Effect Of Length To Diameter Ratio (L/D Ratio) On The Performance Of Flat Plate Solar Cavity Collector

Dr. Lakshmipathy. B, Dr. Kajavali. A, Dr. Krishnan. S, Dr. Senthil kumar.M

ABSTRACT: The utilization of solar energy has been used over a long period of time. The applications like air heating and water heating are the main usage of solar energy and it is globally accepted and still utilizing in many countries. Still various types of research work were in under progress through worldwide to improve the solar gadgets to work more efficiently. It has been evident that every solar gadgets need a little bit of improvement in order to perform well. The better solution for the improvement of flat plate collector is the **cavity collector**. The experimental analysis of a solar cavity collector has been presented in this research paper. It has proposed to conduct an experimental analysis on solar cavity collector to determine its optimal efficiency under various conditions. A parametric analysis is carried out to find the optimal performance and effective utilization of the solar energy. Various lengths to diameter ratios have been tried viz., 40, 50 and 78.74. The gadget has been tested by changing the mode of flow as parallel and serpentine type with L/D ratios of 50 and 78.74. Comparisons have been made for its optimal performance with circular and rectangular type cavity cover. The formation of eddies at the corner of rectangular casing (cavity cover) withstands or prevents some additional heat losses, thus it should be entertained and thereby the heat losses can be reduced to some extent. As in the case of circular cavities, the heat losses were more because of its simple in construction and thereby no prevention of heat losses. But in the rectangular cavities, there was a possibility to hold up the heat in the corners of the cavity and thus the losses of heat were prevented. Heat can be again reradiated back into the cavities in the form of light. Also the collector was tested with 5 and 7 number of cavities for the same L/D ratio of 78.7. It was tested at various mass flow rate of water such as 0.002, 0.0025, 0.003, 0.0035, 0.0047, 0.0067 kg/sec to investigate its optimal performance. Experimental results show that L/D ratio of 50 gives better results than the others.

Keywords: Solar, Cavity, Cavity collector, Receiver, L/D ratio, Rectangular cavity, Circular cavity

1. INTRODUCTION

Although solar radiation is a high-quality energy resource due to the high temperature and exergy of its source, the low flux density at the Earth's surface makes it unable to extract work or heat. By transferring the heat to a Heat Transfer Fluid (HTF) for heating applications and thus achieve temperatures adequate for general home or industrial applications. The utilization of the solar energy in an effective way plays a vital role to increase the efficiency of the collector and also to reduce the initial and operating costs. Research work was going on to optimize the solar collectors in all possible ways. Cavity collector is an improved version of the flat plate collector. Solar energy is utilized in the collector are generally grouped into two ways for air heating and Water heating applications. The application of the Cavity collector is used to heat the water. Everyone seems to increase the operating temperature of a flat plate collector more and more, one of the methods to achieve this phenomenon is a cavity type configuration. The necessities in the improvement of the flat plate collectors are needed and more 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". As in the case of 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. Flores et al. (1) 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 (2). 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 (3). 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. (4) 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 (5) 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. Hahm et al (6) this paper focuses on the performance of a cone in conjunction with a cavity-receiver. A cone with a small exit aperture suffers from a high amount of rejected rays. A larger aperture on the other hand increases the thermal losses of the cavity. Harjit Singh et al, (7) reported that, natural convective heat transfer in cavities is a complex function of cavity shape, aspect ratio, boundary conditions at the walls natural convection in regular shaped cavities, such as those of rectangular, square, and cylindrical section were analyzed and results show by reducing convective heat transfer considerably, improving the performance of CPC solar collectors also various correlations including Nusselt number have been used. Prakash et al (8) reported that the thermal as well as optical losses affect the performance of a solar parabolic

