INVESTIGATION OF SOLAR ABSORBER FOR SMALL SCALE SOLAR CONCENTRATING PARABOLIC DISH

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Abstract

A solar receiver is an important part in the conversion of solar radiation into thermal energy and it is crucial to investigate the thermal performance of solar absorber in the receiver. In this paper, two types of solar absorbers (stainless steel fibrous wire mesh and silicon carbide honeycomb) working with air as heat transfer fluid were tested in a small scale solar concentrating parabolic dish. The dish has an aperture diameter of 1.2 m and is covered with reflecting film. It is demonstrated that the flat circular absorbers (7 cm diameter) working with air can transform solar radiation into thermal energy with 40 - 80 % efficiency depending on the air flow velocity through the absorber.

Keywords: Solar receiver; small scale solar concentrating system; fibrous wire mesh; silicon carbide honeycomb

1. Introduction

of the parabolic dish and is heated directly. There is also a special type of external receiver called volumetric receiver which is directly irradiated by the incoming concentrated rays, giving minimal heat loss. Parabolic dish solar concentrating systems for high temperature power generation have been described by a number of researchers (Wu et al., 2010, Abbas et al., 2011, Jaffe, 1989, Lovegrove et al., 2011). The system basically consists of parabolic dish mirrors that concentrate the direct beam of sun rays onto a receiver which is placed at the focus of the parabolic dish to intercepts the concentrated sun rays. However, the use of these systems for small scale applications, for instance for solar cooking, are at low stage of development.

In solar cooking, the cooking pot is placed at the focus point of the parabolic dish and irradiated from below(Arenas, 2007, Abou-Ziyan, 1998). Such types of solar cookers, however, have a number of limitations. Cooking can be performed only in the day time during sunshine and the sun rays reflection from the surface of the parabolic dish could burn the cooking pot. To improve such systems, one of the good strategies is to collect the energy in the focus region of the parabolic dish and transport it to thermal storage units. This would facilitate cooking to be performed at any time (including at night) in a house.

The solar receiver is a very critical component in the overall conversion of the solar radiation into thermal energy. It acts as heat exchanger to convert the concentrated solar radiation into thermal energy of the working fluid flowing inside the receiver. The two most common types of receivers employed in parabolic dish solar concentrator systems are the cavity receiver and the external receiver. In the cavity receiver the reflected rays from the parabolic dish enter into the aperture of the receiver cavity and internal reflections within the receiver ensure that the radiation is absorbed in the wall of the cavity (coiled tube). In these types of receiver, the working fluid is heated indirectly and the receivers are subjected to convective heat loss. For external receivers, as the name implies, the absorbing surface are in direct view. The objective of this paper is to investigate the performance of volumetric solar absorbers that employ air as a heat transfer fluid and could be integrated with a small scale parabolic dish concentrator and heat storage for indoor cooking.

2. Description of the system

As shown in figure 1, a test rig consists of a parabolic dish, a receiver, a fan, a sun tracking unit and an air transporting pipe. The parabolic dish has an aperture diameter of 1.2 m and is made from 2 mm thick aluminum plate. It is covered with a commercially available reflecting film (ReflectTech® Mirror film, 94 % reflectivity) and supported with a wooden structure at the back side. The reflecting film has an adhesive backing that can be applied easily to smooth surfaces. The dish concentrates the direct sun rays into a small region at the focus of the dish where the receiver is placed

A conically shaped receiver was designed for our testing purposes. The circular shape of the receiver at the bottom part houses the absorbers, as shown in figure 2. The receiver was supported with four ribs connected to the parabolic dish and its wall insulated with aero gel (Pyrogel® XT) to minimize the heat loss to the surrounding.

Two different types of flat circular absorbers were tested with the parabolic dish. The first one is constructed from a commercially available fibrous wire mesh (STAX Stainless steel fibers) that could resist a temperature as high as 1200 ^{o}C. The fibers have about 0.1 mm diameter, and are irregularly shaped. The fibrous absorber was designed so that it has a weight of 2.45 kg m^{-2} and its center which would be exposed to higher flux density was made relatively thinner compared to the periphery. The second type of absorber is a high temperature resistance porous silicon carbide monolithic having a honeycomb structure. It is characterized by a cell density of 22 cells cm^{-2}, wall thickness of 0.5 mm, cell dimension of 1.6 mm, density of 1.8 kg m^{-3} for the material and 730 kg m^{-3} for the honeycomb, heat conductivity of 40 W m^{-1} K^{-1} at 25 ^{o}C. This type of absorber has been tested for large scale solar concentrating power plants (Carotenuto et al., 1991, Ávila-Marín, 2011, Carotenuto et al., 1993).

