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Development and Testing of Parabolic Solar Collector

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The need of solar energy for daily applications like cooking and heating of water has become vital in today's life. For this purpose mainly two types of collectors are used: Flat Plate Collector and Concentrating Collectors. The limitation with flat plate collectors is the maximum temperature and the collection efficiency. Both these problems can be overcome by the use of Concentrating Collectors. In this paper, the design, development and testing of Parabolic Collector having concentration ratio of 18 is presented. Anodized Aluminium sheets were used as reflecting surface. By providing the support from backside in the form of parabolic bars, the number of reflecting sheets can be reduced. The venture is to make such collectors cost effective. The stagnation temperature of 216 °C is obtained using the parabolic collector with a maximum instantaneous efficiency of 35 %. Boiling point of water is achieved within 20 minutes.

1. Introduction

Solar power is energy from the sun. Although the sun is 150 million kilometers away it is still extremely powerful. The amount of energy it provides for the earth in one minute is large enough to meet the earth's energy needs for one year. The problem is in the development of technology that can harness this 'free' energy source. The devices that are used to harness the solar radiations and convert the energy in to heat are called Solar Collectors in simple terms. Generally this energy is utilized to heat air, water or some small solid matter. They find application in devices like Solar Heater, Air Heater and Solar Cookers etc. The Solar Collectors can be classified into two basic categories: Flat Plate Collectors and Concentrating Collectors.

The concept of concentrating collectors is known since the past 4000 years but the main research in this field only started after the Second World War [1]. The principle is to concentrate the incident solar radiations into a small area so that more heat can be obtained. Basically they can be divided into two types: Point focusing and Line focusing (Trough Collectors). Concentrating Collectors are more efficient and capable of achieving more than 400 °C. In the 18th century, technical prototype of a parabolic dish was prepared to generate steam for steam engines.

The Scheffler Solar cooker [2], one type of parabolic concentrator, is the most suitable application for domestic and community cooking. The problem with box type solar cookers is that the operator has to spend a considerable amount of time in the sun. Hence cooking becomes difficult. But with Scheffler Cookers, the rays of the sun can be concentrated at a location under the roof also. Another type of concentrating collector is a Compound Parabolic Concentrator (CPC) which concentrates the maximum amount of solar radiation. This is made up of two parabolic surfaces, each passing through the focus of the other [3]. Very high heat energy is generated at the centre of the two surfaces. The amount of solar radiations incident is dependent on the aperture area. Large opening is required to achieve high temperature.

Not only heating, solar concentrators can also be used for generating power. They can be used as the heat source in the Carnot cycle to produce work. Apart from this Stirling Engine is also a suitable application of solar concentrators. The hot cylinder of the Stirling engine can be supplied heat by a concentrating collector. This drives the Stirling engine and mechanical power can be obtained directly [3].

Lupfert *et al*. [4] developed parabolic trough collector for various applications in the 200-400℃ temperature range in solar fields up to t he hundreds Megawatts range. The design of a new support structure of the collector included concept studies, wind tunnel measurements, finite elements method (FEM) analyses and resulted in a structure with a central framework element. They claim that their new design would have lower weight and less deformation of the collector structure than the other designs considered.

Lipinski and Steinfeld [5] developed an annular compound parabolic concentrator (CPC) which was a body of revolution consisted of two axisymmetric surfaces produced by rotating a two-dimensional CPC around an axis parallel to the CPC's axis. They found that their design finds application as a secondary concentrator for capturing the annular portion of spilled concentrated solar radiation and further augmenting its power flux intensity.

Xiao [6] designed a closed-box parabolic trough concentrating solar collector. By accepting an optical loss of a few percentages due to reflections by the cover, their design offered several advantages over the current open model, in particular a potential of significant cost reduction. With the new design, they found reduction in the cost, as well as solution to the problem of hydrogen and helium permeations.

The various designs discussed above are complex and hence costly. In this paper, low cost design of parabolic solar collector suitable for heat delivery at about 200℃ is presented. The experiments were carried out with water and castor oil as the heat carrying fluid. To ascertain the performance of collector each experiment were performed six times. Uncertainty analysis of experimental results was carried out and presented. The details of cost analysis are also given at the end of the paper.

