International Journal of Modern Engineering Research (IJMER)

www.ijmer.com Vol.2, Issue.3, May-June 2012 pp-1381-1385 ISSN: 2249-6645

High solar energy concentration with a Fresnel lens: A Review

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ABSTRACT
Solar technology offers great potential in terms of supplying the world's energy needs. The effective way of utilizing sunlight with solar energy concentration technology and recent developments of its applications using Fresnel lens is reviewed in this paper. The present status of application, the ongoing research and development works suggest that Fresnel lens solar concentrators will bring a breakthrough of commercial solar energy concentration application technology in the near future. The paper was focused on the Solar Energy high temperatures using parabolic solar concentrator, Fresnel lens, Reflecting materials and solar tracking. It identified their level of performance. This paper will provide an up-to-date review of solar concentrators and their benefits to make solar technology affordable. It will also analyze on some of the existing solar concentrators used in the solar technology for the past four decades and performance of each concentrator will be explained and compared.

Keywords: *Parabolic solar concentrator, Fresnel lens, Reflecting materials, Solar tracking.*

Introduction
The continuous increase in the level of green house gas emissions and the increase in fuel prices are the main driving forces behind efforts to more effectively utilize various sources of renewable energy. In many parts of the world, direct solar radiation is considered to be one of the most prospective sources of energy. Among the different energy end uses, energy for cooking is one of the basic and dominant end uses in developing countries. Solar energy, which is an abundant, clean and safe source of energy, is an attractive to substitute for the conventional fossil fuels. In concentrated solar system, concentration by reflection or refraction through mirrors. The mirrors can be plane or parabolic.

The reflectivity of the surface materials is an important factor in the optical efficiency. Mirror precision is important and conventional methods to fabricate precision parabolic mirrors are complex and costly. In solar energy applications, back silvered glass plates, anodized aluminum sheets serve as reflectors. They are widely commercially available .Thus improved solar reflectors play an important role in achieving the required cost reductions in solar collectors.

Parabolic dish type concentrators become bulky and transportability is a problem and the rising of temperature is slow.

To overcome this, the change in materials for concentrators and use of Fresnel lenses will raise more temperature than conventional one and can be used in furnace heating. The review was divided in two parts. First one is selection of solar concentrator with tracking and another one is Fresnel lenses.

Selection of solar concentrator
Various designs of the solar concentrator were studied in order to optimize their performance and the variation was depending upon the geometrical form as well as the place of the pot. For the past four decades ,there have been a lot of development involving the designs of solar concentrator .Some of distinguish designs which have shown significant contribution to the solar technology are as shown in table 1 and table 2;

Table 1: Types of solar concentrators

Type	Description
Reflector	Upon hitting the concentrator, the sun rays will be reflected to the PV cell. Example: *Parabolic Trough, Parabolic Dish, CPC Trough, Hyperboloid Concentrator.*
Refractor	Upon hitting the concentrator, the sun rays will be refracted to the PV cell. Example: *Fresnel Lens Concentrator.*
Hybrid	Upon hitting the concentrator, the sun rays can experience both reflection and refraction before hitting to the PV cell. Example: *DTIRC, Flat High Concentration Devices.*

www.ijmer.com Vol.2, Issue.3, May-June 2012 pp-1381-1385 ISSN: 2249-6645

Luminescent	The photons will experience total internal reflection and guided to the PV cell. Example: *QDC.*

(F. Muhammad-Sukki et al,"Design of Solar Concentrators," International Journal of Applied Sciences (IJAS), Volume (1): Issue (1))

Table 2: Summary of the Advantage and Disadvantage of the Concentrators

Type of Concentrator	**Advantage**	**Disadvantage**
Parabolic Concentrator	•High concentration	• Requires larger field of view. • Need a good tracking system.
Hyperboloid Concentrator	• Compact	• Need to introduce lens at the entrance aperture to work effectively.
Fresnel Concentrator lens	• Thinner than conventional lens. • Requires less material than conventional lens. • Able to separate the direct and diffuse light - suitable to control the 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.	• Need a good tracking system.
Dielectric Totally Internally Reflecting Concentrator	• Higher gain than CPC. • Smaller sizes than CPC.	• Cannot efficiently transfer all of the solar energy that it collects into a lower index media.
Flat High Concentration Devices (RR, XX, XR, RX, and RXI)	• Compact. • Very high concentration	• Difficulty to create electrical connection and heat sinking due to the position of the cell. • The cell dimension must be designed to a minimum to reduce shadowing effect.
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.

(F. Muhammad-Sukki et al,"Design of Solar Concentrators," International Journal of Applied Sciences (IJAS), