Influence of Cavity Materials and Selective Surface Coatings on the Performance of SCC

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Abstract

It is evident that the future energy demand can be compensated by using solar energy. The technological improvements are needed to trap the sunlight and have to be utilized in an efficient way. It mainly depends on the type of material which is to be used for this purpose. Solar energy can be effectively captured and utilized to heat the heat transfer fluids. Therefore the usage of solar energy is a right choice as it has the ample availability in countries like India. Solar cavity collector [SCC] is a kind of improvised, modified and redesigned construction of a solar Flat Plate Collector (FPC). In short, SCC is an upgraded and advanced version of FPC. A Copper pipe has been positioned concentrically fitted to a radius (outer) of 16 mm and placed into a metal box like structure having a size of 50 mm. In a similar way, five numbers of such cavities are formed. It has a provision for inlet and outlet water pipes. It has been designed, fabricated and experimented for its optimized level of performance. This paper explains about the usage of materials and solar selective surface coatings that are applicable to Solar Cavity Collector (SCC). The following experimental modifications are carried out in the SCC which are 1. Receiver materials of the SCC have been changed as aluminum and copper. 2. Cavity materials as Galvanized Iron (G.I) material and Mild Steel (M.S) material, both are experimented. 3. Solar selective coatings (SSC) of Black nickel have been used in SCC for the heat transfer improvement.

Keywords: Solar Energy, Cavity materials, Solar Cavity, Solar Selective coatings, cavity configuration.

Introduction

The Traditional usages of combustion of fossil fuels like wood, coal, Petroleum products, etc. have caused major air pollution in many areas globally and associated with lot of problems and diseases. The reason for this is because of the localized release of large amounts of harmful gases including carbon-di-oxide into the atmosphere. And finally it results in the phenomenon of global warming which is now a focused matter of a greater concern. Among the renewable energies, solar energy has been a right candidate for its clean, abundant available, inexhaustible, non-polluting, efficient and more effective renewable energy source.

Solar energy incidental radiation can be easily transformed into Heat or thermal energy for different kind of applications. Mainly it is used for heating and production of hot water by using solar gadgets. With the list of researchers, the cavity collecting methods are mostly used only the following type of collectors such as concentrating and Fresnel lens type collectors. Obviously, a flat plate collector has to be improved in order to works more efficiently. A typical experimentation is needed to
ensure the performance whether the cavity like structure can be utilized or not. After experimentations it came to know that, for optimizing the heat transfer characteristics cavity collectors has more impact than the other methods. One more advantage of SCC is that, inevitable kind of intermittent nature of solar radiations during at cloudy days also it works better when compared to Flat plate. The purpose of SCC which is implemented towards the modification on FPC leads to give better results even if it receives on the earth’s surface is in the form of intermittent type of solar radiation because of climatic changes may occurs on time of the day.

Melchior et al. (1) creates and explains a cubical absorbing surface which is fixed to a cavity model receiver of absorber surface. This model has come with some modified solar reactor and it has been developed and validated experimentally. A tubular Ceramic absorber is used inside the solar chemical reactor that utilizes thermo chemical process. Because of this, the ability to produce higher temperature in a shorter duration of time. This implies to produce a generation of H₂ and other power sources. Performance analysis of cavity model with a cone structure fixed to a model has been described by Hahm et al (2). A cone is created and fixed within the cavity receiver and the model has been generated with some boundary conditions. The following observations are listed down. A conical surface having a small aperture at exit state suffers more Consequently high return/ rejected solar radiations from top. Therefore, lesser the losses from the surface. Similarly, if the surface has a larger aperture then the thermal losses are potentially more. Demichelis and Russo (3) have studied the determination of multi reflector effect on the slope surface macro cavity, cylinder in shape. This paper focuses on the design part of fundamentals of optical losses in cavity and also it explains about the cavity effect. Accordingly, a setoff observation has been expelled and usages of macro cavity were determined for the usage of concentrating collectors. Reyes et al (4) was presented the optical performance of solar collectors with Non-isothermal of flat plate type collector specifically. The feasibility studies of the model and in such a manner the creation of thermo-economic analysis of the proposed model have been reported. Also the determination of annual cost for the operational procedure of solar air heater has been calculated by the means of dimensionless and non-dimensional parameters. Also it includes empirical correlations, mass flow number, thermo economic feasible correlations, etc.

