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Advances on The Flat Plate Collector Design Introduction To Solar Cavity Collector

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Abstract:

Some developments have to be investigated towards the improvements on the Flat Plate Collector (FPC) design so as to meet out the improved energy scenarios. It is mandatory to do such researches in order to improve the performance of the solar collectors' particularly on Flat plate collectors due to its simplified design and lesser maintenances. One such improvement on flat plates is the Solar Cavity Collector (SCC). A solar cavity collector with 5 numbers of cavities has been made initially, which has been fabricated with appropriate design and tested for its performance. The Experimental investigation was carried out for different kinds of working parameters of the cavity collector, namely by a. Changing the mode of flow i) Parallel type ii) Serpentine type. b. Changing the receiver materials as Aluminum and Copper. c. Angle of Inclination of whole set-up. d. Packed with Pebble bed and metal scraps to improve the heat transfer characteristics of SCC. The Experimental study was conducted under standard laboratory a condition that has been especially designed for this purpose. Usually the cavity type configuration is utilized for the Fresnel and concentrating type of solar collectors, but it has been experimented for a development and improvement of FPC design. It shows that the rate of heat exchange in the Parallel mode gives better results when compared to the Serpentine mode. Copper as the receiver material gives more efficiency than the Aluminum. Around 3% improvement in the energy transfer was achieved by the use of Pebbles.

Keywords: *Solar Energy, Cavity, Cavity Receiver, Solar Cavity collector, Pebble bed collector*

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I. INTRODUCTION

Solar energy has been a right candidate or a clean, abundant, inexhaustible, non-polluting, more effective and efficient renewable energy source. Incidental Solar energy can be transformed into thermal energy for various applications such as heating and production of hot water by using solar collectors. The necessities in the improvement of the flat plate collectors are needed and appreciable. It is however useful to point out that the multi reflection effect can be achieved through cavity which is called as the Cavity effect. Flores et al. (2008) reported that in the cubic cavity the radiative heat transfer plays a vital role than the convective heat transfer. They develop a mathematical model and parametric study was carried out from various solar control coating (SCC) absorptances. Influence of multi reflector effect through a macro cavity was presented by Demichelis and Russo. The optical design of the cavity and the cavity effect was determined by them for solar concentrating collectors. The optical performance of Non-isothermal flat plate solar collectors was presented by Torres-Reyes and Ibarra-Salazar. They reported the creation of thermo-economic model and determination of annual cost for solar air heater by means of Dimensionless parameter such as mass flow number. The thermodynamic optimization procedure was evaluated to determine the optimal performance parameters of an experimental solar cavity collector. Tom Melchior et al. (2008) explain about a cavity type receiver containing a tubular absorber model, developed and validated experimentally. The solar chemical reactor containing a tubular Ceramic absorber which utilizes thermo chemical process has the capability of high temperature applications such as the production of H_2. Bairi (2007) form a numerical 2D parallelogrammic cavity which explains about the several inclination angles (α) and heat exchange between active and passive walls with various Nusselt number correlations.

Hunt *et al*, (1986) have reported about solar radiant heating of gas-particle mixtures and they explained about new receiver concepts to substitute the conventional insulated cavity-receiver. Diver, (1987) has explained about the cavity-type configuration used for highly concentrated solar systems. They developed a cavity-receiver having a well-insulated enclosure with a small opening called the aperture through which the radiation entered in. McDonald, (1995) proposed a correlation based on experimental result from a cylindrical shaped frustum receiver, which included the effects of varying receiver aperture size, surface temperature and receiver angle. Reynolds *et al*, (2000) and Dey, (2004) have described about the aspects of design methodology and the heat transfer calculations for an elevated North-South oriented trapezoidal linear absorber, using finite element analysis to obtain the absorber temperature distribution, and optimized the spacing, sizing of the pipes and the absorber plate design.

A. Objectives

The objectives of this work may be stated into the following points:

- By conducting the performance test on cavity collector and finding out the instantaneous efficiencies.
- Testing the gadget and verifying the performance characteristics of various working parameters such as changing the mass flow rate of water, inclination angle, receiver material, packing with pebbles for heat transfer improvement, etc,.
- Comparisons to be made it with better solutions and finding out the optimal performance parameter.
- Analysis is made which parameter influences more to get better results.