The absorbers were painted with high temperature resistance black paint and sized to 0.07 m in diameter in order to fit inside the receiver. The absorber was positioned just below the focus point of the parabolic dish and the reflected rays from the parabolic dish illuminate most parts of the absorber.

A 24 Volt centrifugal fan is used to draw ambient air (working fluid) through the absorber. The heated air can be used to charge a thermal storage unit (e.g. rock bed, phase change material). A simple turbine velocity meter was used to measure the flow of air through the fan. A flexible pipe, insulated with aero gel, is used between the receiver and the fan. The concentrating system, the pipe and the fan rotate as a single unit, tracking the sun.

The sun tracking system utilizes a commercially available Fusionseeker DS-50D5 light sensor and controller. Two independent 24 V DC motors with a gearing system were connected to the controller to yields a two axis solar tracking accuracy ± 0.2 degrees.

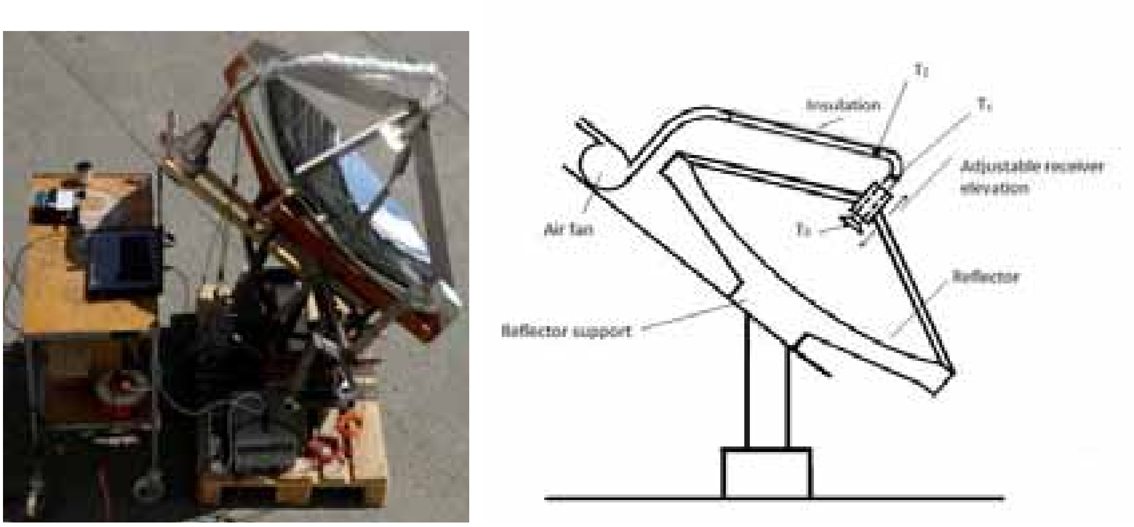

Fig.1: Test rig for absorbers experiment, a Photograph (left) and schematic drawing showing the location of the thermocouples (right)

A) B1) B2) C)

Fig. 2:The receiver (A1) and the two types of flat absorbers, ceramic honeycomb (B1) and fibrous wire mesh (B2) absorber. The absorbers fitted into the receiver (C).

3. System test

Determination of the focus point of the parabolic dish and the flux distribution near the focus point is very critical in the design of the solar absorber and locating the position of the receiver. For this, a vertical laser beam was used to scan the parabolic dish and map the distance of the reflected beam from the focal axis. This type of approach has been extensively discussed by (Mlatho, 2009). Experiments were performed to map the reflection of the laser beam ray from the parabolic dish on a flat paper placed near the theoretical focal point.

In the receiver, air is sucked from the front of the absorber and flow parallel to the incident direct radiation direction. Three K-type thermocouples were installed to measure the air temperature at the receiver: one at the front of the absorber and two at the back side of the absorber. All the thermocouples were connected to an analogue to digital converter (ADC) module of NI 9211 with NI ComapctDAQ chassis which could measure the temperature with a high precision. The daily solar radiation was recorded at the Physics department, NTNU, which is near to the testing site. A flow velocity measuring device was used to determine the mass flow rate of the air using a state equation for the gas density.