Singh et al (5) has studied and enumerates the convection mode of heat transfer mechanism happenings in a cavity. Also this can be a complex function to control all the parameters such as aspect ratio, shapes of the cavities, conditions of the boundary walls if it incorporates in regular shaped cavities. Natural convection at the end of walls also affects the shape of cavities like square, rectangular and cylindrical shaped surfaces. They analyzed and tested in the above aspects and the results shows while reducing the convective heat transfer significantly, performance of CPC (Compound Parabolic Collector) collectors can be improved. Also, they reported with different correlations which include mass number, Nusselt number and flow patterns used for their research. Bairi (6) form a parallelogrammic 2 Dim cavity numerically with certain wall conditions. The study includes the heat transfer and optimal operating parameters for the designed cavity system. He applied the heat exchanging possibilities between active and passive walls and the same have been compared with various Nusselt number correlations and several inclination angles (α). The thermal, optical losses and how it affects the system of the dish type collection system has been reported by Prakash et al (7). They conduct a performance test for the inlet fluid temperatures range from 50°C to 75°C. They made another more test with various receiver inclinations of 0°, 30°, 45°, 60° and 90°. The results were compiled by using the Fluent CFD software. They reported that that the Convective loss increases with the mean receiver temperature and decreases with increase in receiver inclination angles respectively. Kribus et al (8) procured an experimental setup which uses two heating stages namely, lower temperature stages and high interactive temperature receiver stages which is termed as directly irradiated receiver. That is, a partial ring is introduced in the intermediate temperature zones and further it divides a cavity tubular receiver into two stages. These two stages has been applied and implemented for the improvement of generation of high temperature. Their end results comprise the reduced convective heat losses and also the partitioning losses were minimized.

Lakshmipathy and Sivaraman (9) has been investigated the various influencing and inducing parameters of SCC. Furthermore, they investigate among the different working parameters which one
guides more heat transfer than a flat plate SCC. Experimentations have been made with various lengths to diameter ratios (L/D) based on the commercially available pipe diameters. They concluded that the temperature of the water has an increase at exit if the ratio of L/D increases. While cavity area increases with the increase in diameter of the receiver decreases with the increase in L/D ratio and so on. Cruz et al (10) reported about the low cost passive water heater which can comprise the regulative and rejuvenate design, construction, and testing procedural activities. In their present study, they tested the model with a constant tilt angle of 45° especially designed for the climate in Portugal. Their conclusion explains about the energy saving largely depends on thermal stratification and model design aspects within the storage cavity. The experimentations with different inclination angle have been conducted by Lakshmipathy and Sivaraman (11) for the optimum performance of SCC. The results show that a maximum efficiency of 59% has been obtained with 11° inclination angle. At the same time the 20° inclination angle yields an efficiency of 56%. Also, they conclude that the preferable optimum level of inclination tilt angle for SCC is 11° with the test results. Flores et al. (12) had made the analysis of heat transfer with in the cavity body and surfaces of the collector. They strongly agree with the fact that the convective heat transfer does not play a vital role when compared to the radiative heat transfer that in a cubic cavity. The analysis is made compared with the developed mathematical model and carried out a parametric study with specific conditions for various solar control coating (SCC) absorptances. This study is to enlightening the heat transfer characteristics of the model with coatings. Garcia et al. (13) has studied about the thermal analysis of solar cavities provided and fitted with baffle spacing. They deliberately explain and reported the thermal energy distortion in baffle gaps. A cavity with baffles separated with some spacing provided has been fabricated and tested. Their results ensure that the specific dimensions of baffles spacing gives a better improvement on reduction of heat transfer considerably. Also the convection mode of heat transfer loss is much reduced in particular.