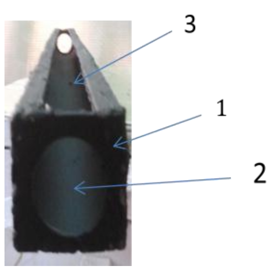
- *Dr. Lakshmipathy. B, Dr. Kajavali. A, Dr. Krishnan. S, Dr. Senthil kumar.M*
- *Corresponding Author - Assistant Professor, Department of Mechanical Engineering, Annamalai University, Annamalainagar – 608 002 - INDIA,*
- *Assistant Professors, Department of Mechanical Engineering, Annamalai University, Annamalainagar – 608 002 - INDIA*
- *Email: blakshmipathy10@yahoo.com*

dish-cavity receiver system. The experiments were conducted for fluid inlet temperatures between 50°C and 75°C and for receiver inclination angles of 0°, 30°, 45°, 60° and 90° using the Fluent CFD software. It was found that the Convective loss increases with mean receiver temperature and decreases with increase in receiver inclination. Kribus et al (9) done the experiment by using two heating stages which was 1.high-temperature receiver stage is the Directly Irradiated Annular Pressurized Receiver (DIAPR).and 2.low-temperature stage is implemented as a partial ring of intermediate-temperature cavity tubular receivers which was done by dividing the aperture into two stages. Results show convective heat losses were reduced and minimizing the partitioning losses. Jose M.S. Cruz et al (10) this paper reviews about the design, construction, and testing of a simple, Low-cost passive water heater for the climate in Portugal. They reported the energy saving largely depends on thermal stratification within the storage cavity. A constant tilt angle of 45° was actually employed in their present study

1.1 OBJECTIVES

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

1. Conducting the performance test on cavity collector and finding out the instantaneous efficiencies.
2. Testing the gadget by various working parameters such as changing the mass flow rate of water, mode of flow and various L/D ratios, etc,.
3. Comparing it with better solutions and finding out the optimal performance parameter.
4. Analysis is also made for which parameter will influences more to get the better results.



1-Cavity support, 2-Cavity, 3-Aperture opening for incoming radiation

***Fig.1.** Detailed view of a single cavity tube*

2. SOLAR CAVITY CONFIGURATION

The cavity structure of the collector enhances the heat availability within the flat plate collector. In other words, the heat holding capacity of the flat plate collector was increased by the use of cavity configuration. Increase in heat availability was effectively utilized to heat the working fluid (water) which flows inside the receiver tube and ultimately increases the efficiency of the collector system. The presence of cavity also makes the solar collector more effective during late afternoon hours due to multiple reflection effect of the light energy within the cavity. The problems behind in the conventional flat plate collectors are they don't have the temperature stability. That is fluctuations occur in exit temperature of water during part cloudy days. Cavity type receivers are stable even at cloudy or part cloudy days. The heat fluctuations are compensated by the cavity itself to meet the required outlet temperature of water. So that, it ensures that there was no sudden drop in the exit temperature of water. Usually the cavity type configuration was applied to Fresnel lens collector and Concentrating type collectors but it was tried for the flat plate configuration. For better performance of the cavity collector the experiment was conducted with various L/D ratios.

2.1 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. The diagram (Fig. 2.1 and 2.2) shows the experimental arrangement of the cavity collector. The transparent pipes in the cavities were connected in parallel and also serpentine type. A single glass cover plate was used and it was 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° to the horizontal. Global radiation was measured with Pyranometer at the location of Annamalai nagar and it's Latitude of 11°N Temperatures at different locations were measured by digital temperature indicator with the use of thermocouples. The ambient temperature was recorded using mercury thermometer with a precision of 0.1°C. Thermocouples (Copper – constantan type) 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. For optimizing the working parameters various experimental work have been carried out such as a) L/D ratio of 78.7 was tested for both serpentine and parallel modes, b) Testing was carried out with L/D ratio of 40, 50, 78.7, c) Rectangular and circular box covers (outside of the cavity) of same L/D ratio of 78.7 were tested, d) Number of cavities was also been tested with 5 and 7 for L/D ratio of 78.7.

Table -1 *CONSTRUCTIONAL DETAILS OF THE COLLECTOR*

Collector size : 1 × 0.85 × 0.05m	Thickness of glass plate : 0.004m
Cavity absorber material : copper	Collector insulation : Glass wool
Absorber coating :Industrial mat black paint	Number of cavities : 5
Area of each cavity : 0.101 m^2	Diameter of the tube : 0.0127m

