Abstract—Due to ever increasing need of energy and dependence on fossil fuel to meet energy requirement, a lot of efforts is being put on new renewable and alternative technologies to meet this requirement. This paper presents one such effort to investigate the potential of convex lens to be used for water heating application. In this paper, a Convex lens CSP prototype is design and manufactured using six Convex lens of dia. 10 cms (4 inches) each. The panel is a Rectangular box of size 14.5cms x 21cms x 70cms made of plywood of 8 mm thickness. The receiver is a copper tube of 6.25mm (1/4th inch) and 1 mm thickness and is placed at the focal point of the lens panel. The two axis manual tracking system with north-south axis orientation is used to continuous track the sun. The concentration ratio obtain is 400 and the maximum focal temperature obtained is 195°C. Testing of the prototype is done with different mass flow rates and the results obtained are discussed. The collector efficiency of the prototype is found to remain almost constant as 68% for the different mass flow rates and the maximum temperature of the water is found to be 67°C. The paper also shows the proposed Convex lens CSP panel prototype was found to be more efficient than conventional panels.

Keywords—Convex lens, Concentrating Solar Power (CSP), Collector efficiency, CSP Panel, Sun Tracking

I. INTRODUCTION

Due to ever increasing need of energy requirement and limited reserves of available resources, there is a much dependence on fossil fuels for the fulfilment of the energy needs. This gives a wide scope and motivation to find the new methods of renewable and alternative methods of energy. The solar energy is found to be one of the most abundant and freely available source of energy today. The solar conversion technologies are be classified as Solar Photovoltaic and Solar Thermal technologies. The Solar Photovoltaic Technologies made the use of the use of Solar Cells which works on photo-electric effect. In Solar Photovoltaic, the incident solar energy is directly converted into electricity by solar PV panels. The cost of solar photovoltaic panels along with their low conversion efficiencies is one of the barrier involved with solar photovoltaic which results in high cost of solar pv electricity.

On the other hand, the solar thermal technologies involve focusing of solar radiations for the direct conversion of incident solar energy into some useful form of thermal energy. It involves the use of special surfaces which captures the falling solar energy and converts it into some useful thermal energy. It includes Non-Concentrating Solar Conversion such as Flat Plate Collectors and Concentrating Solar Conversion also called as Concentrating Solar Power (CSP). The Non-concentrating collector requires more space and involves the limitation of dilution of solar energy and hence limited to water heating applications only. In CSP, the incident solar radiations are concentrated at some specific point with the help of reflective or refractive surfaces and very high temperatures are produced in the range of 100°C to 1500°C is produced. This high temperature produced can be directly utilized for producing steam and power for many applications.

II. CONCENTRATING SOLAR POWER

The principle of concentration of the incident solar rays from a concentrator to a smaller receiver area is the efficient way to utilized solar energy to high temperature applications. The principle is being utilized also with Solar PV called as Concentrating Photovoltaic CPV. The purpose behind use of Concentration of solar rays in CPV panels is to reduce the cost by reducing the semi-conductor area of the cells[2]. In CSP, the same principle is utilized to achieve high temperatures with reduction in the receiver area and making it suitable for power generation. The CSP systems can be classified into two basic type as Line focused type and point focused type. In Line focused type CSP system, the linear receiver is used to receive the concentrated solar radiations by the concentrator. In this type, the concentration Ratio achieved is about 10-40 only. In point focused type system, the incidents solar rays by the concentrator is focused at a single point. The wide range of Concentration Ratio (CR) is achieved ranging from 150-1500 with very high receiver temperature.

The Basic four types of CSP systems are:
1. Parabolic through type
2. Fresnel Lens Linear type
3. Parabolic Dish Collector
Out of the various solar technologies discussed, the non-concentrating type does not require the tracking mechanism and most widely used for water heating applications with lower thermal efficiency. The CSP technologies discussed are used for high temperature applications. Of the discussed CSP technologies, the Parabolic through collector are line focused type and have linear receiver with reflector on which the solar rays are concentrated by the receiver. In this type, the Single axis tracking is required to track both receiver and reflector which may be East-West tracking or North-South tracking; East-West tracking is generally preferred. The Fresnel Lens Linear Collector makes the use of Fresnel lens which concentrates the incident Solar rays on the linear receiver and heats the working fluid up to 400°C. The linear Fresnel collector may be a stationary collector in which the receiver tracks the incident rays or the tracking Collector with stationary receiver[3]. The Parabolic Dish Collectors is a point focused type which has a hemispherical reflector which concentrates the incident solar rays at a focus point. It requires two axis tracking mechanism and very high temperatures up to 1500°C is possible which makes them suitable for power generation. The Solar Towers make the use of large numbers of computer controlled mirrors called heliostats which focuses the incident solar rays on the receiver mounted on the Central Towers.

Basics of Convex lens

A piece of glass in the shape of the intersection of these two spherical volumes would be a thin spherical lens. The intersection of two spherical surfaces is a circle. That circle would be the rim of the lens. The plane passing through this circle is called as Plane of the lens.

The basic characteristic of the convex lens is that when an infinite set of parallel rays parallel to principal axis of the lens fall on the lens surface, they are concentrated at a single point by the lens surface. Basically, number of reflections and refraction takes within the lens surface and the rays are concentrated at a single point. The point at which the rays are focussed is called as Focal point and the distance of focal point from the the plane of lens is called as Focal length.