B. Solar Cavity Collector - An Introduction

The better solution for the improvement of flat plate collectors are much more, among the better one is the cavity collector configuration. As in the case of conventional Flat plate collector, the absorber plate is used to receive the irradiative energy from the sun. Here, for this type it has been replaced by the receiver tube. We made an experimental investigation on solar cavity collector. The Parameters which are changed such as, material of the receiver, type of flow, change in inclination angle, packed with pebble bed and metal scrap chips was changed for the better results.Fig.1 and Fig.2 shows a detailed view of a single cavity tube and multi reflection process happens in a cavity tube respectively.

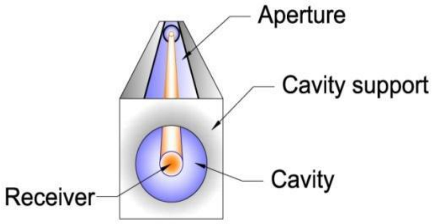

Fig. 1. Detailed view of a single cavity tube

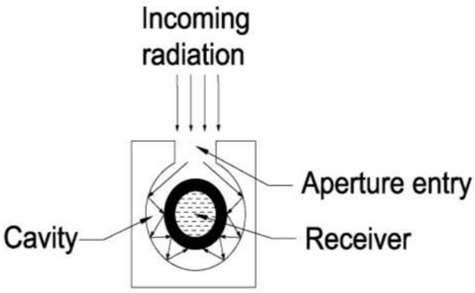

Fig. 2. Multi reflection process of a solar radiation in a solar cavity collector

II. EXPERIMENTAL ANALYSIS

This section describes the experimental setup and the parametric analysis of the solar cavity collector which includes the type of flow, varying the Length to Diameter ratio, change of the receiver material, various tilting positions and performance of collector packed with pebble bed and metal scraps.

A. Description of Experimental Set up

The solar cavity consists of a cylinder made-up of Copper with the radius of 16 mm and insulated with glass wool insulation on the underside. Five numbers of such cavities are placed in a rectangle metal box with equal distance. The tubular absorber coated with the black paint with an outer radius of 6.35mm was positioned concentrically with the cylindrical cavity. Table 1 explains the details of the collector. Fig.3 shows the experimental arrangement of the cavity collector with a cut sectional view at X-X. Fig 4 shows a schematic diagram of SCC. The transparent pipes in the cavities were connected in parallel and also serpentine type. A glass plate mounted on the top serves as a protective shield for spilled radiation and also it reduces the top heat loss from the collector to the surroundings. All the joints of the metal box were well sealed. The bottom end of the collector tube was connected to the fresh water tank. The setup was tilted at an angle of 11^o to the horizontal. Global radiation was measured with Pyranometer. Temperatures at different locations were measured by digital temperature indicator with the use of thermocouples. The ambient temperature was recorded using mercury thermometer.

B. Testing of Solar cavity collector

Thermocouples were located at different locations viz, at all cavities, glass plate, inlet and outlet pipes. The bottom and sides of the collector was properly insulated to reduce the heat losses. The collector was kept in open yard facing south and exposed to solar radiation. The experiments were conducted from 9.30 AM to 5 PM. Observations were made with a time interval of 10 minutes on different days with different mass flow rates of water. A performance investigation on the cavity collector was made. Various parameters were changed for its optimal performance. First the gadget was tested by 1. Changing the mode of flow viz, parallel and serpentine .That is, the receivers of the 5 numbers of the cavities were connected by parallel and serpentine type. 2. The material of the receivers were tested with aluminum and copper.3. The same set-up was packed with the pebble bed and metal scrap chips. The pebbles were packed with a. at the bottom surface b. at the top surface and sides. 4. Changing the tilt of the collector as 11^o, 15^o, 20^o, 25^o. The observations were made for every 10 minutes interval.

TABLE I. DETAILS OF THE COLLECTOR

Collector size	: 1 × 0.85 × 0.05m
Number of cavities	: 5
Area of each cavity	: 0.101 m2
Diameter of the tube	: 0.0127m
Thickness of glass plate	: 0.004m
Cavity absorber material	: copper
Collector insulation	: Glass wool
Absorber coating	: Industrial mat black paint

