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Solar Concentrators – A Review

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ABSTRACT: An attempt has been made to classify different types of concentrators and its working by various researchers all over the world. The specifications of the various designs have been highlighted and the advantages are mentioned which will be helpful for the researchers working in this field. Moreover, the concentrators used for the direct conversion of solar energy into electric energy have been analysed for the best performance and principle behind the system is presented. In addition, the concentrators used for the conversion of solar energy into thermal energy have also been mentioned. The equation for thermal and optical efficiency of the various designs of concentrators by the researchers is reviewed and presented. Specific results regarding each design of the concentrator along with its working principle have been explained for better perception for the researchers in the field of concentrators. The advantages and disadvantages of each design are written in the paper in order to optimize the design and operational parameters of the system for better performance in all climatic conditions. The status of the concentrator for the possible production of electricity is mentioned after a brief review of the existing designs of concentrators. The paper also presents the schematic diagram of the designs of concentrators with better perception.

The solar concentrator is a device that converts solar energy into solar thermal energy or direct energy conversion in the linear focus receiver or other arrangements. In the detailed in thermal collectors the solar energy has converted into steam and then converted into electricity. In addition, in photovoltaic collectors the solar energy is directly converted into electricity. The present paper is an attempt that has made the review of the present state of solar concentrators.

KEYWORDS: concentrator, optical efficiency, Thermal efficiency, Energy.

I. INTRODUCTION

Solar concentrator is a device to collect light energy through a large area from the Sun and focusing it on a smaller area, i.e., receiver. Concentrators can provide higher temperatures compared to flat plate collectors, since the energy is focused on a smaller area. Moreover, concentrators cannot account for the collection of diffuse radiation. Therefore, it is necessary to orient the concentrators continuously towards the direction of motion of the Sun, to collect direct solar radiation only, by a mechanical tracking device. Concentrators can be utilized to collect solar energy throughout the year, as the annual solar energy incident on the ground surface is higher in amount and fulfil the demand for energy sources.

Solar concentrators are classified into solar thermal conversion systems and direct conversion systems. In solar thermal conversion system, the sunlight is collected and converted into thermal energy and other useful forms of energy, whereas, in the direct conversion system, the sunlight is directly converted into electrical energy. Table 1. Shows the detailed classification of solar concentrators under solar thermal conversion system and direct conversion system.

The behaviour of the temporal temperature in a specimen placed on the focal point of a parabolic dish solar concentrator was predicted by Andrade et al. [1] and concluded that the results of the simulation have good agreement with the experimental results. A numerical investigation of the effect of mirror curvature on the optical performance of a Linear Fresnel Reflector solar field installed recently in Morocco has been developed by Benyakhlef et al. [2] and evaluated the optical performance of the system as a function of mirror curvature and receiver height. Theoretical studies have been performed for solar angles using time and geographic parameters in Tunisia have been developed by

