# A NOVEL DESIGN OF OCTAGONAL LINE FOCUSING SOLAR COLLECTOR

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## Abstract
For solar-thermal applications principally two types of systems are used namely: flat plate collector and concentrating collector. The main limitation of flat plate solar collector is the maximum achievable temperature. Conversely, parabolic point focusing collector can give relatively higher temperature but it is very difficult and costly to manufacture exact parabolic shape. In this paper, the novel design of octagonal solar collector is presented. The reflector has been given a shape of frustum of octagonal pyramid with its base acting as aperture to capture the solar radiation. The reflector reflects most of the beam radiation and it is concentrated along a line where cylindrical vessel has been kept to absorb the energy. This energy is transferred to the fluid which can be used for different applications. The collector has been tested extensively. Temperature of around 100°C was achieved with water as working fluid. In order to measure the maximum achievable temperature, high boiling point fluid like castor oil has been used. With castor oil as working fluid temperature of around 130°C was achieved. The collector was tested without and with two types of cover namely glass cover and acrylic cover. 10 to 15°C higher temperature was achieved with glass or acrylic cover compared to without cover. It seems that the octagonal solar collector can become the cost-effective design compromise between flat plate collector and parabolic collector.

**Keywords:** Octagonal solar collector, line focusing, cost effective, novel design

## 1. Introduction
Sun is the prime source of all forms of available energy. Before discovery of fossil fuels human race was completely dependent on energy sources such as solar energy, wind energy, firewood etc for its energy needs. With over exploitation and limited reserves of fossil fuels, renewable energy sources such as solar energy, wind energy, biomass are gaining importance. In Indian villages around 85 to 90% of the energy is consumed in cooking. Considering the limited availability of conventional fuels and global worming issues associated with them, use of solar energy for cooking purpose has become the attractive solution.

Solar energy can be used in two modes namely solar-thermal and solar-photovoltaic. Solar collectors are devices that convert solar energy into thermal energy. Currently they are the most economic means of converting solar energy into usable energy. The heat generated by solar collectors can be used for cooking, pool heating, domestic hot water supply, distilling saline water, and many other purposes. Moreover, if the operation temperature is sufficient, electric power generation can be feasible. In some regions, thermoelectric conversion may compete with photovoltaic electricity generation.

For solar-thermal applications principally two types of systems are used namely: flat plate collector and concentrating collector. The concentrating collectors give various advantages compared to flat plate collectors like: (i) Reflecting surfaces requires less material and are structurally simpler than flat plate collectors therefore cost is less (ii) The absorber area of a concentrator system is smaller than that of a flat plate system for same solar energy collection and hence the radiation intensity is greater at absorber surface (iii) As the area from which heat is lost to the surroundings per unit of the collecting area is less, the working fluid can attain comparatively higher temperatures in a concentrating system for the same collecting surface (iv) As the temperature attainable with concentrating system is higher, the amount of heat which can be stored per unit volume is larger and consequently the heat storage costs are less for concentrator systems. The main limitations of the concentrating collector are it uses mainly beam component of the radiation and it requires sun tracking.

The flat plate solar collector is the simplest of all designs but the maximum temperature is limited to 70 to 80°C. Parabolic point focusing collector gives temperature above 200°C depending upon concentration ratio. But, it is costly and difficult to fabricate the exact parabolic shape. A lot of research has been done to improve the performance of solar collectors by adopting novel designs.

Sayed And Rehim (1998) developed a new design of solar water heater as a pyramid shaped frustum. It was a compact system in which collector and a water storage tank were integrated together into one unit. The frustum of pyramid solar water heater had five surfaces; four surfaces represent liquid flat plate collectors as roof and three sides which receives the entire solar radiation incident on them. The absorber consisted of copper tubes formed in a serpentine shape which are connected to the tank. They reported that their new design gave good performance and can provide175 litres/day of hot water at an average temperature of 40°-60°C depending on the weather conditions and solar intensity.