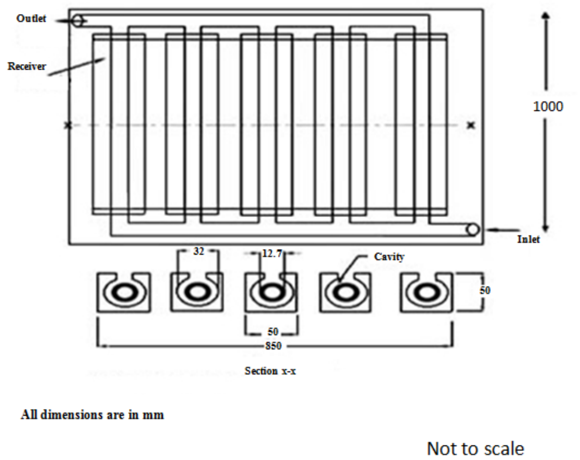

Fig. 3. Experimental Arrangement of a flat plate cavity collector

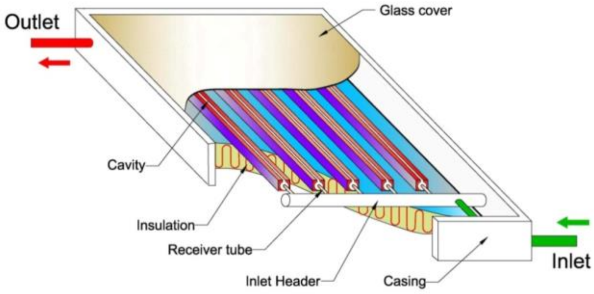

Fig. 4. Schematic diagram of a flat plate cavity collector

III. RESULTS AND DISCUSSION

Solar collectors usually can employ the cavity type configuration for highly concentrated solar applications. The cavity receiver has an advantage of multiple reflection of radiative energy inside the cavity itself. That-is proper design of the cavity makes the effective capture of solar radiation entering through a small opening, called aperture. The application of the cavity collector can be to heat either liquid or gas. Water has been used in this research work. For improving the heat transfer characteristics, cavity type collectors are the better choice, since it can be used during cloudy days where intermittent nature of the solar energy is inevitable. It gives the better results even if the solar radiation that has received is of intermittent type. Cavity type collectors are also well suited for the solar radiation of intermittent type. The radiative energy once absorbed by the air inside the cavity can withstand the temperature and distribute it to the surrounding working fluid either air or water. It is however useful to point out that the multi reflection effect is considered through the cavity and thus increases the heat holding capacity for a long time in the cavity. Fig.5 shows the Variation of Water outlet temperature and Efficiency with respect to mass flow rate of water of SCC. It is inferred that the temperature of water at outlet reaches around 70^{o}C in the cavity collector, when compared to the conventional flat plate collector where it was around 50 – 60^{o}C depending upon the configuration of the collector. In terms of efficiency also SCC works much better than FPC.

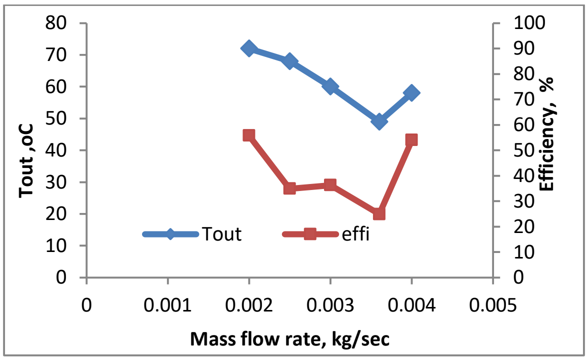

Fig. 5. Variation of Water outlet temperature and Efficiency with respect to mass flow rate of water

Fig.6 shows the Variation of water outlet temperature with respect to parallel and serpentine mode of flow .In both parallel and serpentine modes, 0.002 kg/sec was found to give better result. When compared to serpentine mode, the parallel mode gives better results with a minimum difference in temperature of 3^{o}C. Parallel mode attains a maximum water outlet temperature of 70 °C and in serpentine mode it was 65ºC at a flow rate of 0.002 kg/sec of water.

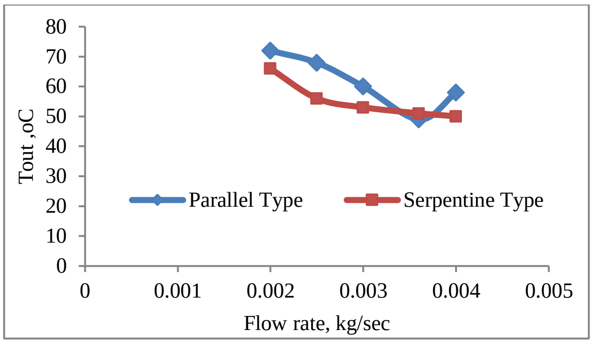

Fig. 6. Variation of water outlet temperature with respect to mode of flow

From Fig.7, it has been reviewed that the efficiency of the collector was also getting increased in the case of parallel type of flow whereas it was uniformly decreasing in serpentine type of flow. As per the experimental analysis, the parallel mode attains an average efficiency of 56% at the flow rates of 0.002 and 0.004 kg/sec. In serpentine mode it has attained a maximum of 27% and a minimum of 15%. Variation in efficiency in parallel mode could be happen due to various factors like time of the day, wind speed, Radiation variance, intermittent type of radiation available, etc.