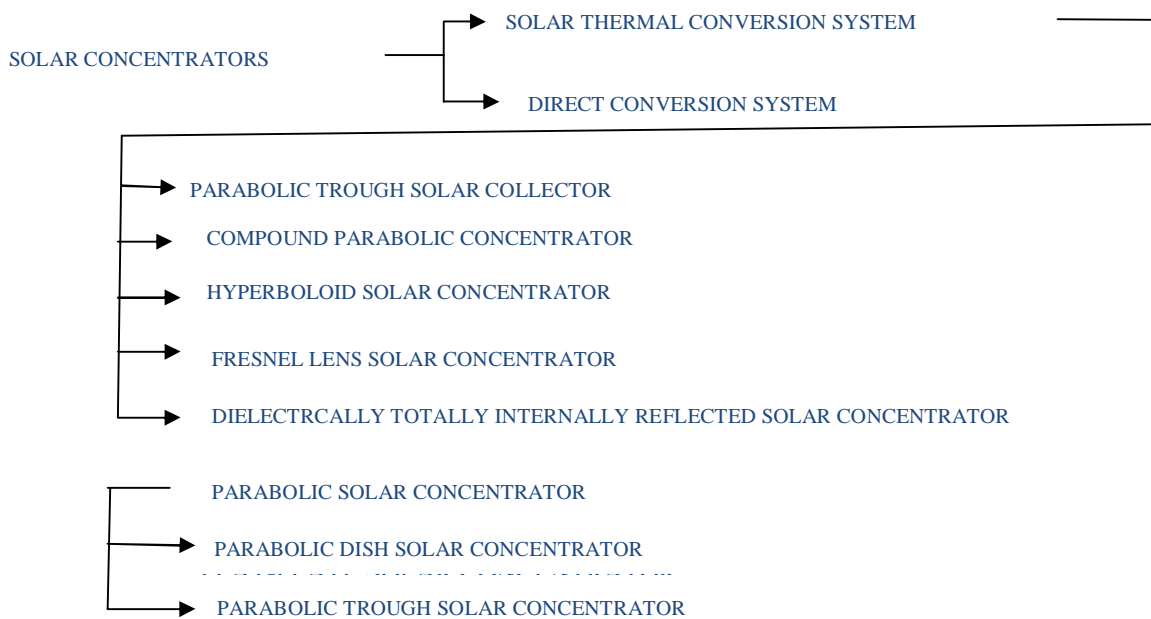
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Safa Skouri et al. [3] and three pilot sun tracking systems have been designed, realized and compared. The non-uniform distribution of the temperature on the circumference of the tube of a parabolic trough solar collector has been described by Sourav et al. [4] and calculated the analytical equations of the deflection tube. A novel hybrid between a solar cavity receiver and combustor have been presented by Jin Han Lim et al. [5] and showed that the combustor achieve the same efficiency as a conventional boiler. Effects of spacing, receiver height of a linear Fresnel reflectors have been investigated by Vashi Sharma et al. [6] and analyzed collector configuration has no significant effect on annual shading. A point-focus Fresnel lens photo voltaic/thermal module has been proposed and studied by Ning Xu et al. [7] and estimated the electrical efficiency of 28% and thermal efficiency of 60%. Monte Carlo Ray Trace code is used to compare the energy effectiveness and flux intensity of receiver for different days of the year and different orientations in Almería, Spain, and in Aswan, Egypt has been proposed by Abbas et al. [8] and concluded that Linear Fresnel Concentrators with secondary reflector receiver achieve higher concentration factors than Parabolic Trough Collectors. The range of incidence angles for a required transmittance of elementary prisms in a curved Fresnel lens and hence to determine the curvature of the lens has been proposed by Xing long Ma et al [9] and The optimal transmittance condition of prism (OTCP) has been derived. Three different optical models for parabolic trough solar collectors has been derived by Hongbo Liang et al. [10] and estimated the Effects of varying Parabolic Trough Collector's geometric parameters on optical efficiency. Free and forced convection heat losses from modified cavity receiver have been derived by Reddy et al [11] and proposed the Nusselt number to calculate combined convection heat losses from the receiver as a function of receiver inclination, wind direction, wind velocity and aperture diameter ratio. Many researchers have made sincere efforts to design, fabricate and analyze the performance of different designs of solar concentrators in both solar thermal conversion system and direct conversion system. Different types of concentrators designed by a few researchers have been presented for the purpose of getting precise knowledge about the design, fabrication and performance.

Table 1. Classification of solar concentrators



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II. PARABOLIC TROUGH SOLAR COLLECTOR

Researchers have designed different parabolic trough concentrators and tracking mechanisms have been used to track the Sun. The Sun controller sheet (or highly reflecting paint) can be used for the purpose of reflecting solar radiation towards the focal point of the trough. Researchers have used glass, copper or aluminium receivers on the focal point of the trough receive the solar radiation reflected by the reflectors. The fluid, mostly water, absorbs the heat radiation from the receiver through which the fluid is allowed to flow.