Lupfert et al. (2001) developed parabolic trough collector for various applications in the 200-400°C temperature range in solar fields up to the 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. They also mentioned that, in future it will be possible to connect more collector elements on one drive which results in reduced total number of drives and interconnecting pipes, thus reducing the installation cost and thermal losses.

Lipinski and Steinfeld (2006) 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 analyzed its ability to further concentrate the incoming radiation when used in tandem with a primary solar parabolic concentrator. 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 (2007) 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. It was a hermetic box with a transparent cover and the parabolic reflector forming the back. They also proposed a non-permanently sealed partially evacuated tube which was filled by a low-conductivity gas. With the new design, they found reduction in the cost, as well as solution to the problem of hydrogen and helium permeations.

Luijtelaer and Kroon (2009) designed a novel type of high temperature solar collector called the rotating solar boiler. It was having two concentric tubes. The inner tube, *called absorber*, absorbs sunlight and boils water. The outer transparent tube, *called cover*, was filled with air. The boiler was rotated to prevent convection losses completely in the insulating air layer in between the tubes. Thus the heat losses have been considerably reduced which resulted in increased efficiency of a solar collector than conventional flat plate solar collectors. They reported that the rotating solar boiler is much cheaper than conventional evacuated tube collectors especially due to its lightweight.

The various designs discussed above are complex and hence costly. They also use the parabolic reflector which may be cost effective for temperature above 200°C. In this paper, low cost design of octagonal line focusing solar collector suitable for heat delivery at about 130°C is presented. The experiments were carried out with water and castor oil as the heat carrying fluid. To study the effect of glazing on the performance of collector tests were conducted without cover and with two different types of cover material viz. glass and acrylic.

## 2. The Octagonal Solar Collector

The collector is working on the principal of reflection of beam radiation which concentrates along a straight line, where collector has been kept. The collector absorbs the solar energy and converts into thermal energy.

The main components of octagonal collector are reflector, absorber, transparent cover, sun tracking mechanism and base frame. The reflector has a shape of frustum of octagonal pyramid with its base acting as aperture to capture the solar radiation. It is prepared by arranging eight trapezoidal glass of 3 mm thickness at an angle of 45°. These glasses are supported by 26 Gauge G.I. sheet from the back side. Due to high reflectivity of the glass, more than 90% of beam radiation is reflected and concentrated along a line.

Along the axis of the reflector energy receiving device 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 with thin layer of dull black board paint. 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. To reduce the convection losses a transparent cover has been provided. The collector has been tested with two types of transparent cover viz. 3 mm thick transparent glass and 3 mm thick acrylic sheet. The cover facilitates reduction in convection as well as re-radiation losses and thus enhancement in the performance of the collector can be achieved.

The relative position of sun with respect to earth changes throughout the day as well as round the year. Hence for daily and seasonal tracking of the sun two different tracking mechanisms are provided namely Equatorial tracking and Azimuth tracking mechanism. Equatorial tracking mechanism consist of semi circular disc of 3 mm thick M.S. plate with locking pin, on the periphery of which 6 mm diameter holes are provided at an angle of 10°. An alignment pin is also provided to assure that the aperture area is normal to the sun rays. Azimuth tracking mechanism consists of 15 mm diameter M.S. rod which can be moved inside 16 mm diameter G.I. pipe. To support the whole assembly the base frame consist of 10 mm diameter M.S. rod and M.S. channel have been used.

## 3. Experimental Setup

The experimental setup consists of the octagonal collector, RTD sensors with digital temperature indicator, pyranometer with milli voltmeter. The fluid and atmospheric temperatures were measured using RTD sensors with digital temperature indicator. The intensity of global radiation was measured using pyranometer with milli voltmeter. The photograph of the experimental setup is shown in Fig. 1.

*Figure 1. Experimental setup*

The collector has been tested extensively. Experiments have been performed with water and castor oil filled in the cylindrical vessel. At regular interval of half an hour temperature of water/ castor oil, global solar radiation and ambient temperature were measured. The experiments were performed without cover and with two types of covers viz. glass and acrylic. The tests were also conducted with no load conditions.