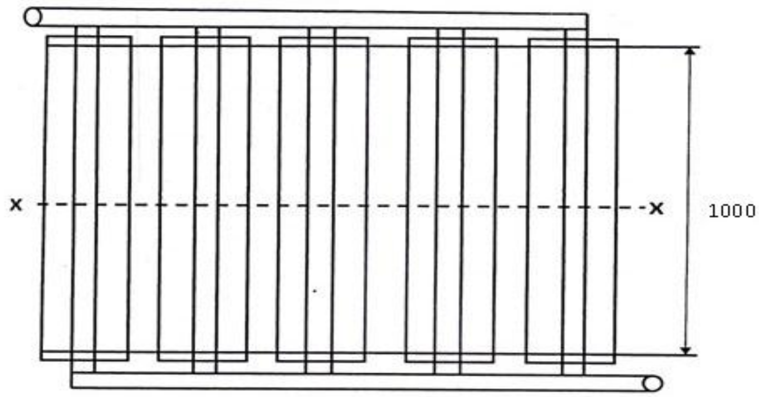


Fig. 2.1 Flat Plate Cavity collector

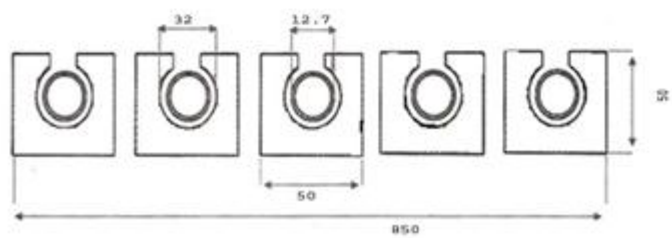


Fig. 2.2 section from x – x

ALL DIMENSIONS ARE IN MM

Fig 2.1 & 2.2 Dimensional Details of Solar Cavity Collector

3. 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. 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 particularly inside the cavity.