WORKING

The present PTC system is manufactured by fiberglass with the collector of large Aperture area of 3.5m^2 and optimum concentric ratio of 21.2. The diameter of the receiver is 22mm. Schematic diagram of the parabolic dish is shown in the Fig. 1.

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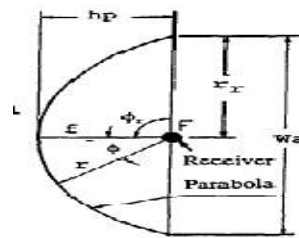


Fig. 1 Parabolic trough concentrator

Tracking mechanism has been made by using a small motor provided with a speed reduction gearbox and control system. Control system detects the Sun's position by using focus sensor, cloud sensor and daylight sensor, and the collector is rotated to the desired position with respect to the results of the sensor in the control system. It is found that the system has higher optical and thermal efficiency compared with the previous methods of tracking adopted by the researchers. Fig. 2 shows the schematic diagram of the control system used in this study.

Kalogirou S [1]

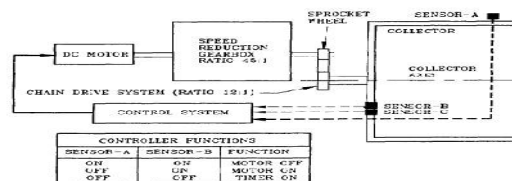


Fig. 2 Control system of the parabolic trough concentrator

The thermal efficiency of the collector is given by

$$\eta = mc_p \frac{(T_{fo} - T_{fi})}{AI} \quad (1)$$

Optical efficiency

$$\eta_o = \rho_m \tau_c \alpha_e \gamma \left\{ \left(1 - A_f \tan(\theta) \cos(\theta) \right) \right\} \quad (2)$$

From the results, it has been concluded that the experimentally calculated optical efficiency varied 0.8% with theoretical values.

III. PARABOLIC DISH SOLAR CONCENTRATOR

To analyze the performance of the proposed concentrator, theoretical and experimental performances were calculated with the cavity receiver at the focal plane. Real time analysis has also been performed.

WORKING

The cavity receiver placed at the focal plane absorbs the solar radiation and transfer the thermal energy to the working fluid. Paraboloidal dish is fabricated with Aluminum frames with aperture diameter of 2.405m and 65° rim angle. The concentration ratio of the concentrator is 295 and the reflectance of the Aluminum surface range from 0.8-0.9. The reflectors are glass mirrors of 1mm thickness, pasted on the aluminium surface to focus the solar radiation onto the absorber, i.e. cavity receiver.

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Kaushika ND and Reddy KS [13]

Fig.3 ExPerimental set up of the paraboloidal solar concentrator

The thermal conversion efficiency of the collector is

$$\eta_T = \eta_R \rho \quad (3)$$

Where

$$\eta_R = [\Phi_0 \alpha_{eff} + (1 - \Phi_0)] \frac{Q_L}{S \phi_0 \rho} \quad (4)$$

Where Q_L is the total heat loss rate of the receiver involves conductive, convective and radiative losses of the cavity and convective and radiative losses of the external absorbing surface. From the results it has been concluded that the maximum efficiency achieved at the aperture radius 0.035m and A_w/A_f is 8. The performance analysis of the dish collector system with a modified cavity receiver, the solar to steam conversion efficiency is 70-80% at 450°C.

IV. PARABOLIC DISH SOLAR CONCENTRATOR

The Solar dish concentrator is a device to produce low and medium temperature applications. The proposed concentrator has an aperture area of 20m².

WORKING

In the above system, the flux distribution at a focal plane of the dish has been evaluated theoretically. The reflected radiation from the dish forms a central cone due to interception of reflected radiation from the two halves of the dish. The elliptical image in the focal plane is generated by reflecting radiations from each element. The dish was tested in the location having latitude of 13.06°N and longitude of 80.28°E. The superposition of numerous elliptical images of different numerate for different orientations and sizes was determined and the flux was mapped. The outer portion of the image has zero intensity beyond the semi major axis of the ellipses. The decrease in number of ellipses at a point is due to the variation in local solar radiation intensity. Daily performance was evaluated for different equilibrium temperatures, varying time constant for flow rates of heat transfer fluid and operating conditions and presented. Fig.4 shows the diagram of the solar dish concentrator.