2. Parabolic solar collector

The parabolic solar collector works on the principle of reflection of rays from a parabolic surface. The rays parallel to the axis of the parabola meet at the focus after reflection from the surface. The principle of parabolic solar collector is shown in Fig. 1. Mathematically a parabola can be represented as $r^2 = 4fx$, where 'f' is the length of the focus from the vertex. This is where the rays concentrate after reflection. The focus of the parabolic collector discussed here is 0.4 m. Hence the equation is:

$$r^2 = 0.16\,x \qquad (1)$$

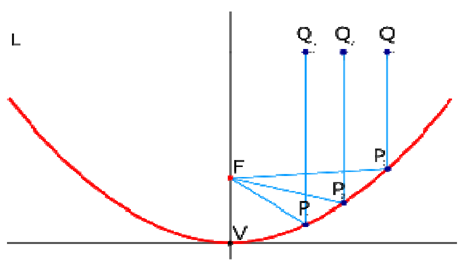

Figure 1. Concentration of rays at focus


Figure 2. Support structure

The concentration ratio in concentrating collector is generally kept in the range of 10 to 15. But in the present design, the collector has concentration ratio of 18 so that higher collection efficiency can be achieved. The main components of parabolic collector are reflector surface, absorber (heating vessel), tracking mechanism and base frame. The reflector is a paraboloid shaped dish made up of 10 no.s of Anodized Aluminium sheets of 0.3 mm thickness. These sheets are supported by support structure made up of aluminium bars bent in parabolic shape. Support structure is the most critical part of the whole collector. To bend the aluminium bars in exact parabolic shape, a die was prepared and then they are bent in the roller.

Along the axis of the reflector heating vessel in the form of cylindrical vessel has been kept. The absorber is an Aluminium vessel of size φ 140 mm × 180 mm height. To prevent the re-radiation losses from the vessel surface, the vessel has been painted black from outer side. The black coating has a property of high absorptance for short wave radiation and low emittance in the long wave radiation range. This helps in reduction in re-radiation losses and hence improvement in the performance of the collector.

3. Experimental setup

The experimental setup consists of the parabolic collector, cylindrical vessel, RTD sensors with digital temperature indicator, pyranometer with shading ring and milli voltmeter. The fluid and cooking surface temperatures were measured using RTD sensors with digital temperature indicator. The intensity of beam radiation was measured using pyranometer with milli voltmeter. The photograph of the experimental setup is shown in Fig. 3. The experiments were carried out on this collector using Water and Castor Oil as working fluids.

Figure 3. Experimental setup

4. Results and discussion

The experiments were carried out with 2.8 kg of water and 2 kg castor oil placed in the vessel. To ascertain the performance of collector each experiment were performed six times. The readings were taken in the months of March & April, 2011between 10:00 am to 12:00 pm for water and 10:00 am to 2:00 pm for castor oil; when sufficient solar insolation is available and this period is most suitable for domestic cooking. The instantaneous efficiency is calculated as the ratio of the amount of heat collected by stagnant fluid in the vessel in duration of 20 minutes and average incident solar radiation in that period.

Water is the most common fluid used for most of the cooking purposes. The boiling temperature of water i.e. 100 ℃ is achieved within 20 minutes. After this water starts vaporizing and hence no further temperature rise is observed. Once the water reaches to 100 ℃, there is no further rise in the temperature hence the instantaneous efficiency becomes zero. The variation of water temperature, surface temperature of vessel, instantaneous collection efficiency and intensity of global radiation with change in time with water as a working fluid is shown in Fig. 4.