## 4. Results and Discussion

The experiments were carried out with 1, 2 and 2.8 liters of water and castor oil placed in the vessel. However, results of experiments carried out with 2.8 liters of fluid are presented here. The readings were taken from 9.30 am to 4.00 pm when sufficient solar insolation is available. The instantaneous efficiency is calculated as the ratio of the amount of heat collected by stagnant fluid in the vessel in duration of 30 minutes and average incident solar radiation in that period.

## 4.1 Water as working fluid

When the collector was tested with water as working fluid filled in the cylindrical absorber, temperature of around 100°C was achieved. The temperature did not increase beyond 100°C due to boiling of water. The variation in fluid temperature ($T_f$), intensity of global solar radiation ($I_g$) and instantaneous efficiency ($E_i$) with respect to time are shown in Fig. 2. It can be seen that initially efficiency is higher as the working fluid temperature rises rapidly and then efficiency decreases successively. When water temperature reaches the boiling point (i.e. around 100˚) the efficiency becomes zero as there is no further rise in the temperature.

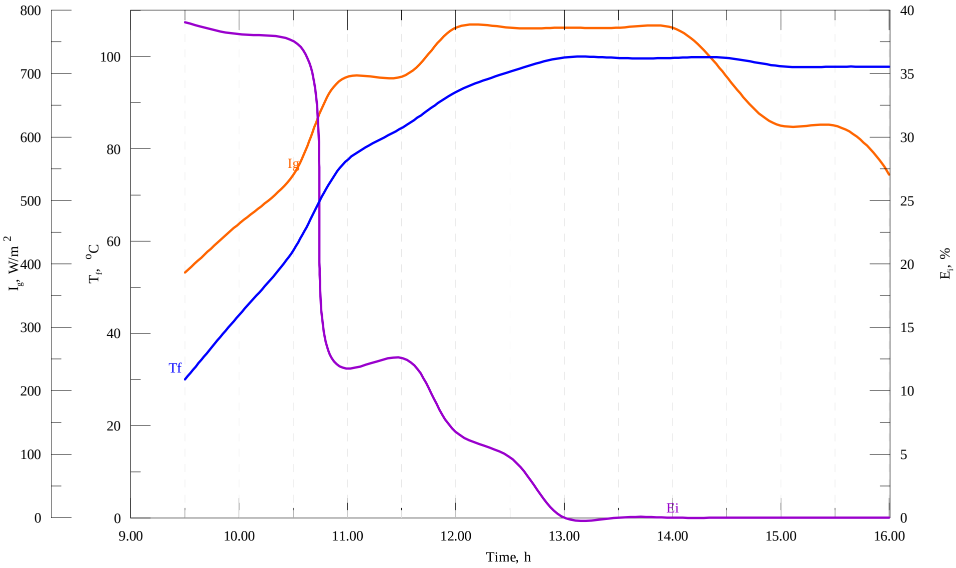


*Figure 2. Variation in water temperature, intensity of global radiation and instantaneous efficiency with time*

## 4.2 Castor oil as working fluid

In order to measure the maximum temperature achievable, the collector was tested with high boiling point fluid such as castor oil. With castor oil as working fluid temperature of around 130°C was achieved. The variation in fluid temperature ($T_f$), intensity of global solar radiation ($I_g$) and instantaneous efficiency ($E_i$) with time are shown in Fig. 3. In this case also, instantaneous efficiency is initially higher and subsequently when fluid reaches the stagnation temperature the efficiency becomes zero. If the fluid would have been circulated through the absorber, higher efficiency would be resulted with higher radiation.

