clean and safe source of energy. It is an excellent alternative to fossil fuels, especially in domestic applications. A solar cooker is a good example for domestic application. In solar cookers, sunlight is converted to thermal energy. Recently, many researchers may be found in solar cookers field [1-5]. In spite of solar cookers benefits, they have not experienced widespread success [6]. The main reason may be sought in solar cookers characteristics. Generally, solar cookers may be divided into two main categories: box-type cookers and concentrating cookers. Box type cookers are more prevalent. Since they are cheaper and may be constructed easily. However, their operating temperature is relatively low. Therefore, it takes several hours to complete cooking by box-type cookers. On the other hand, really higher temperature may be achieved by concentrating cookers. This temperature is suitable for boiling, baking or even grilling. Despite of its convinced characteristics, manufacturing a suitable concentrator is difficult and costly. In spite of box type cookers, a handmade concentrating cocker is not usual. So, few people would prefer to consider the sun as a source of energy.

In this study, a 90 cm standard old satellite dish is used in design, fabrication and testing a solar cooker. This standard satellite dish is available for all and it does not cost too much, especially for people who use reaction vehicles or campers. It is only required to prove its performance.

2. Solar Cooker Structure

Fig.1. Photograph of the Solar Cooker.

The solar cooker is shown photographically in Figure 1. The cooker is of a simple design and its fabrication does not require skilled labor. An old satellite dish with 90cm aperture diameter was used as cookers concentrator. Its rough surface condition ensures authors that the optical efficiency in no case will be less than this prototype. A commercial self-adhesive aluminum reflective sheet was employed to cover its surface. Moreover, a suitable support was designed for this cooker. The support may be disassembled into a compact form which can be transferred easily (Figure 2). The cooker may be assembled in less than 30 seconds. Its usage is very simple and it’s really user-friendly. It can be adjusted toward the sun, enjoying two rotating mechanisms.

Fig.2. Photograph of the Disassembled Solar Cooker

3. Cooker Structure and Experiment

The performance of the cooker was measured experimentally two times in one day (23rd June), once before solar noon and once after solar noon. The experiments were conducted on the roof of the Science College of Azad University in Marvdasht. The latitude, longitude, and altitude of Marvdasht are, respectively, 29° 52' N, 52° 48' E and 1595 m above sea level. The sky was completely clean and ambient temperature during experiments was constant and equal to 31.7°C. Two set o experiments were performed. In each set, at first, one kilogram of distilled water was heated by the cooker. Ambient temperature and water temperature were recorded every minute. The heating process took eighteen minutes. Results are shown in Figure 3.

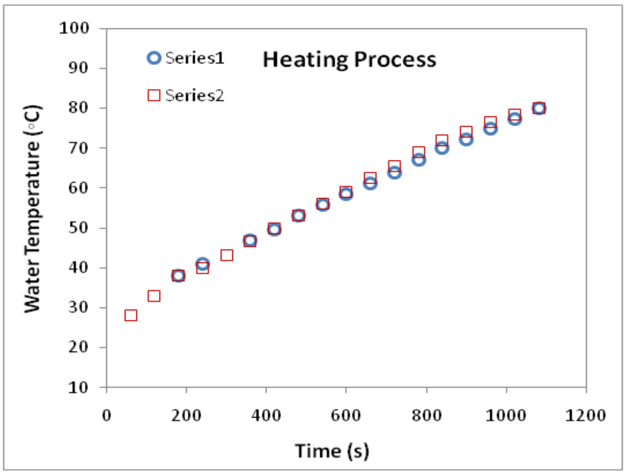

Fig.3. Water Temperature Variation During the Heating Process.

At the end of the heating process, the reflector was turned to opposite direction. So, the water was cooled down slowly. Results are shown in Figure 4.

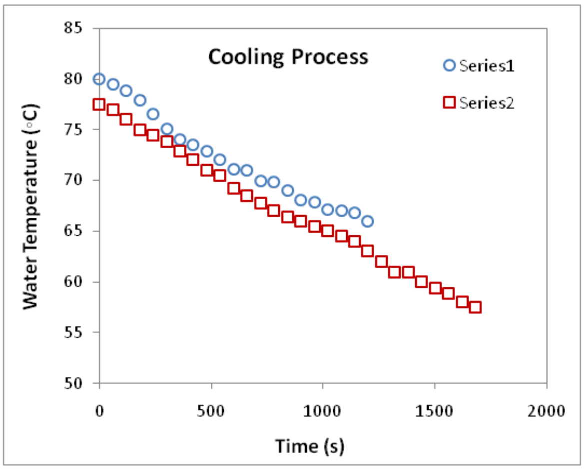

Fig.4. Water Temperature Variation During the Cooling Process.

