

A Review on the Application of Fresnel Lenses in Solar Radiation Concentrator

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ABSTRACT: The abundance of solar energy has urged mankind to use it as a substitute for many prevalent sources of energy. One of the most efficient ways of utilizing solar energy is by harnessing the heat in the sun light and using it instead of the heat obtained by fossil fuels, as photovoltaic cells are costly and less efficient. Most common way of concentrating solar power is using parabolic reflectors, which has many disadvantages. Solar energy concentration technology using Fresnel lens is an effective way to make full use of sunlight. The ongoing research and development involves imaging systems and non-imaging systems. Compared with imaging systems, non-imaging systems have the merits of larger accept angles, higher concentration ratios with less volume and shorter focal length, higher optical efficiency, etc. Concentrated photovoltaics is a major application and the highest solar-to-electric conversion efficiency based on imaging Fresnel lens and non-imaging Fresnel lens are reported as over 30% and $31.5 \pm 1.7\%$, respectively. Moreover, both kinds of systems are widely used in other fields such as hydrogen generation, photo-bio reactors as well as photochemical reactions, surface modification of metallic materials, solar lighting and solar-pumped laser. During the recent two decades, such applications have been built and tested successfully to validate the practicality of Fresnel lens solar concentration systems. Although the present application scale is small, the ongoing research and development works suggest that Fresnel lens solar concentrators, especially non-imaging Fresnel lenses, will bring a breakthrough of commercial solar energy concentration application technology in the near future. This paper attempts to state the advantages of the use of Fresnel Collectors in concentrating solar power.

KEYWORDS: Solar Energy, Solar Collectors, Fresnel Collectors, Renewable Resources, Parabolic Concentrators, Solar Tracking, Quantum Dot Concentrator.

I. INTRODUCTION

The air pollution caused by fossil fuels and the increase of greenhouse effect makes it a must to use renewable sources of energy. Among the available renewable sources of energy solar power is the most abundant form of energy and it has a great potential to become a substitute for coal and other fossil fuels. So, today we see many countries like Germany, China, Japan, etc. switching to solar energy as their primary source of energy.

Currently, solar energy is harnessed in three ways (Twidell *et al*, 2006) namely

- i) Photo thermal - Incident radiation is concentrated and turned to heat.
- ii) Photo chemical - Radiation between 0.3 and 1.0 μm can cause chemical reactions, sustain growth of plants and animals and through photosynthesis convert exhaled carbon dioxide to breakable oxygen.
- iii) Photo electric - radiation in the band between 0.33 and 1.2 μm can be converted directly into electricity by photovoltaic cells.

This paper focuses only on the Photo Thermal type.

The incoming solar radiation suffers depletion in the following ways (Chen, 2011)

- i) Absorption by the ozone in the upper atmosphere.
- ii) Scattering by dry air.
- iii) Absorption, scattering and diffuse reflection by suspended solid particles.
- iv) Absorption and scattering by thin cloud layers.
- v) Absorption and scattering by water vapour.

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After the energy being lost in the above mentioned ways, the average energy reaching the earth's surface is 1800 kwh/m² (Folaranmi, 2009).

Solar energy is concentrated by three methods, reflection, refraction and hybrid of both. In reflection type, the sun rays falling on the collectors are reflected to get focused on a photovoltaic cell or steam tubes. In a refraction type, the light rays pass through the lens to get focussed. In a hybrid type, a part of the sun's rays is reflected and the remaining is refracted. The hybrid method of concentration can provide better energy utilization.

Types of Solar Concentrators

Type of Concentrator	Advantages	Disadvantages
Parabolic Concentrator	High concentration	Requires larger field of view Need a tracking system
Hyperboloid Concentrator	Compact	Need to introduce lens at the entrance aperture to work effectively
Fresnel Concentrator lens	Able to separate the direct and diffuse light – suitable for controlling of illumination and temperature of a building interior	Imperfection on the edges of the facets causing the rays improperly focused at the receiver.
Compound Parabolic Concentrator	Higher gain when its field of view is narrow	Needs a good tracking system.
Quantum Dot Concentrator	No tracking needed Fully utilize both direct and diffuse solar radiation	Restricted in terms of development due to the requirements on the luminescent dyes

II. THEORETICAL ANALYSIS OF FRESNEL SYSTEM

Principle of Fresnel Lens

There are two types of Fresnel lens namely refractive lens and reflective mirrors. The refractive lenses and used mainly used in the photovoltaic applications and the reflective mirrors are used for photo thermal applications. Fresnel lenses are more flexible as far as optical design are considered and can produce uniform flux density on the absorber. Fig. 1 below shows the schematic view of refractive Fresnel lens and the reflective Fresnel mirror concentrating systems.