Section 1.01 Aim of the Proposed present Work

Some of the aim/ objectives and salient features of this work are explained and listed below

- The performance test on SCC has to be conducted and to find out the instantaneous efficiencies for each modification.
- SCC has to be tested by varying such important working parameters which includes, changing the cavity materials, changing the receiver materials and different watermass flow rates.
- Cavity collector has been experimented for Solar Selective (absorber) receiver coatings.
- Comparisons have to be made with the modifications done and getting better appropriate solutions and finally finding out the optimum performance parameter.
- Design changes if any have been made to do such that, the reflection an immense effect on the performance of SCC.
- Also the parametric analysis of SCC has to make to get the better results for which parameter will influences much more between them.

Solar Cavity Collection - An Introduction

This section explains about the cavity fundamentals and its operations.

The cavity structure or simply called as a cavity of the collector. Usually, it enhances the availability of heat present inside in SCC. Furthermore, the flat plate collector’s heat holding capacity increased considerably with the usage of cavity model of configuration. The net available heat energy inside the SCC decides the efficient capture of solar radiation and thus the increased level of total heat availability have been effectively transferred to the any kind of liquid often called as working fluid (water) that circulates in the receiver tubes. The available heat energy holds on cavity surfaces both
inside and outside ultimately increases the Thermal and overall efficiency of the system as well. Existence of cavity inside the SCC compels the collector more effective during the time of late afternoon hours. It occurs because of the radiation multiple reflection effect of the light energy enters and gets reflected within the cavity. The main limitations of the conventional FPC are that they don’t have the temperature stability throughout the time of the day. The fluctuations in outlet water temperature on part cloudy days might happen and whenever there is intermittent type of radiation is received. The heat fluctuations are compensated by the cavity structure itself to meet out the desired water outlet temperature. Therefore it ensures there is no sudden drop in the exit temperature of water by its virtue of operation. Cavity type configuration most often used in Fresnel lens collector and Concentrating type collectors. For experimentation purpose it has been tested for the flat plate configuration improvements.

Structure of a Specific view of a cavity (single) look like has been showed in Fig.1. It consists of three main parts which includes the receiver, cavity support structure and aperture. Receiver is a part that can transform the available solar radiation into heat energy. Cavity structure is used to withstand and holds the cavity. The aperture view on top is a small opening which allows the solar radiation rays inside to the cavity. Also it explains the location of the cavity and receiver tubes as well with the help of the figure. Fig.2 describes the solar radiation enters into the SCC and how the multi reflection is functioning inside the cavity. Based on the illustration, the heat is transferred to the receiver tubes through the cavity can be understood. Solar radiation admitted through the aperture, then gets deflected and reflected by the cavity. Again, and again it re radiates back to the receiver tube. The reflection has been continued and prolonged inside the cavity. Some part of it may escaped from the cavity and cavity top through the aperture opening. The receiver absorbed the reflected light rays which comes in and receives the heat energy by virtue of its position and thus it heats up the operating substance like water.

Section 1.02 Details of Experimental Set up And Testing Method

The SCC experimental setup consists of cylinder made up structure termed as a cavity. It is made up of the Aluminium and copper material. It has a 16 mm of radius with black painting coated and insulation made with glass wool material on bottom and sides of the collector setup. This comprises a single cavity and similarly the same procedure is followed for constructing five numbers of cavities. It has been put down in a square metal enclosure with identical distances. A tubular receiver cum absorber of radius 6.35mm is located in concentric all manners. The same is coated with the black paint as shown in the Fig.3. It manifests the photographic view of the cavity collector. Fig.4 illustrates the experimental arrangement of SCC with all dimensions. In order to set out as safeguarding shield for radiation, a single glass cover is fixed at the top surface. Also it reduces the top loss of heat from the collector to the surroundings. The top outlet tube is connected with a pipe having provisions for collecting the water and the bottom end is connected to the fresh water tank. The entire experimental setup is tilted to an inclination angle of 11° with respect to horizontal.