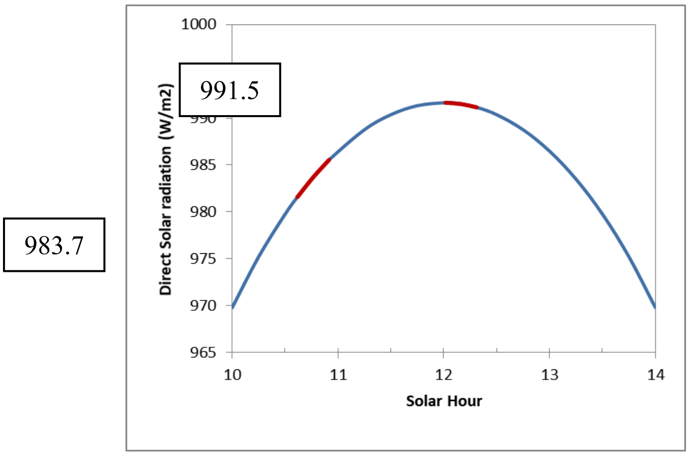

Fig.5. Direct Solar Radiation.

The total amount of direct solar radiation during the experiment were estimated by Hottel's equation [7].

$$I = I_o\left(a_0 + a_1 \exp\left[\frac{-k}{\cos(t_s)}\right]\right) \tag{1}$$

in which I_o is extraterrestrial solar radiation for nth day of year and calculated by the following equation:

$$I_o = 1367\left(1 + 0.034\cos\left(\frac{365n}{365.25}\right)\right) \tag{2}$$

in which n=174 for the experiment day. Three constants in Eq. (1) are:

$$a_0 = (0.4237 - 0.00821(6 - A)^2) \tag{3}$$

$$a_1 = (0.5055 + 0.00595(6.5 - A)^2) \tag{4}$$

$$k = (0.2711 + 0.01858(2.5 - A)^2) \tag{5}$$

where A=1.595 km is local elevation. The amount of direct solar radiation is shown in Figure 5. Also, the amount of direct solar radiation during the heating process and the average values have been specified in Figure 5.

4. Results and Discussion

Assuming steady state condition with constant ambient temperature during the cooling process, one can write:

$$\left[(mCp)_w + (mCp)_P\right]\frac{dT}{dt} = -UA_t\left(T - T_\infty\right) \tag{6}$$

in which m and C_P indicated to mass and specific heat capacity, respectively. w and P indexes refer to water and cooking pot respectively. U is overall heat loss coefficient and A_t is effective heat transfer area. Neglecting the cooking pot total heat capacity, $(mC_P)_P$, in comparison to water total heat capacity, the solution of Eq. 6 is:

$$\frac{\left(T - T_\infty\right)}{\left(T_0 - T_\infty\right)} = e^{-t/\tau} \tag{7}$$

in which T_∞ and T_O is the ambient and water initial temperature, respectively and τ is introduced as:

$$\tau = \frac{(mCp)_w}{UA_t} \qquad (8)$$

Normalized temperature difference for two test series is shown in Figure 6. According to this figure, τ = 3125 s and therefore, UA_t=1.34 W/K.

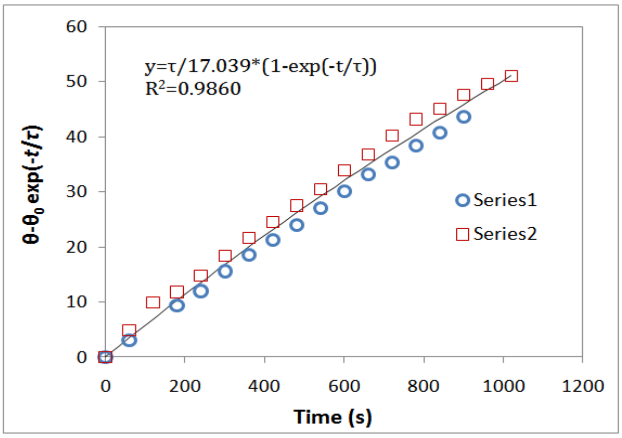

Fig.6. Normalized Temperature Difference for Two Test Series.

For the heating process, one can write:

$$(mCp)_w \frac{d(T - T_\infty)}{dt} = -UA_t (T - T_\infty) + IA_c \eta_{op} \qquad (9)$$

in which I, A_c and η_{OP} are direct solar radiation, reflector aperture area and optical efficiency, respectively. Assuming constant solar insolation, the solution of Eq. 9 is:

$$(T - T_\infty) - (T_0 - T_\infty) e^{-t/\tau} = \frac{\tau}{\beta} \left(1 - e^{-t/\tau}\right) \qquad (10)$$

in which τ = 3125s according to previous results and β is defined as:

$$\beta = \frac{(mCp)_w}{IA_c \eta_{op}} \qquad (11)$$

Eq. 10 is shown in Figure 7.