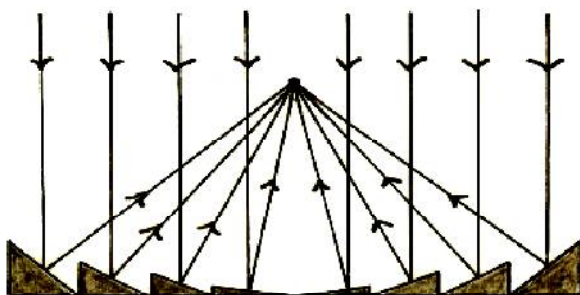
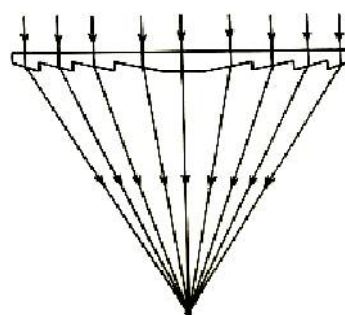


Fig 1. a) Reflective Fresnel mirrors



b) Refractive Fresnel Lens

Fresnel lens can also be classified as imaging and non-imaging lenses. In case of imaging Fresnel lens image of the source to be formed at the focal point and in case of non imaging lens, the exact image of the source is not formed at the focus.

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Based on the focus, Fresnel lens can also be classified as point focus and line focus. Fig. 2 shows a point and line foci.

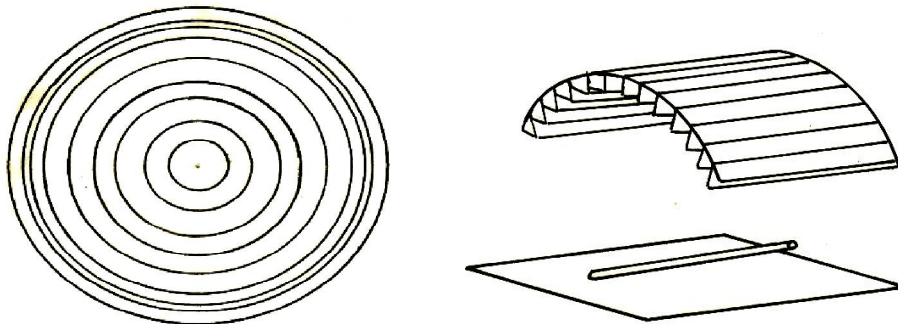


Fig 2. a) Point focus

b) Line Focus

III. LITERATURE SURVEY

Udawant et al (2016) "Study of Performance of Fresnel Lens Solar Concentrator". The demand for process heat particularly low pressure steam is increasing in recent past. Solar energy can be utilized for generating medium temperature (100°C -150°C) low pressure ($T < 200^\circ\text{C}$) steam. By using solar concentrators, low pressure steam can be generated by using low cost technology [1]. Fresnel lens solar concentrators are very useful to generate low pressure steam for industrial and cooking applications. The study of performance of Fresnel lens solar concentrator and steam generation using Fresnel lens solar concentrator is presented in this paper. The overall efficiency of Fresnel lens solar concentrator is around 51% and can generate process steam required in the industry. The thermal performance and cost benefits of Fresnel lens solar concentrator are also described. The studies presented in this paper concerns with Fresnel Lens Solar Concentrator System which are most useful for generating process heat for industrial applications. Thermal performance of Fresnel lens solar concentrator (FLSC) system can be studied by evaluating useful heat gain from the system when exposed to solar radiation [1]. FLSC system consists of Fresnel lens, receiver tracking system and heat removing device. An attempt has been made to evaluate the performance of FLSC system with two methods viz. continuous fluid flow test method and Steam generation test method. The study reveals that Fresnel lens Solar Concentrator system has a very good potential in generation of low pressure steam.

Nura & Kamarulazizi (2015) "Concept of Bee-Eyes Array of Fresnel Lenses as a Solar Photovoltaic Concentrator System". This paper presents a proposal of a new configuration of an optical concentrator for photovoltaic application which may enhance the efficiency of solar cells. Bee-eyes array Fresnel lenses concentrator proposed here provide high concentration factor which is greater than 1000x at the 20th zone. In addition, the system also provides room for increasing the number of zones to achieve the high concentration factor if needs arise. The transmission efficiency greater than 90% has been achieved with f-number of 1.25. Mathematical relations derived to obtain flux distribution at the absorber plane and the transmission efficiency as well as the position of the solar cell were used in the ray tracing simulations for 6, 18, 36, 60, 90, 126, 168, 216, 270, and 330 suns concentration systems. A transmission efficiency is linearly decreasing with the increase in the number of arrays in which the transmission efficiency of 94.42% was recorded at the array of 6 suns and 74.98% at 330 suns.