The performance of the absorbers were compared based on the overall efficiency of the concentrating solar system (parabolic dish and the receiver) to transform the incident solar radiation at the aperture of the parabolic dish to thermal energy for the air at the absorber:

$$\eta_{themal} = \frac{Q_{abs}}{\int I_T A_{ap}}$$

(eq. 1)

where I_T is the direct solar radiation flux (W m^{-2}), A_{ap} is the aperture area of the parabolic dish and Q_{abs} is the rate of energy gained by the air at the absorber and is defined as:

$$Q_{abs} = \dot{m} c_p \Delta T$$

(eq. 2)

where $\dot{m}$ is the mass flow of the air (kg s^{-1}), C_p is the specific heat capacity of air (J $kg^{-1}K^{-1}$) and ΔT is the temperature rise of air (K) across the absorber. The thermodynamics data of the air is taken at the temperature of the air at atmospheric condition and at the exit from the absorber.

4. Results and discussions

Figure 3 shows the flux distribution produced by the laser diodes near the focal point of the parabolic dish. In ideal condition a point image would be expected at the focal point of the dish. However, no reflection is ideal and a finite size of a focal image is produced. Comparing the figures, a distance 48 cm from the vertex of the parabola is most narrow focal region.

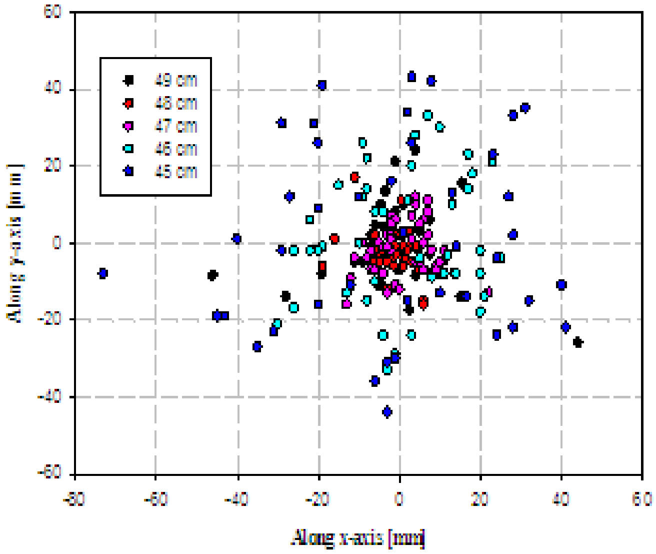

Fig.3: Laser beam recordings on a flat paper placed at different heights along the focal axis

The basic objective of the experimental work is to measure the temperature of the air after exchanging heat with the absorbers and the performance of the concentrating solar system (the parabolic dish and absorber) in transferring the solar radiation into thermal energy. As we see from figure 4 and figure 5, the temperature of the air increases with time and become stable and a lower air flow velocity yields a high air temperature.