The instrument called Pyranometer is used to measure the global radiation at the location of Annamalai nagar and its Latitude is 11°N. Ambient temperature is recorded with a mercury
thermometer has a precision of 0.1°C. Temperatures at different locations of cavity collector such as all cavities, glass plate, receivers, etc have been measured by thermocouples which are connected to a digital temperature indicator. Temperatures at different locations on SCC such as all cavities, glass plate, inlet and outlet pipes have been fixed with thermocouples. Thermocouples of Copper – constantan type are used for this purpose. The collector has been properly insulated at besides and bottom sides to reduce the heat losses escapes from the collector. SCC is kept in open yard facing south and exposed to sun with maximum possible solar radiations has to fall. Experiments are conducted on the time of the days from 9.30 AM to 5 PM. Observations have been made with a time interval of 10 minutes on different days with different mass flow rates of water. Performance investigations on the SCC have been made in order to optimizing the operating parameters. The parameters which have been carried out such as receiver materials of the SCC have been changed as aluminum and copper. 2. Cavity materials of both Galvanized iron (G.I) material and mild steel (M.S) plates are experimented to get better results. 3. Solar selective coatings (SSC) of black nickel have been used in SCC for the heat transfer improvement. The constructional details of SCC have been shown in Table 1. It enumerates the inner details of SCC in detail. Similarly, Fig.5 illustrates the Schematic sketch of a cavity collector.

Table 1 - Constructional details of SCC

| Parameter                      | Details          |
|--------------------------------|------------------|
| Area of each cavity           | 0.101 m²         |
| Collector size                | 1.25 × 0.85 × 0.05 m |
| Diameter of the tube          | 0.0127m          |
| Number of cavities            | 5                |
| Receiver material             | copper           |
| Receiver coatings             | Industrial mat black paint |
| Thickness of glass plate      | 0.004m           |
| Collector insulation          | Glass wool       |

Fig.3 Photographic view of SCC
Results and Discussion

An attempt to a new design and development towards Flat plate collector, SCC has been established and conducted experiments for different kind of working parameters with their end results are listed down.

For highly concentrated solar applications like solar power plant operation, conversion of water into steam, etc, normally can employ the cavity type arrangements and often equipped with any one type of concentrating collectors. The cavity receiver has enormous advantage over FPC as it has the radiative energy gets magnified using multiple reflection of inner surface of the cavity certainly. Especially a proper design of the cavity relatively increases effective capture of sun light enters in it. The air filled inside the cavity can absorbs the radiative heat; consequently it withstands the temperature inside and dispenses the heat to the surrounding operating fluid. Fig. 6 illustrates mass flow versus Water outlet temperature for both receiver materials copper and Aluminium. Also it is inferred that the usage of receiver materials especially copper works more efficiently than the aluminum. Maximum water outlet temperature of 68°C has been obtained when copper material used.
It should be noted if copper being used as a receiver material, obviously there was no sudden decrease in temperature due to its capability of retains heat.

Fig.6. Differentiation of receiver materials being used

![Graph showing temperature vs flow rate]

It is important to notify that the cavity case cover materials have a greater footprint on the performance of SCC. Performance curves for both G.I and M.S have been tested in SCC are shown in Fig. 7. Throughout the examination, a fixed water flow rate of 0.0025 kg/s has been kept constant for both the cases. Also from figure, the gradual efficiency increase can be observed by using G.I material with respect to time. But radical variations appear in efficiency curve of M.S during the investigation. Also efficiency of 43% of maximum has been derived while the other has a efficiency of 47%. It has been observed that with the use of G.I, up to 130 PM there is a constant increase in efficiency and after that it starts gradually decreasing trend. Therefore from the experimentation it came to know the better cavity case cover material is G.I.