Lei Jing et al (2014) "Design and Optimization of Fresnel Lens for High Concentration Photovoltaic System". A practical optimization design is proposed, in which the solar direct light spectrum and multijunction cell response range are taken into account in combination, particularly for the Fresnel concentrators with a high concentration and a small aspect ratio. In addition, the change of refractive index due to temperature variation in outdoor operation conditions is also considered in the design stage. The calculation results show that this novel Fresnel

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lens achieves an enhancement of energy efficiency of about 10% compared with conventional Fresnel lens for a given solar spectrum, solar cell response, and corrected sunshine hours of different ambient temperature intervals.

Kapurkar & Kurchania (2013) "Performance evaluation of fresnel lens concentrated solar water heater cum distillation unit". A composite unit of Fresnel lens concentrated solar water cum distillation unit, having a capacity of 70 liters was developed to perform the functions of water heating and distillation. In this system two insulated tanks with glass cover were fabricated where one was used for water heating and the second tank was for condensation of water vapour. Solar energy concentrated by Fresnel lens was absorbed by the plate and surrounding water contained in water heating tank was heated by this absorber plate's heat through conduction. Water vapour from hot water was condensed in dehumidification tank by the comparatively colder surfaces of copper tube used to feed fresh water and top slanting glass surface. Condensed water was collected in a collection trough. Overall efficiency of solar water heater was found to be 42.38 per cent and 27.48 per cent for distillation unit. The final hot water outlet temperature was 65.12 and the yield of distilled water was 4.72 kg/m² /day. The total cost of the composite unit was Rs. 7524.

Iuliana & Constantin (2012) "Thermal Analysis of a Linear Fresnel Lens Solar Collector with Black Body Cavity Receiver". Tuburile vidate sunt printre cele mai utilizate captatoare pentru conversia termică a energiei solare. Această lucrare își propune să analizeze un astfel de captator, care folosește o soluție constructivă diferită de cele clasice, și să compare performanța acestuia cu a captatoarelor comercializate în prezent. Acesta utilizează lentile liniare Fresnel pentru a concentra radiația solară pe un receptor cilindric tip cavitate. Suprafața interioară a tubului de sticlă este acoperită cu un strat reflectorizant. În consecință, majoritatea razelor care pătrund în cavitate sunt absorbite (principiul corpului negru). Evacuated tubes are among the most common collectors used in solar thermal energy conversion. This paper aims to analyse such a collector that uses a different constructive solution than the classical, and compare its performance with other currently marketed collectors. The collector uses linear Fresnel lens to concentrate solar radiation on a cylindrical cavity receiver. The inner surface of the receiver's glass tube is coated with a reflective layer. Consequently, most of the rays that penetrate the tube are trapped inside the cavity (black body principle).

Xiea et al (2011) "Renewable and Sustainable Energy Reviews". Solar energy concentration technology using Fresnel lens is an effective way to make full use of sunlight. This paper makes a review about the recent development of the concentrated solar energy applications using Fresnel lenses. The ongoing research and development involves imaging systems and non-imaging systems. Compared with imaging systems, non-imaging systems have the merits of larger accept angles, higher concentration ratios with less volume and shorter focal length, higher optical efficiency, etc. Concentrated photovoltaics is a major application and the highest solar-to-electric conversion efficiency based on imaging Fresnel lens and non-imaging Fresnel lens are reported as over 30% and 31.5 ± 1.7%, respectively. Moreover, both kinds of systems are widely used in other fields such as hydrogen generation, photo-bio reactors as well as photochemical reactions, surface modification of metallic materials, solar lighting and solar-pumped laser. During the recent two decades, such applications have been built and tested successfully to validate the practicality of Fresnel lens solar concentration systems. Although the present application scale is small, the ongoing research and development works suggest that Fresnel lens solar concentrators, especially non-imaging Fresnel lenses, will bring a breakthrough of commercial solar energy concentration application technology in the near future. Finally, the advantages and disadvantages of two systems are also summarized.

Mohammed S. Al-Soud et al. (2010) "A parabolic solar cooker with automatic two axes sun tracking system". A parabolic solar cooker with automatic two axes sun tracking system was designed, constructed, operated and tested to overcome the need for frequent tracking and standing in the sun, facing all concentrating solar cookers with manual tracking, and a programmable logic controller was used to control the motion of the solar cooker. The results of the continuous test performed for three days from 8:30 h to 16:30 h in the year showed that the water temperature inside the cooker's tube reached 90°C in typical summer days, when the maximum registered ambient temperature was 36°C.

IV. CONCLUSION

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In conclusion, the need for the construction of a parabolic dish solar steam generator arose as an alternative to solve the thermal energy needs of the populace. This will also reduce the total dependency on fossil fuels and other non-renewable and exhaustible energy sources which have been known to be depleted with ages to come as they are being used up. As such, deforestation and other environmental populations are reduced to a minimum. Earlier studies have shown that use of parabolic solar concentrator gives high concentration requires larger field of view and need a good tracking system. The use of reflective material plays an important role. Parabolic dish type concentrators become bulky and transportability. Thus Fresnel Concentrators shine as a good alternative.

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