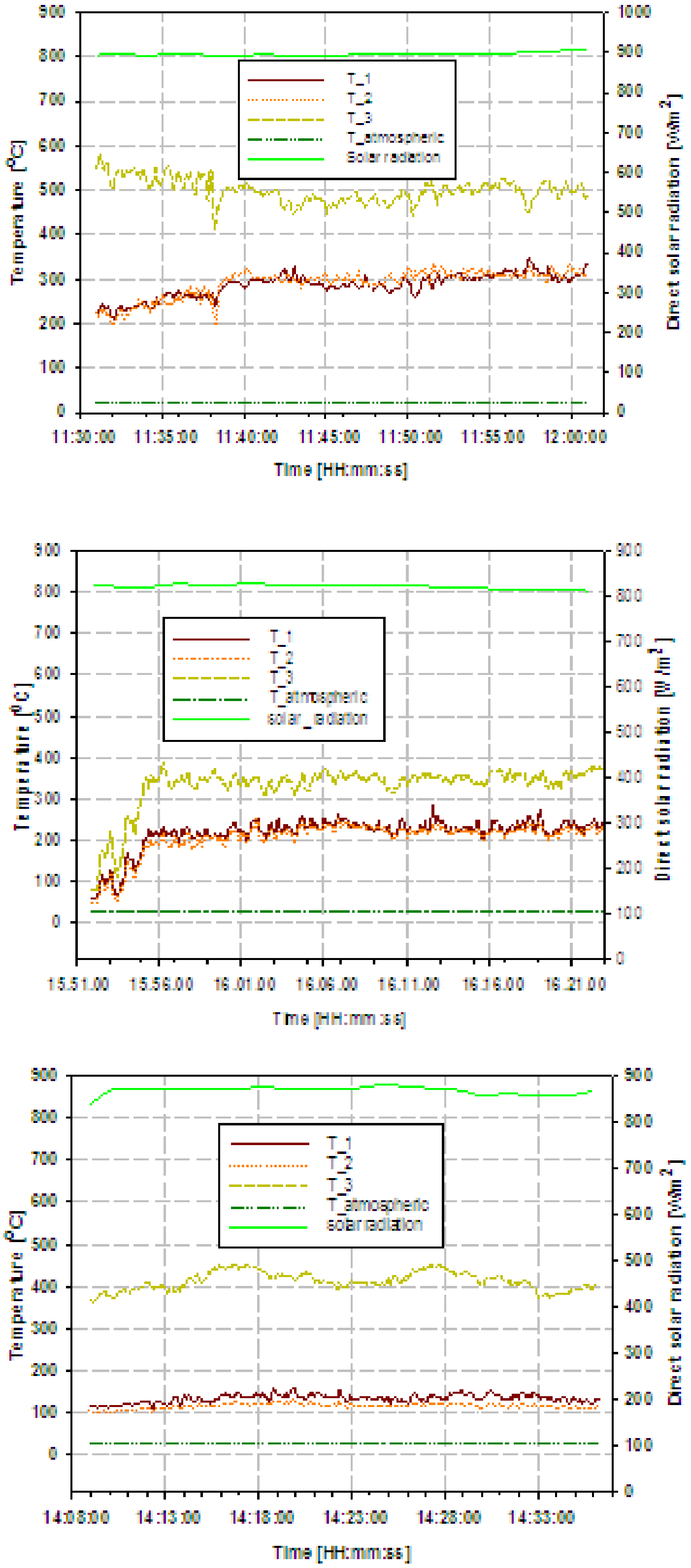

Fig. 4: Temperature measurements of air for 0.07 m fiber absorber at air speed of 1 cm (top), 2m s^{-1} (middle) and 4 m s^{-1} (bottom). The direct solar radiation for the testing site is shown on the top of the temperature profile. The positions of the thermocouples are given in figure 1.