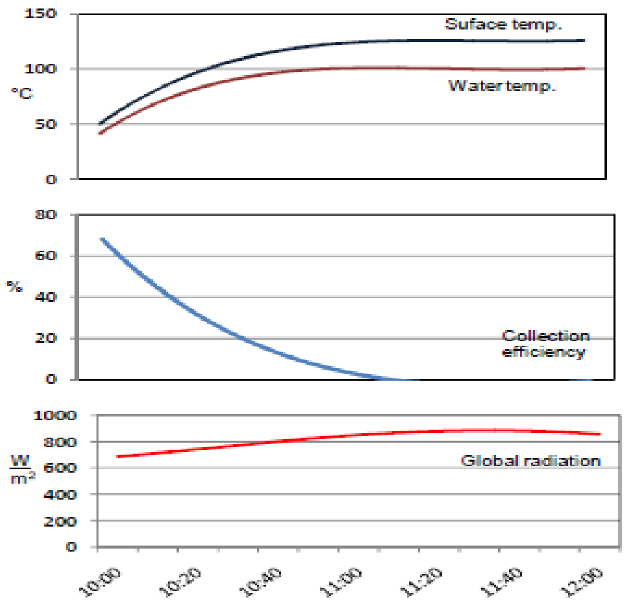

Figure 4. Variation of parameters with water as working fluid

To find the maximum achievable temperature in the collector, experiments were performed with Castor oil as the working fluid as its boiling point is about 320 ℃. 2 kg of castor oil was used. The maximum temperature achieved with castor oil as working fluid was found to be 216 ℃. Once the temperature becomes co nstant, the instantaneous efficiency becomes zero, as in case of water also. The variation of various parameters with castor oil as working fluid is shown in Fig. 5.

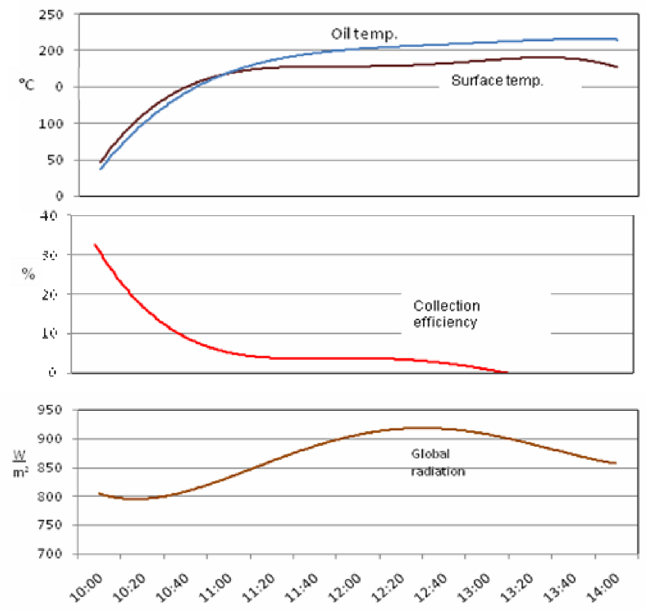

Figure 4. Variation of parameters with castor oil as working fluid

Uncertainty analysis of experimental data is carried out using Kline and McClintock method [7]. Considering error in measuring temperature = 0.1˚C, error in measuring time = 1 second, error in measuring intensity of global radiation = 7.5 W/m^2 uncertainty analysis was carried out and it was found that the results are subjected to 3 to 5% error.

5. Cost details

By providing a support structure, the number of sheets used is reduced to 10.eets are This saves the material as well the initial and maintenance cost of the reflector. Moreover, Anodized Aluminium sheets are available at comparatively lower costs than mirrors which are widely used now a day. The cost of reflective sheets accounts for almost 50% of the total cost of the collector. The experimental results showed that anodized aluminium proves equally effective. The cost details of the parabolic collector are given in Table 1.

Table 1. Cost details

S. N.	Name of Component	Cost (Rs.)
1	Anodized Aluminium Reflector Sheets	2316/- (47%)
2	Aluminium Bars for supporting structure	1600/- (33%)
3	Base frame	1000/- (20%)
Total		4916/-

6. Conclusion

The design, development and testing of Parabolic collector is presented. Anodized Aluminium sheets were used as reflecting surface in place of mirros which are most commonly used as reflecting surface. By providing the support from backside in the form of parabolic bars, the number of reflecting sheets is reduced and the reflector became sturdy. In this manner, the collector was prepared at much lower cost.

The experiments were carried out with 2.8 kg of water and 2 kg castor oil. It was found that, the water starts boiling within 20 minutes with maximum instantaneous efficiency of 71%. With castor oil as the working fluid, the maximum temperature of 216 ℃ is obtained with maximum instantaneous effic iency of 35%. From uncertainty analysis of experimental data it was found that results are subjected to 3 to 5% error. The present design may be cost-effective in the temperature range of 180 to 250 ℃. The results of present findings may be useful for the researchers working in the similar area.

7. Future Scope

Even higher temperature can be achieved if the fluid is made to flow. Moreover, Auto-Tracking Mechanism can be incorporated in the design to eliminate the need for manual tracking.

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