Reddy et a l [14]

Fig.4 Experimental set up of Solar dish concentrator

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Direct solar radiation was measured by pyrheliometers. Rotometer and K-type thermocouples were used for the measurement of volume flow rate of water and working fluid and receiving temperature at different points within the receiver. The thermal efficiency of the parabolic dish collector with respect to heat gained by the fluid is written as

$$\eta_{ther} = \frac{\int_{t_{ini}}^{t_{fin}} m c_p (T_{fo} - T_{fi}) dt}{A_p \int_{t_{ini}}^{t_{fin}} I_{bn} dt} \quad (5)$$

From the results, it has been concluded that the overall heat loss coefficient is found to be 356W/m²K. The time constants of heating and cooling of parabolic dish are 44S and 47S for flow rate of 250L/h. The average thermal efficiency of parabolic dish collector is found to be 74%.

V. COMPOUND PARABOLIC SOLAR CONCENTRATOR

The CPC was fabricated by joining two parabolic segments providing an entrance aperture with an acceptance angle of 2θ, and concentrator focuses the reflected sunlight on to the exit aperture.

WORKING

Highly reflective material was pasted on the inner surface of the two parabolic segments and copper tube was used to connect the top and bottom of the metal absorber mounted at the focal point of the 3D compound parabolic concentrator. Tracking mechanism was used for the concentrator to back the motion of the Sun. Heat transfer fluid is circulated through the copper tube to the metal absorber and steam is generated. The performance analysis of the proposed CPC was done by ANOVA software. Fig. 5 shows the photograph of the proposed CPC concentrator.

Reddy KS, Sendhil kumar, Natarajan and Veer shetty [15]

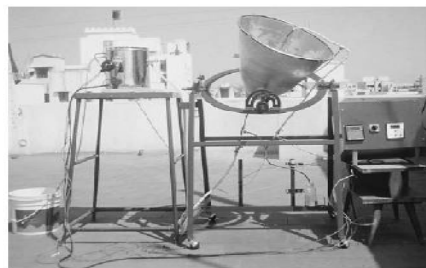


Fig. 5 Photograph of compound parabolic concentrator

The optical efficiency is calculated by using the equation

$$\eta_0 = \frac{m^0 C_w (T_0 - T_i)}{I_b A} \quad (6)$$

From the results it has been concluded that the experimental optical efficiency have good agreement with theoretical values. The 3D CPC provides high optical efficiency, in turn, increase the thermal efficiency of the collector and the average efficiency over the period of the day was 0.582. The values of heat loss coefficient of the CPC at zero solar irradiance 3.27W/m²°C have good agreement with the value of heat loss coefficient obtained at the instantaneous curve.

VI. FRESNEL LENS SOLAR CONCENTRATOR

The Fresnel lens solar concentrator is based on the principle of refraction of light. The light refracted by the lens can be focused to a point and known to be as point focusing Fresnel lens solar concentrator. Hasan nia *et al.* [5] fabricated a point focusing Fresnel lens concentrator, and analysis was done by conducting experiments in the local climatic conditions.

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WORKING

Mineral oil is used as heat transfer fluid and the reservoir is kept at the focal point of the Fresnel lens solar concentrator. The heat absorbed by the oil is transferred to thermo electric module. The hot side of the Thermo electric module is full of hot oil and water flows with the flow rate of 0.002kg/s through the module to produce steam. The steam runs a turbine to produce electricity.