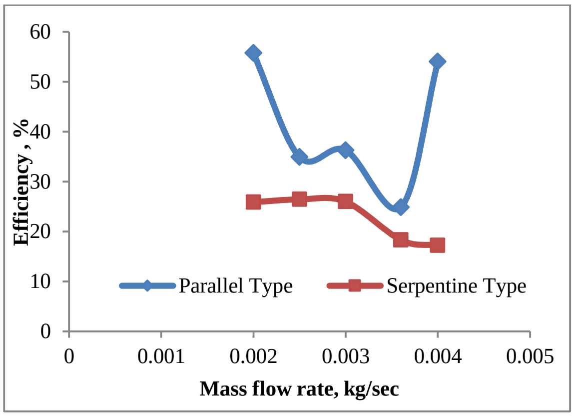

Fig. 7. Efficiency comparison for two modes of flow

From Fig.8, it is inferred that the receiver material of copper gives better results when compared to aluminum. The maximum outlet temperature of water about 68^{0}C was achieved when copper was used. It should be noted that when copper has been used as a receiver material there was no sudden decrease in temperature since copper withstands more amount of heat for a longer duration.

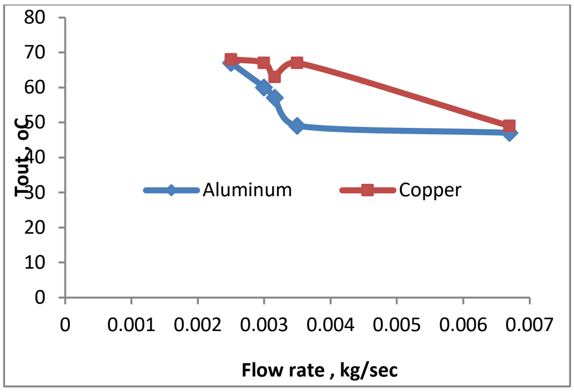

Fig. 8. Comparison of the receiver materials as Copper and Aluminum

Efficiency variation according to the Inclination angle has been shown in fig.9.In general; the base of the cavity collector was inclined at an angle α with respect to horizontal. In order to receive or accept maximum incoming light rays, the experiment was carried out to find out the better inclination angle which is applicable to the cavity collector. It can be reviewed by changing the angle of collector from 11^{o} to 25^{o}. From the experimental results, the inclination angle of 11^{o} and 20^{o} gives more efficiency (Average) of 60 % and 56 % respectively. We know that, generally the collector tilt angle of 11^{o} gives the maximum efficiency as in the case of FPC, but it was experimented for the cavity collector for its optimal performance. Hence it was found that the optimum level of tilt angle for cavity collector was 11^{o}.

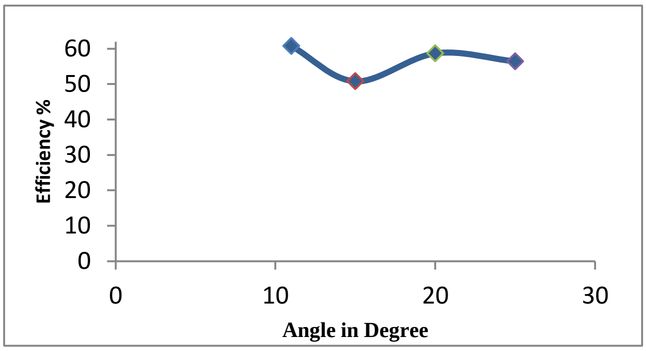

Fig. 9. Variation of Efficiency with respect to the Inclination angle

The inference from Fig.10 was, at lower and higher flow rates the efficiency of the cavity collector packed with pebble bed varies slightly. But the collector efficiency was more, at the flow rates ranging from 0.002 kg/sec to 0.0035 kg/sec. It should be noted that, the efficiency varies drastically as very high at these flow rates. That is, it varies with roughly as double the level. To enhance the heat transfer rate and heat holding capacity in the collector, the pebbles and metal chips were used. Pebbles were packed at the sides and bottom of the cavity collector gives better results when compared to pebbles packed at top of the collector.