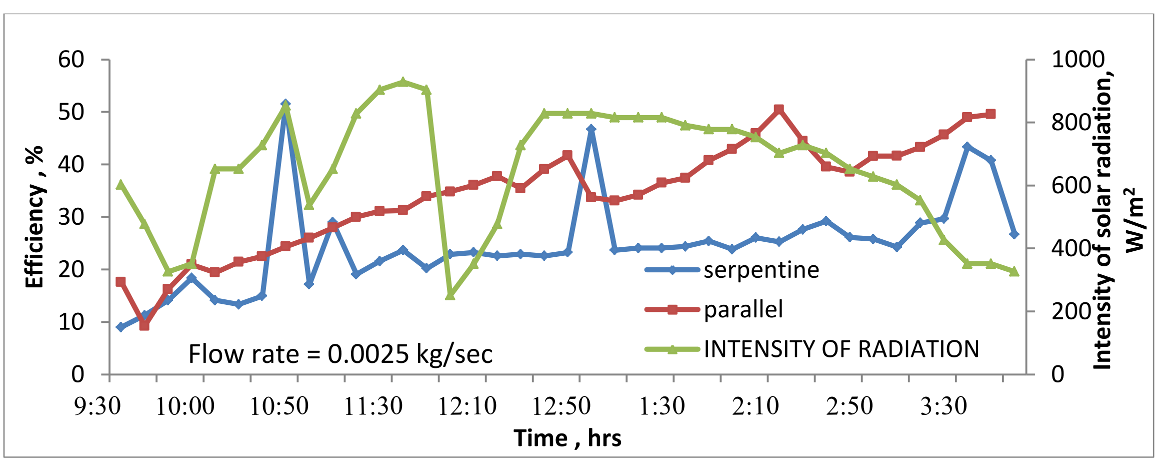


Fig.3 *Variation of efficiencies with respect to the mode of flow*

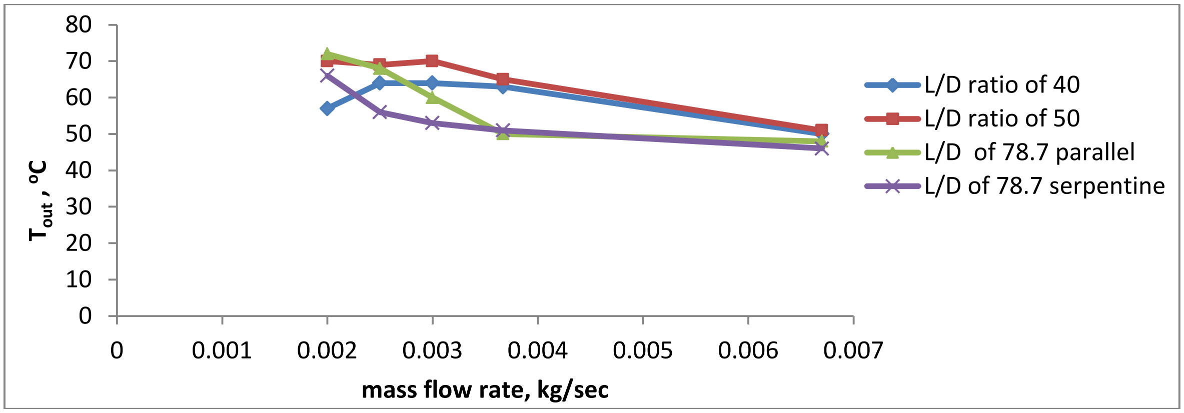


Fig.4 *Effect of L/D ratio on water outlet temperature*

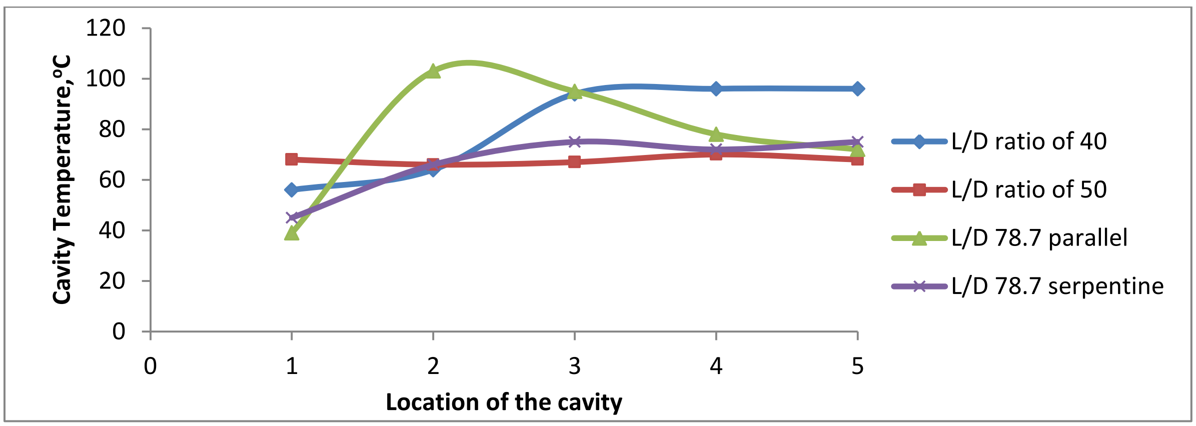


Fig.5 *Temperature distribution along with the location of cavities*

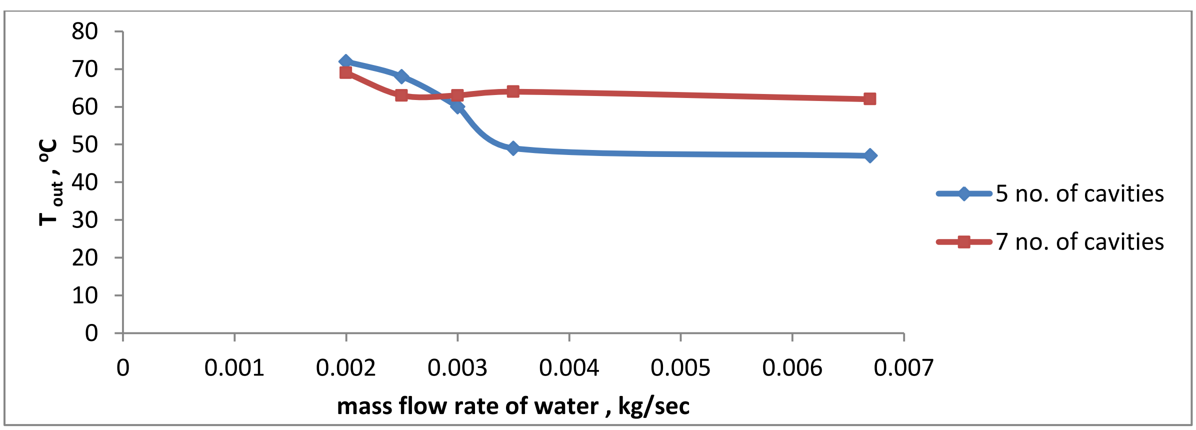


Fig.6 *Variation of water outlet temperature with number of cavities being used*

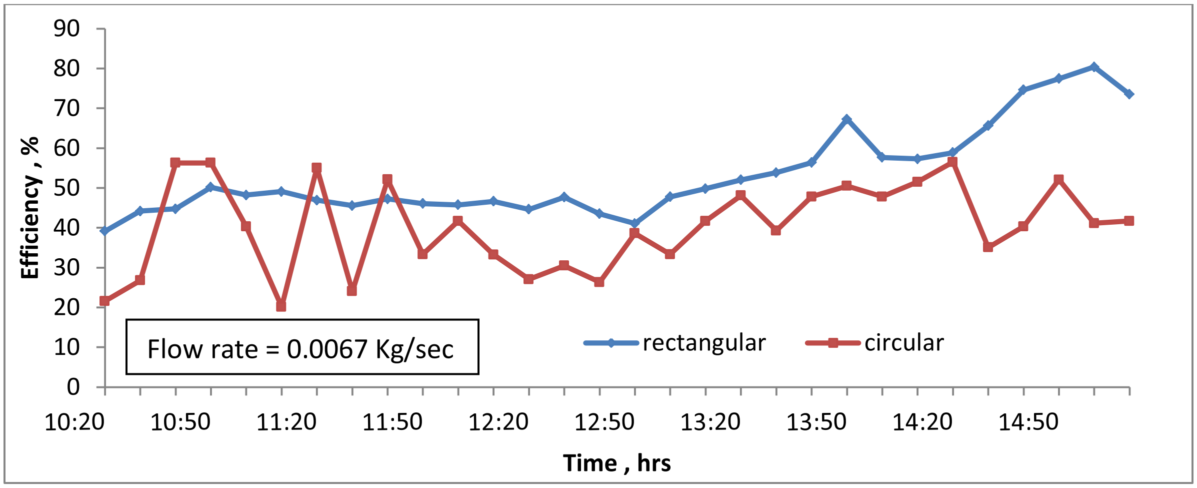


Fig.7. *Efficiency comparison for rectangular and circular cavities*

With reference to fig.3 the instantaneous efficiency of the collector was high in the case of parallel mode. Also there were no sudden ups and downs on efficiency graph when comparing to serpentine mode. Comparison was made between the efficiency curves of parallel & serpentine modes of flow shows that, the variation in efficiency curve at the instant was more in parallel mode and also the type of curve was far better than the serpentine type. The fact that if the intensity of solar radiation was low after 12 noon or 1 pm, the efficiency of the flat plate collector would decreases immediately. But using the cavity type configuration, it was evident (from figure-3) that the efficiency of the cavity collector was of increasing trend at afternoon hours. It should be noted that there was no sudden drop in efficiency; as the cavity collector has the ability to withstand heat for a long time. From Fig.4 it is inferred that L/D ratio of 50 gives better result rather than L/D ratio of 40 & 78.7 and also around 72^{o}C exit temperature of water (maximum) was achieved by the collector. The variation ranges for all L/D ratios were small. As it known very well about if mass flow rate of water increases the outlet temperature of water will decreases, but how much variation in outlet temperature of water would increases or decreases that would decide by the influence of L/D ratio only. At first, cavity collector was experimented with both parallel and serpentine mode of flows for L/D ratio of 78.7. From the experimental results, parallel mode flow mode was more efficient than the serpentine type. At lower flow rate say 0.002 kg/sec it show that L/D ratio of 78.7 parallel mode was good enough but the L/D ratio of 50 seems to be a better one for all mass flow rates of water and outlet temperature of water 70^{o}C(maximum) was achieved at a mass flow rate of 0.002 kg/sec. As a comparison between parallel and serpentine mode of L/D ratio of 78.7, the parallel mode of flow of water was more efficient and the curve for serpentine mode