Hasan Nia M, Abbas Nejad A, Goudarzi AM, Valizadeh M and Samadian P [14]

Fig.6.Experimental set up of Fresnel lens solar concentrator

The thermal efficiency of the system is found by the equation

$$\eta_{ther} = \frac{Q_w}{I_{FL}} \times 100 \quad (7)$$

From the results it has been concluded that the maximum available temperature on the oil reservoir surface is equal to the 130°C. The maximum thermal efficiency is 51.9% and the thermal power transferred to water is 30.93W and utilizing water with a flow rate of 0.002Kg/s and an initial temperature of 19°C, electrical power in the matched load condition was 1.038W.

VII. LINEAR FRESNEL LENS SOLAR COLLECTOR

Linear Fresnel solar concentrator refracts the light falling on the lens and focuses in a line.

WORKING

Lin et al.[6] have designed and fabricated a Fresnel lens made of Polymethymethacrylaten. Cavity receiver has been used at the focal line of the lens and stepper motor with subdivision driver has been used for single axis tracking. The beam width of linear Fresnel lens is 26.7mm and concentric ratio is 15. The Optical efficiency has been found using the expression

$$\eta_o(\theta) = \frac{Q_{ab}}{I_b A_c} \quad (8)$$

Where

The thermal efficiency

$$\eta_t = \frac{m C_p (t_{out} - t_{in})}{A_c I_b} \quad (9)$$

The optical and thermal efficiency of the system has found to be 81.2% and 40.5% with the utilization of rectangular cavity receiver at 90°C.

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Lin M, Sumathy K, Dai YJ and Zhao XK [15]

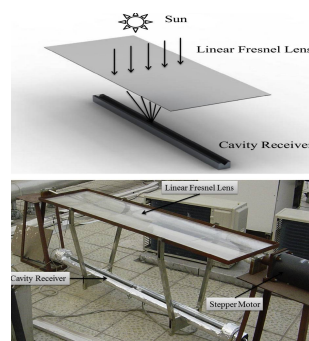


Fig.7. Photograph of Linear Fresnel lens solar concentrator

VIII. HYPERBOLOID SOLAR CONCENTRATOR

The hyperboloid system internally reflects the rays falling on the entrance, and they reach the exit of the aperture.

WORKING

Imhamed M.Saleh Ali *et al.* [7] have fabricated a concentrator using the thick aluminum sheet. No tracking mechanism has been adopted since the concentrator receives the rays entering through the aperture and delivering the rays through the exit of the concentrator. Water has been flown through the helical receivers mounted on the exit of the concentrator and hot water is collected in the collection tank. Two such concentrators are connected in series and convective heat loss has been reduced by enclosing the receiver in a chamber covered with glass wool.

The equation for optical efficiency is

$$\eta_{opt} = \left[\left(\frac{\sum_{i=1}^N (I_i P^J)}{I_0} \right) \right] \quad 0 \leq J \leq m. \quad (10)$$



Fig.8. Experimental setup of Hyperboloid solar concentrator

From the results it has been concluded that the area of the fabricated model of the elliptical hyperboloid concentrator is 20% less than optimum dimension, loss of reflectivity of the thin film due to air traps in the internal surface of the concentrator, heat loss from the surroundings and external shading the performance of the concentrator has been reduced.

From the analysis, it has been predicted that the optimal concentration ratio of 20X with 28% efficiency. The maximum stagnation temperature recorded was 125°C and outlet temperature of the system was 125°C with a flow rate of 0.5kg/minute and by increasing flow rate to 1kg/minute the maximum outlet temperature was 68°C.

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IX. FLAT HIGH CONCENTRATION DEVICES

These types of concentrators are capable of achieving maximum acceptance-angle-concentration. There are five possible designs of concentrators' viz., RR, XX, XR, RX and RXI where R denotes refraction, X denotes reflection and I denote total internal reflection. For simplicity, discussion has been restricted to RXI concentrator.

WORKING

Minano *et al.* [8] have designed an RXI concentrator with rotational symmetry with a dielectric of refractive index 1.5 and acceptance angle of $\pm 2.7^\circ$. The concentrator can achieve a concentration factor of 1000x.

