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Portable solar cooker and water heater

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ABSTRACT

A portable solar water heater was designed, built and tested. This application of solar energy devices is particularly important for the Bedouin community which can gain a great deal from the solar energy that is continuously available in the desert. It can be also used by campers and those who use recreation vehicles. A normal satellite dish of 150 cm diameter was used as a concentrator for solar radiation. The surface of the dish was covered with reflective aluminum foil which was used to concentrate solar energy on a cooking pot in one mode of operation. This mode was operated in two ways: one with bare pot and the other with the pot being covered with glazing by putting it inside a glass box. The device was also used in another mode of operation to heat water for domestic use by placing a specially designed solar collector in the focus.

It was found that, when the device was operated in the bare cooker mode, a 7 kg of water at 20 °C was brought to a boil in 1 h. Putting the pot inside the glass box reduced the time required for boiling to 40 min and the cooking power was increased by 275%. In the collector mode, the device was able to heat 30 kg of water from 20 °C to 50 °C in 2½ h. The highest efficiency obtained for this mode was 77% and the slope of the efficiency curve was -10.63 W/m^2 °C.

1. Introduction

Solar domestic hot water heating is considered one of the most important solar energy applications. Most of these systems are basically composed of a solar collector and a storage tank, where natural (thermosyphonic) driving force is used to circulate water between the collector and the tank. There are, however, few systems of the batch type, which utilize a tank whose sides are insulated except one side, which is glazed and is directly heated by solar radiation. Most of water heating systems developed so far are of the stationary type, which are typically used for residences. The types that can be easily moved from one place to another are quite few, and they are made for a single use, that is water heating for a shower [1]. This portable use application is especially useful for Bedouins, campers and nomads who move around quite often.

There are, however, several designs for solar cookers of various types. The three basic classifications of solar cookers are: (i) concentrator type, (ii) box type, and (iii) evacuated tube type which uses heat pipes [2–4]. Several works focused on the same idea of portable solar device, which combines the portable water heater with the portable cooker.

Odeh [5] built a device entitled "Bedouin solar cooker and water heater" in an effort to make solar energy available to Bedouins. He used a circular aluminum sheet that is made of several circular sectors to build the concentrator. This configuration was not effective due to the low reflectivity of aluminum sheets and to the fact that the concentrator could not be folded, and therefore it was not easily portable.

Ayoub [6] continued the work of Odeh by making changes to the tracking mechanism to ease the movement of the dish. He also tested a "heat exchanger" that was placed in the focus of the concentrator in order to be used in the water heating mode. It was found that the exchanger configuration which was an uncovered cylindrical steel can, with a copper tube wrapped around, which carries the water, was inefficient. The fact that this heat exchanger was not covered with glass was mainly the reason behind the unsatisfactory performance of the device in the water heating mode.

Jayyousi [7] replaced the heat exchanger used by Ayoub with a small solar collector, but the results were not satisfactory either due to the fact that the collector was "transparent" from both sides.

Akyurt et al. [8] reviewed heat pipes for waste heat recovery including their use in solar cooking.

Saleh and Badran [11] introduced the satellite dish technology into solar cooker application. They built the device using a 180 cm standard satellite dish which was moved by two jacks for tracking. But the tests were inconclusive, and the system was substantially heavy.

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Halawa et al. [10] combined both the water heater and the cooker in a one portable device, using a miniatured conventional collector and keeping the tracking mode to be a manual one. Their results were inconclusive because of breakage problems in the collector caused by excessive concentration of heat on the collector. Yousef [12] concluded their work by re-designing the collector part to be formed of two parallel circular plates, as will be shown in detail in this work.

In an effort to reduce losses, Joudeh [13] tested the device in the cooking mode using a glass box that surrounds the pot. He found that the cooking power and the efficiency were increased by 275% and 38%, respectively. Thereby the cooking time was reduced by 33%.

In this work, the collector component was modified in shape, dimensions and inner construction of the absorber plate. Also the cooker component was more investigated by adding glazing around the cooking pot to reduce convection losses.

2. Theory

In order to be able to measure the performance of the device in its two modes of operation, the following equations were used, the first of which [14,15] defines the useful power, in Watts, for the device in the water heating mode:

$$q_u = \eta_o G A_a - U_L (T_r - T_a) A_r \quad (1)$$

where η_o is the optical efficiency, G is the solar radiation, in W/m^2, U_L is the overall loss coefficient of the device, in W/m^2 °C, A_a and A_r are the aperture (concentrator) and the receiver (absorber) areas, T_a and T_r are their temperatures, respectively.

Dividing Eq. (1) by $G A_a$ gives the instantaneous efficiency of the device in the water heating mode:

$$\eta_c = \eta_o - U_L (T_r - T_a)/GC \quad (2)$$

where C is the concentration ratio = A_a/A_r.

For the cooking mode of operation, the cooking power, P is defined [9] as:

$$P = m C_p \Delta T_w / t \quad (3)$$

where m is the mass of liquid in the cooking pot, C_p is its specific heat and ΔT_w is the temperature rise of water during a time period t of the test.

The adjusted cooking power is defined [9] as:

$$P_{adj} = 700\, P/G \quad (4)$$

This power is calculated to relate the power obtained under any solar radiation to that if the radiation was 700 W/m^2.

The efficiency of the system in the cooking mode may be defined as:

$$\eta = m C_p \Delta T_w / A_a G \quad (5)$$

3. Experimental

The device was essentially based on a dish/concentrator made of a satellite dish, 150 cm in diameter, covered with aluminum foil, as shown in Fig. 1. The dish/concentrator was made of two pieces, to facilitate carrying on an animal's back. As shown in Fig. 2. The dish was installed on a steel base that was also designed for easy carrying on an animal's back.

In the water heating mode, the dish carries a circular collector/receiver, as shown in Fig. 3. The collector/receiver envelope was manufactured of stainless steel, and the design had a glass aperture facing the concentrator. The absorber is composed of two circular parallel steel sheets that are spaced by 2.5 cm rim and backed by insulation and stainless steel cladding facing the sun. The collector/receiver is placed at the focus of the dish.

Fig. 1. The device in the water heating mode.

Fig. 2. The dish/concentrator.

The hot water storage tank capacity is 30 l. It was insulated with polyurethane foam and was installed on the steel base as shown in Fig. 1. The empty mass of the tank is 5 kg. The total mass of the device in this mode is 25 kg.

The cooking mode is obtained simply by replacing the circular collector with a cooking pot, as shown in Fig. 4. The pot is made of aluminum, has a diameter of 23 cm. and a height of 18 cm, and its volume is 7.5 l. In order to test the effect of convection on the pot, it was placed inside a glass box, 45 × 45 × 30 cm, as shown in Fig. 5. The pot lid was covered with polyurethane foam to reduce losses.

4. Results and discussion

Tests for the collector mode were performed to show two types of performance: the instantaneous efficiency whose results are shown in Fig. 6, and the tank temperature rise with time, Fig. 7.

Tests for the cooker mode were performed to show three types of performance: the cooking power vs. ΔT_a for both cases, with and