was gradually decreasing in trend. Fig.5 clearly shows that the cavity number 1 reads a lower temperature for all the cases. It should be noted that there was no drastic changes in temperature of the individual cavities for L/D ratio of 50. Moreover cavity number 3, 4 and 5 reaches the maximum temperatures for all the cases except L/D ratio of 78.7 parallel types. Even though all five numbers of cavities were exposed to solar radiation at the same time, there were some variations in the cavity temperatures; which means the temperature measured or recorded by cavity number 1 will not match with temperature of cavity number 2 and so on. It may happen because of slight variation in pressure of the working fluid and the restriction of flow inside the receivers, flow pattern of air and water in the collector also influences the variation in cavity temperatures. The inference from Fig.6 was, the collector works in a more efficient way when the number of cavities was increased. For the same mass flow rate, L/D ratio of 78.7 and numbers of cavities 5 reaches a temperature of 72^{o}C (maximum) whereas on the other hand for 7 numbers of cavities it was 70^{o}C. At higher mass flow rates (that is 0.003 kg /sec onwards), collector fitted with 7 number of cavities records higher temperature rather than the other. By increasing the number of cavities of the cavity collector was worth full and also it results in a better performance and the heat holding capacity of the collector was improved. Fig.4 and 6 clearly shows that the temperature of water at outlet reaches around 70^{o}C in the cavity collector, when compared to the conventional flat plate where in it was around 50 – 60^{o}C depending upon the configuration of the collector. 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 1-2^{o}C. Increase in number of cavities as 7 (refer fig.6) helps to hold the heat for a long time and the curve shows that water flow rate from 0.003 to 0.007 kg/sec, deviation on the curve was more when comparing to 5 number of cavities. In other words, water mass flow rate of 0.003 kg/sec and thereafter, the influence of increasing number of cavities will resulting in outlet temperature of water remains more stable and no more fluctuations in water outlet temperature. Comparison was made between two kinds of cavities namely rectangular and circular. Referring from fig.7, efficiency curve of rectangular cavities was increasing trend even at afternoon hours. It should be noted that fluctuations was more in circular cavities and on the other hand, curve for rectangular cavities was more stable.