Minano JC, Gonzales JC and Zanesco I [17]

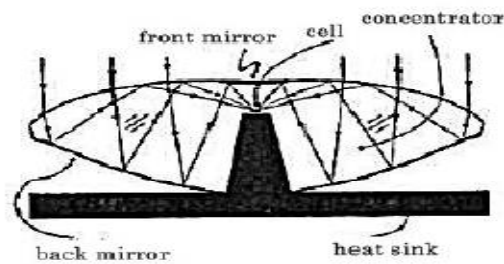


Fig.9.Schematic diagram of Flat high concentrator device

X. DIELECTRIC TOTAL INTERNAL REFLECTING SOLARCONCENTRATOR

This concentrator is known as secondary concentrator, and are optical elements having the capability to achieve concentration close to the theoretical maximum limits. There are two methods of producing DTIRC, maximum concentration method and phase conserving method.

WORKING

Ning *et al.* [9] have designed and fabricated a DTIRC consisting of three parts. The curved front surface received the radiation hitting on it and is refracted. The refracted rays are directed towards the side walls where they are totally reflected internally to the exit aperture.

Ning X, Winston R and Gallagher JO [18]

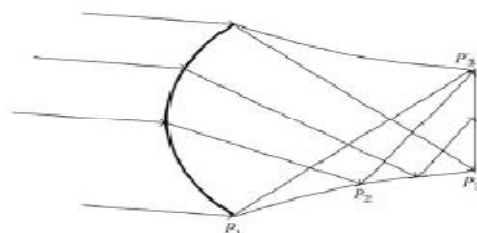


Fig.10.Schematic diagram of Dielectric Total Internal Reflecting Solar Concentrator

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XI. QUANTUM DOT SOLAR COLLECTOR

Quantum dot concentrators are planar devices to concentrate solar radiation into quantum dot-doped glass or plastic substrate. Photovoltaic cells are fixed beneath the substrate to convert the solar radiation into electrical energy.

WORKING

Gallagher SJ, Norton B and, Eames PC [19]

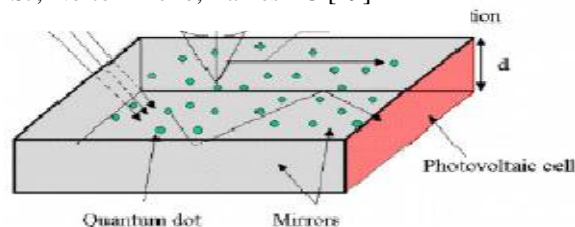


Fig.11.Schematic diagram of Quantum dot solar collector

Gallagher *et al.* [10] fabricated a quantum dot solar concentrator consisting of a transparent sheet of fluorescent material doped with quantum dots. The radiation gets refracted by the fluorescent material and absorbed by quantum dots. Photons are reemitted from the substrate and guided towards the PV cell by total internal reflection. The photoelectric current produced by PV cell is then connected to the external circuit or battery to store the electrical energy.

The conversion efficiency is given by the equation

$$\eta = \frac{\rho_{max}}{A_r E_e} \quad (11)$$

From the results it has been concluded that comparative concentrating factors ranging from 1.33 to 3.05 compared to the reference A and much higher concentrating factors between 3.78 and 8.65 compared to the reference B. Highest fill factor achieved by sample 5 and efficiency 12.5% lower than the specified manufacturers.

XII. CONCLUSION

The solar radiation produces abundant clean energy that can be transformed into heat and electricity. Concentrator integrated with Photovoltaic module has shown better optical and thermal efficiency among the different types of concentrators and also gives output from microwatts to megawatts. The solar thermal system is one of the most promising renewable energy options to substitute the increasing demand for conventional energy. Among all the solar concentrating collectors, parabolic trough collector has been designed to reach the temperatures from 100°C to 600°C and employed for a variety of applications, including steam production for industrial process heat applications. Moreover parabolic dish concentrator is cost effective and efficient in the production of useful energy.

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