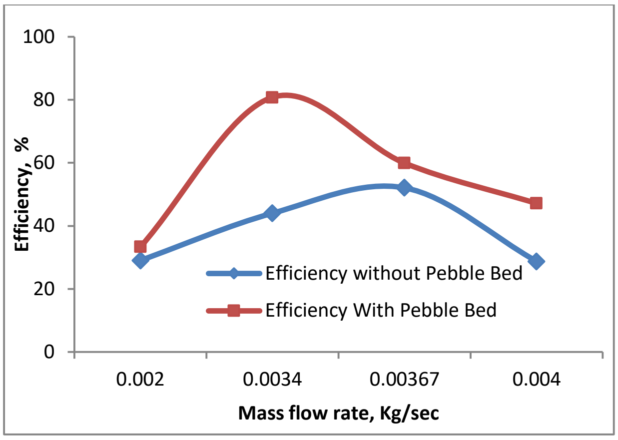

Fig. 10. Effect of Pebble bed on the performance of Cavity collector

Fig.11 shows the effect of pebbles on water outlet temperature of SCC packed with and without pebbles. The corresponding intensity of radiation are also been shown in the figure.SCC added with pebbles reaches a maximum temperature of about 72oC at 1:10 PM. A maximum water outlet temperature of about 69oC is obtained by the SCC without pebbles. Moreover the time taken to reach this temperature is also more. That is, a maximum temperature of 69o C is obtained at 1.40 PM only. Therefore the addition of pebbles in the SCC gives an improved performance; not only it has an effect in water outlet temperature but also it improves overall thermal efficiency of the collector.

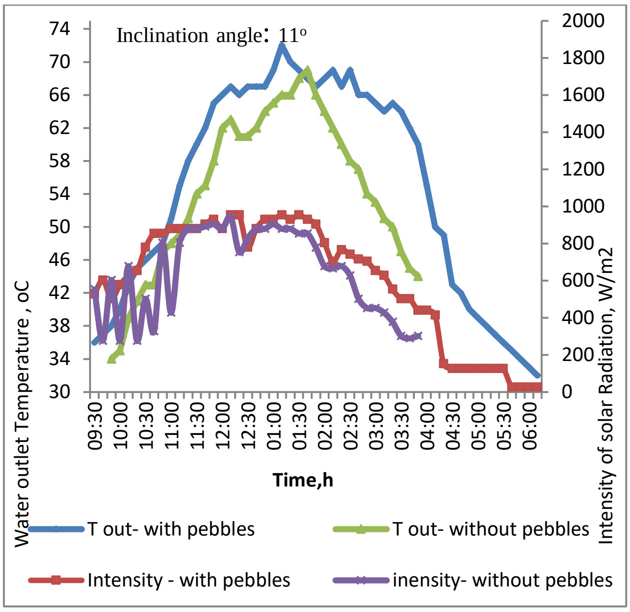

Fig. 11. Effect of pebbles on Outlet temperature of water

IV. SUMMARY AND CONCLUSIONS

Experiments were conducted to determine the optimal performance parameters for different mass flow rates. Cavity collector was designed, fabricated, and tested for its performance. Cavity collector was more efficient than the flat plate collector. To convert the flat plate collector into cavity collector the requirement was, least alteration in design and little bit of extra cost. The advantages of cavity collector over the conventional type, there was no sudden decrease in water outlet temperature even at cloudy days. It gives uninterrupted hot water supply at part cloudy days whatever be the desired level. It holds heat for a long time and also withstands more heat over a period of time. Cavity type configuration also gives better performance at late afternoon hours. It should be noted that, at this time the intensity of solar radiation was low. The heat holding capacity of the cavity receiver was improved about 3-12 % by the collector packed with pebble bed. Also the cavity collector works more efficiently when the pebbles were packed at top rather than packed with bottom and sides of the collector. The performance of the cavity collector goes on increasing trend by varying the working parameters which was analyzed earlier. The results show that the receiver material of copper gives better performance compared to aluminum. The flow mode of parallel type was more efficient (provided with common inlet and exit header) than the serpentine type. With the use of pebbles the heat transfer rate got increased by 3 %. But at the time of late afternoon hours, the SCC performs better due to the presence of pebbles. The overall efficiency was also improved with the pebble bed. By cavity type configuration, the water outlet temperature was increased by 2ºC to 10ºC with the use of pebble bed.

A. NOMENCLATURE

A_c Collection area, m^2

η Efficiency, %

α Inclination angle with respect to the horizontal axis , º

ṁ Mass flow rate, kg/sec

L Length of the collector, m

B Breadth of the collector, m

H Height of the collector, m

l Length of the single cavity, m

h Height of the single cavity, m

I_t Intensity of solar radiation, W/m^2

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