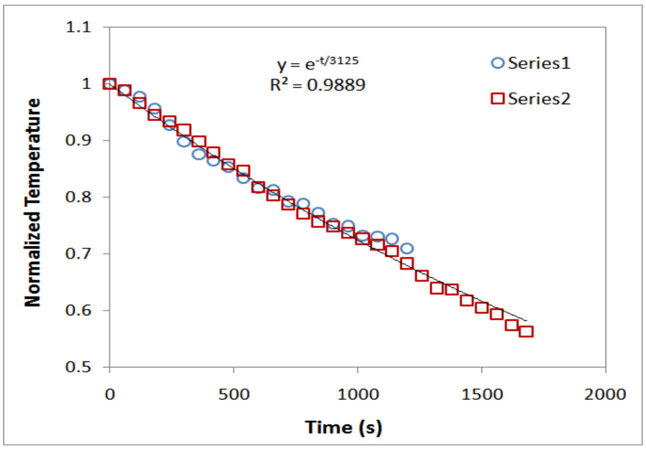

Fig.7. Estimation of β for Two Heating Process.

In this regard, the solar cooker optical efficiency is equal to:

$$\eta_{op} = \frac{(mCp)_w}{\beta I A_c} = 39.1\% \tag{12}$$

This optical efficiency depends only on cookers structure and is independent of climate condition or solar radiation.

First law efficiency of solar cooker is defined as:

$$\eta_I = \frac{(mCp)_w (T_L - T_0)}{I A_c \Delta} \tag{13}$$

in which and Δ are the water temperature at the end of heating process and heating process duration, respectively. The average first law efficiency of solar cooker in two series of experiments was, $\eta_I = 32.6\%$.

Knowing that first law efficiency is the product of optical efficiency and thermal efficiency (efficiency related to heat loss), thermal efficiency is deduced as:

$$\eta_{th} = \frac{\eta_I}{\eta_{op}} = 83.4\% \tag{14}$$

In spite of optical efficiency, first law efficiency and thermal efficiency depends on ambient temperature, pot temperature, and solar isolation. Although at the first glance, the first law efficiency is relatively low, this low efficiency beside free and abundant solar energy source, inexpensive and portable cooker is not important.

5. Exergy Analysis

Useful exergy is the amount of increase in exergy level of water at the end of the heating process and may be introduced as:

$$Ex_{useful} = (mCp)_w \left[(T_1 - T_0) - T_\infty \ln (T_1 / T_0) \right] \tag{15}$$

Solar exergy may be introduced as [8]:

$$Ex_{solar} = IA_c \Delta \left(1 - T_\infty / T_{sun} \right) \tag{16}$$

Considering that the effective sun temperature is ¾ sun temperature as a black body, T_s= 4500 K [9] and finally, the 2nd law efficiency may be introduced as:

$$\eta_{II} = \frac{\dot{E}x_{useful}}{\dot{E}x_{solar}} = 2.55\% \tag{17}$$

The average 2nd law efficiency of solar cooker in two series of experiments was, $\eta_{II} = 2.55\%$. It is well known that second law efficiency in low-temperature solar applications is very low.

Conclusions

In this research, a concentrating solar cooker was designed, fabricated and tested. In this cooker, an old standard satellite dish was employed as a concentrator. It is inexpensive and available for all. But its usefulness should be approved before applying. The result solar cooker was a portable and inexpensive which can be used a water heater also. Results showed that it can provide more than 40 °C temperature difference in one kilogram of water at only fifteen minutes. The solar cooker optical efficiency was deduced about 39.1%. This efficiency is independent of climate or solar isolation. Its first law efficiency was about 32.6% and second law efficiency was 2.55%. To estimate the efficiency, no cover glass was used to reduce heat loss from utensil. Even the bottom of utensil was not blackened. Using conventional utensil ensures authors that efficiency would not be lower under no circumstance. These figures may prove its proficiency beside its simplicity.

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Nomenclature

A	Local elevation, km
A_c	Reflector aperture area, m^2
A_t	Effective heat transfer area, m^2
Cp	Specific heat, J/Kg.K
Ex	Exergy, J
I	Direct solar radiation, W/m^2
I_o	Extraterrestrial solar radiation, W/m^2

m	Mass, kg
T	Temperature, K
t	Time, s
U	Overall heat loss coefficient, W/m^2K

Greek Letters

Δ	heating process duration, s
η_I	1st law efficiency defined
η_{II}	2nd law efficiency
η_{op}	Optical efficiency

Subscript

∞	Ambient
0	Initial
sun	Sun
w	Water
P	Cooking pot