Fig.7. Comparison of efficiency with different cavity case covers materials

Fig.8. shows the outcome result of SSC on the water outlet temperature of SCC. It enumerates a typical curve of mass flow rate versus water outlet temperature for both with and without SSC coatings. For both the cases a constant decreasing trend of the curve, followed with respect to the mass flow rate of water. Also it is inferred from Fig.8 that the observation of maximum temperature of 74°C has been obtained with the usage of SSC coatings for water mass flow at 0.002 Kg/s. While on the other hand, 70°C of maximum temperature has been recorded without coatings.
The variation of efficiencies with respect to the SSC coatings has been illustrated in the Fig. 9. The efficiency curve goes on increasing trend for with SSC when compared to without SSC. That is, the differences in efficiency curve for both cases are visible with some constant values. Average efficiency of 59.21% has been achieved by the collector for the case of SCC with SSC coatings made. Moreover the trends followed by the SCC with SSC coatings are far better than that of without SSC coatings. Even though at the same time, all five numbers of cavities are exposed to sun, there are some variations in the difference in temperatures of both curves. The variations is not constant because of different parameters such as, slight pressure variation of the operating fluid and the restriction of flow inside on the receivers, flow pattern of air and water in and outside of the collector also influences the variation in temperatures. Moreover it mainly depends on the shadow effect of the cavities inside the SCC.

Summary and Conclusion

The main objective is, to enlarge a novel, more efficient, better conversion of radiation energy into heat and higher heat grasping capacity like configuration. Apparently one solution is a Cavity type collector or receiver methods used to trap the sunlight effectively. Moreover, conventional flat plate collector performs lesser efficient than the concentrating type collectors. But the problems associated with concentrating collectors are more costly and needs complicated tracking mechanism too. Therefore the solution made from both type of collectors is a cavity collector which has a numerous advantages of both flat plate and concentrating type collectors. Cavities like configurations are often
used in concentrating type collectors as many researchers done their experimentations. But it has been strongly recommended for the development of FPC is a cavity collector. There is a significant improvement on the performance parameters on both efficiency and water outlet temperature. The need in changing an FPC into SCC, a least alteration is required and the conversion cost also too low. Investigations work has a center of attention to increase efficiency and should be on more effective collection methods. SCC works more efficiently during a certain period of time if there is no sunlight. Also it is best suited for cloudy and part cloudy days which in turn during the cloud interruptions are inevitable. Furthermore its efficiency has not dropped suddenly during afternoon hours as in the case of FPC.

Obviously the copper receiver gives better performance when compared to the aluminum material. Also with the heat transfer aspects it looks good enough. Experimentation end results clearly shows that the G.I has more potential than that of M.S as a cavity cover case material. Since the G.I sheets won’t allow the heat from the cavity structure as it has the capability to retains the heat energy more when compared to Mild steel sheets. The usage of SSC coatings especially black nickel has a consequential effect on the experimentation of SCC. It increases not only the water outlet temperature but also improve efficiency of the whole system with a reasonable increase in cost.

**Nomenclature**

| Symbol | Description                  | Unit   |
|--------|------------------------------|--------|
| A<sub>c</sub> | Area of the Collector | m<sup>2</sup> |
| Dim   | Dimensional                  |        |
| I<sub>s</sub> | Intensity of solar radiation | W/m<sup>2</sup> |
| η     | Efficiency, in %            |        |
| m     | Mass flow rate of water, in kg/s |        |
| H     | Height of the collector, in m |        |
| α     | Collector Inclination angle with respect to the horizontal axis, in ° |        |
| L     | Length of the collector, in m |        |
| h     | Height of the single cavity, in m |        |
| SCC   | Solar Cavity Collector      |        |
| T<sub>out</sub> | Water outlet temperature, in °C |        |
| B     | Breadth of the collector, in m |        |
| SSC   | Solar Selective Coatings    |        |
| l     | Length of the single cavity, in m |        |

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