III. CSP Convex Lens Panel Prototype

Some initial experiments were carried out to determine the important parameters in order to determine the potential of the proposed work. The Convex lens of the Magnifying Glass available easily in local markets of dia. 10cm(4 inch) was chosen. The focal length of this lens was found out to be 18.5cms and the maximum temperature attained at the focal point is found out to be 195°C by placing a thermocouple junction under direct solar radiations. The Solar Collector is a Rectangular box of size 14.5cms x 21cms x 70cms made of plywood of 8 mm thickness. Six circular holes of 10cms dia. are cut where convex lens were fixed at the top of the box. The lenses used were the simple Convex Lens from Magnifying glass which is available easily in local markets. The lenses are fixed in the holes of the receiver box by Plaster of Paris (POP) as it provides easily removal of the lenses for further adjustments and also easily available in market. The Collector Receiver is made of a Copper tube 6.25mm (1/4” inch) in dia. and 1 mm thickness. The length of the tube is 75cms and is fitted in the Panel Box at its focal length. The tubes were provided with Flow valve to precisely control the flow rate of water through the panel. The Solar rays incident on the six lens area are concentrated at the focal point where the receiver tube is placed. Six thermocouples (J-type) are attached near the focus point in order to determine the surface temperatures and study the variation of these temperatures along the length of tube. The simple manual tracking mechanism with nut bolt arrangement is designed and manufactured to continuously track the sun. The Sun is tracked from East to West with axis of the receiver tube axis along North-South directions and the collector is inclined as per designed inclination. The inclination of the collector can be adjusted such that the incident radiations are normal to the collector surface. Two Flow Control Valves were installed at the inlet and outlet of the panel to precisely control the flow rate of water in the panel.

The experimental set up during the test is as explained in the following figure
IV. PERFORMANCE OF THE CSP PANEL

Due to the constructional similarity of the panel with Flat Plate collector (FPC), the performance of the panel is evaluated in the same manner as FPC. The collector efficiency is the measure of collector performance and is defined as the ratio of the useful heat gain by the collector over any time to incident solar energy over the same period of time.

\[ \eta = \frac{Qu}{(I \times A) \times 100} \]

Where,
- \( Qu \) = Useful Energy transfer to the working fluid (Watts)
- \( I \) = Total Solar Radiation per unit area (W/m²)
- \( A \) = Collector Area (m²).

The rate of useful heat transfer to the working fluid is given by,

\[ Qu = (4a \times FR \times \left[ S - \frac{UL}{C} \times (T_s - T_a) \right]) \]

Where, FR = Heat removal factor
- \( S \) = Useful Solar Flux (W/m²).
- \( Ul \) = Overall heat loss Co-efficient.
- \( C \) = Concentration Ratio for the given lens.
- \( Tp \) = Receiver tube surface Temperature (°K)
- \( Ta \) = Ambient Air Temperature (°K).

V. RESULTS AND DISCUSSIONS

The experimental testing of the panel is done for five clear sunny days. The readings are taken each after half hour for whole day by manually the sun. The figure shows the variation of maximum solar intensity for the respective days which varies 1124 W/m² to 1061 W/m².
During the test, Six thermocouples are placed near the focal point of the lens on the receiver tube in order to understand the variations of temperature along the length of the tube. The temperature of the tube along the length almost remains constant as shown in the figure 5.

![Figure 5. Variation of temperature along the tube length.](image)

The test is performed by varying the mass flow rate from 0.24 kg/s to 1 kg/s on different days. The maximum outlet temperature is found to be $67^\circ$C with 0.24 kg/s while the temperature decreases with increase in mass flow rate as shown in the figure 6.

![Figure 6. Variation of outlet Water Temperature with Mass Flow Rate](image)

The performance of collector is evaluated by calculating the collector efficiency and it is found to remain almost for all the mass flow rate. For all the values of flow rate, the collector efficiency is found to be nearly 68% which almost remain constant. It is illustrated in the figure 7.

![Figure 7. Variation of Collector efficiency with mass flow rate](image)

During the test, the useful heat gain is found to be increase from 34.24 watts to 36.22 watts with increase in solar intensity from 1061 W/m$^2$ to 1124 w/m$^2$ with almost constant efficiency. The figure 8 shows the variation of heat absorbed with solar intensity.

![Figure 8. Variation of Useful Heat Gain with Solar Intensity](image)

VI. CONCLUSION

The aim of this experiment was to elaborate the study on existing CSP technologies and to highlight the potential of Convex lens to be one of the alternative solutions. From the test performed the following results were concluded,

1) The various CSP technologies such as Parabolic through collector, Fresnel linear collectors, Solar Towers etc. having CR ranging from 150-1500 have been studied and their low collector efficiency is a major factor due to thermal and optical losses involved
2) The project undertaken aims to develop and manufacture a convex lens CSP prototype in order to reduce these thermal and optical losses but it suffers the limitation of converting only the direct solar radiation into useful energy has been understood.

3) The test on the panel was performed with different mass flow rate and the collector efficiency is found to be almost constant. Also, the collector efficiency is almost constant with variation in solar intensity.

4) During the test, manual tracking is used which involve human errors, the outlet water could have been increased with automatic sun tracking.

5) Thus, the potential of the convex lens prototype to be used for water heating application is been proved with the test. The limitation of very small mass flow rate but it can be overcome by scaling with prototype on large scale.

6) The project shows the potential of convex lens prototype to be used as one of the alternative solutions in future. Also, the low boiling fluids have good thermal properties can be used with these type of panels as they can have good heat transfer properties and can increase the heating effect.

REFERENCES