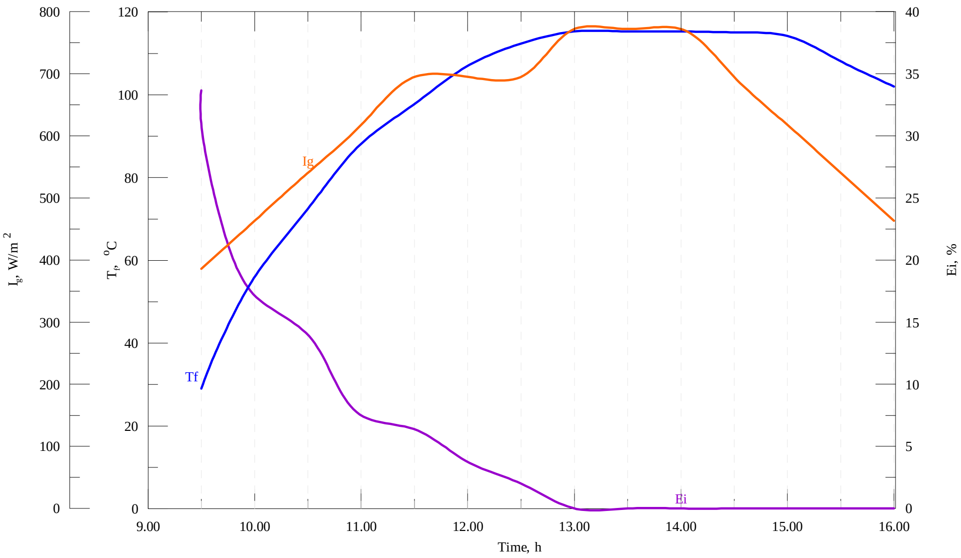


*Figure 3. Variation in castor oil temperature, intensity of global radiation and instantaneous efficiency with time*

### 4.3 Effects of glazing

As discussed earlier to prevent convection losses two different types of glazing (cover) viz. 3 mm thick transparent glass and 3 mm thick acrylic sheet have been used.

Variation in water temperature without cover ($T_{f,woc}$) and with glass cover ($T_{f,wgc}$) against time are shown in Fig 4. The variation in global solar radiation ($I_g$) and instantaneous efficiency ($E_i$) are also shown for both the cases. Effect of glazing could not be recorded in terms of higher water temperature due to boiling of water. It is found that, initially there is not much difference in fluid temperature due to glass cover. However, when solar insolation decreases the cover helps in retaining the fluid temperature.

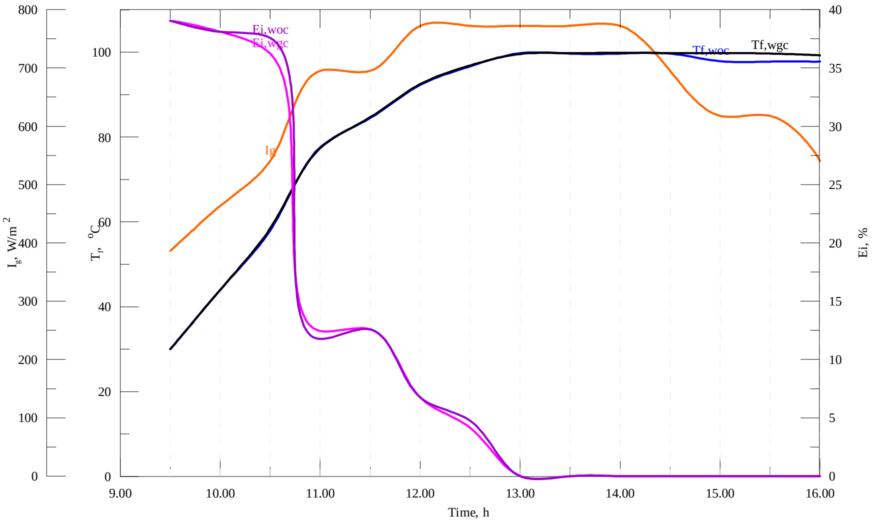


*Figure 4. Variation in water temperature, intensity of global radiation and instantaneous efficiency with time (without and with glass cover)*

The effect of glazing was observed by higher temperature of caster oil when the collector was tested with glass and acrylic cover. Variation in castor oil temperature without cover ($T_{f,woc}$), with glass cover ($T_{f,wgc}$) and with acrylic cover ($T_{f,wac}$) against time are shown in Fig 5. The variation in global solar radiation ($I_g$) and instantaneous efficiency ($E_i$) are also shown for all the three cases.