4. SUMMARY AND CONCLUSION

The objective was to develop a new, more efficient and high heat holding capacity type configuration. Thus the solution was a Cavity type collector or receiver. Moreover the conventional flat plate collector does not give more efficient and on the other hand, concentrating type configuration requires tracking mechanism and more costly too. Thus it's simple to construct a cavity type configuration which has numerous advantages of both flat plate and concentrating type collectors. The cavity is a small air gap provided circumferentially concentrated around the receiver tube. Many papers were investigated about the cavity type configuration for the application of concentrating type collectors, but now it was tried on the flat plate collector. It shows that there was a significant improvement in collector efficiency and also water outlet temperature. Proper design would increase the performance of the cavity collector better and better. Experimental work has been focused on to increase the efficiency and effectiveness of the collector. It was found from the experiment, as the L/D ratio increases the efficiency was increases and the temperature of working fluid (water) at outlet was also increases. Efficiency of the cavity collector was better than that of the conventional flat plate collector. It also works more efficiently even there was no radiation source for a certain period of time and at part cloudy days. More over it gives better performance at late afternoon hours. The efficiency of the collector was not suddenly dropped the afternoon hours. Both parallel and serpentine mode of flow for L/D ratio of 78.7 was tested, parallel mode gives better performance than the other. Various L/D ratios were experimented viz, 40, 50, 78.7. Results show that optimum L/D ratio among them was found to be 50. Around 70 ^{o}C of water outlet temperature was recorded by the use of L/D ratio of 50. L/D ratio of 78.7 parallel mode of flow also achieves the same temperature but for higher mass flow rates of water it decreases. When comparing to other L/D ratios, curve for L/D ratio of 50 moves on increasing trend with respect to the mass flow rate of water. For all L/D ratios cavity number 5 records maximum temperature, and similarly cavity number 1 records the minimum temperature. It was observed from the experimental results, L/D ratio of 78.7 was preferable for only lower mass flow rates; but L/D ratio of 50 was a most suitable one irrespective of the mass flow rate of water. There was a reasonable improvement was found that by increasing the number of cavities as 7. In other words, performance of the cavity collector was better, if the number of cavities was increased to 7. It was observed from the experimental data, efficiency of the cavity collector was better if rectangular cavities have been used instead of circular cavities. Also it was concluded that the rectangular cavities has the capability to withstand more heat inside the collector. It will act as a shield within the collector in such a way heat losses was considerably reduced by not allowing the heat from individual cavity to the collector setup. That is, holding more amount of heat inside the cavity so that multi reflection effect of radiation would be more within the cavity itself.

NOMENCLATURE

η	Efficiency, %
α	Inclination angle with respect to the horizontal axis, ^{o}
$\dot{m}$	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
A_c	Collection area, m^2

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