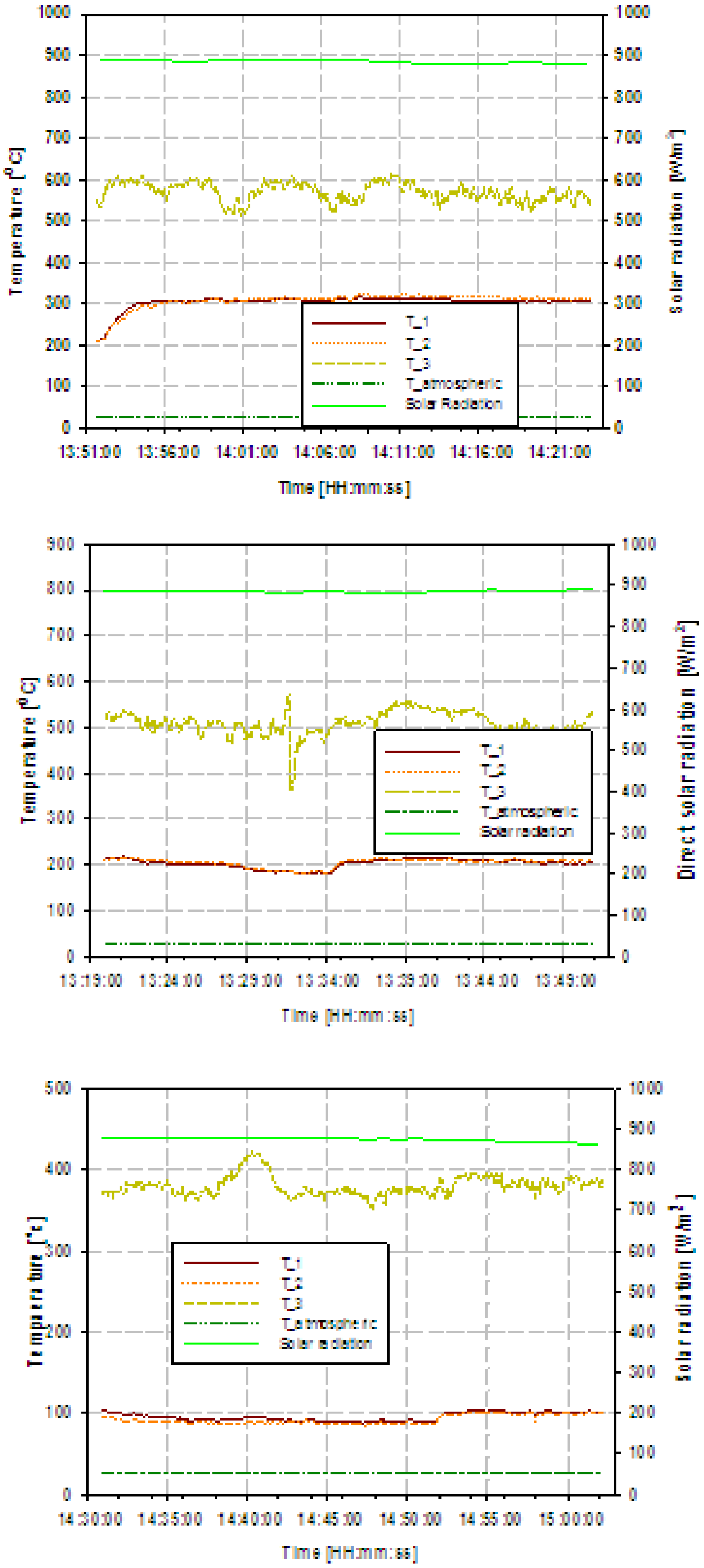

Fig.5: Temperature measurements of air for0.07 m honeycomb absorber at air speed of 1 cm (top), 2m s^{-1} (middle) and 4 m s^{-1} (bottom). The direct solar radiation for the testing site is shown on the top of the temperature profile. The positions of the thermocouples are given in figure 1.

To investigate the thermal performance of the absorber with respect to the different flow velocities, the overall conversion of the available solar energy to thermal energy at the absorber were studied by equation (1) and equation (2) and the result is reported in Table 1 and Table 2. Air flow at a velocity of 1 m s^{-1} has produced higher air temperatures; the corresponding overall efficiency is the lowest. This is mainly due to an increase in radiation loss at high temperature. This shows the higher air temperature at the absorber can be obtained but at the cost of a performance drop.

It is observed that a flow velocity near 2 m s^{-1} is an optimum value for the honey comb absorber. Further increasing in the air speed is causing a decrease in the efficiency. However, for the fibrous absorber, the increase in the flow velocity shows an increase in thermal performance. But, the rate of increase in performance is lower when the velocity increase from 2 m s^{-1} to 4 m s^{-1} compared from 1 m s^{-1} to 2 m s^{-1}.

Even if the solar radiation intensities are not equal, comparing the two types of absorbers, it seems that the fibrous wire mesh shows a better thermal performance than the silicon carbide honeycomb. However, the temperature of the air leaving the honeycomb absorber is smoother indicating that response of the honeycomb towards the solar radiation is more stable compared to the fibrous wire mesh. It was also observed that the black paint on the fibrous absorber turns into white gray color. But no significant color change was observed with the honeycomb.

Tab. 1: Rate of energy gained at the solar absorbers

Absorber type	**Rate of energy gained (W)**		
	1 m s^{-1}	**2 m s^{-1}**	**4 m s^{-1}**
Fibrous wire mesh	430	565	773
Honeycomb	400	648	582

Tab. 2: Overall average efficiency of the concentrating system to convert solar radiation into thermal energy

Absorber type	**Efficiency**		
	1 m s^{-1}	**2 m s^{-1}**	**4 m s^{-1}**
Fibrous wire mesh	43 %	72 %	81 %
Honeycomb	41 %	66 %	60 %

As the absorbers were tested without glass cover, it is expected that convective heat loss in strong wind would reduced the energy collection. If a glass cover were applied on the absorber, the performance of the absorbers could potentially increase. Difference in wind velocity could also have affected the results reported above.

5. Conclusion

Solar receivers with two types of absorbers are tested in a set up with a small scale parabolic dish solar concentrator. Air is heated as it passes the absorbers placed below the focus of the parabolic dish. The temperature, air flow and radiation measurements were used to estimate the energy conversion efficiency. The temperature of the air increase from 100 °C - 300 °C with the decrease in air flow velocity from

4 m s^{-1} to 1 m s^{-1}.The efficiency drops with the decrease in velocity. It is conclude that a small scale parabolic dish with fibrous wire mesh absorber shows a promising result in converting the solar radiation into thermal energy. The energy could be used to charge a rock bed to store solar thermal energy during the day time.

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