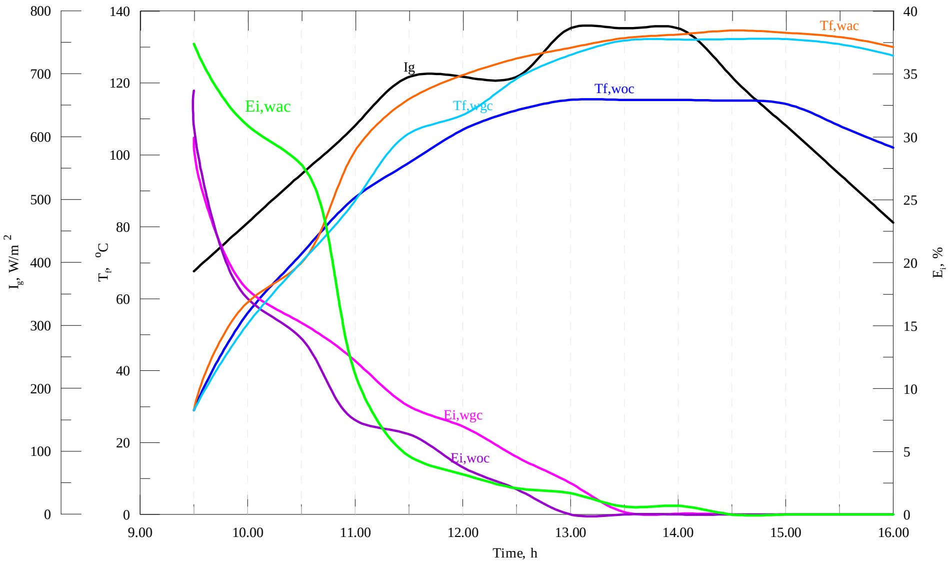


*Figure 5. Variation in castor oil temperature, intensity of global radiation and instantaneous efficiency with time (without and with glass & acrylic cover)*

By using glass or acrylic cover 10 to 15°C higher temperature was achieved. Performance of the collector with acrylic cover was better than that with glass cover however degradation of acrylic would be faster than glass.

Uncertainty analysis of experimental data is carried out using Kline and McClintock method (1994). Considering error in measuring linear dimensions = 1 mm, error in measuring temperature = 1˚C, error in measuring time = 1 second, error in measuring intensity of global radiation = 8 $W/m^2$ uncertainty analysis was carried out and it was found that the results are subjected to 3 to 5% error.

## 5. Conclusion

The application of flat plate solar collector is limited by its maximum temperature which is around 110°C. The parabolic solar collector gives comparatively higher temperature than that of flat plate solar collector but it puts limitation from construction aspect, as it is difficult to get exact parabolic shape. Also they are cost effective for temperature more than 200°C. The octagonal solar collector is the cost-effective compromise between flat plate solar collector and parabolic collector as it can give higher temperature than that achievable with flat plate collector and ease of manufacturing in comparison with parabolic collector. Hence it can be used in medium temperature range of 70 to 150°C with relatively low cost. The collector has concentration ratio of 5. The collector of described geometry can be suitably modified to achieve higher or lower concentration ratio depending on the desired working fluid temperature.

## 6. Future Scope

In lieu of the vessel in which the stationery fluid is heated, the absorber can be suitably modified to have continuous flow of working fluid through the absorber. The flow may be by natural convection current or mechanically assisted. In case of forced circulation of working fluid, higher heat removal rate can be obtained. Also flow rate can be adjusted to obtain desired working fluid outlet temperature.

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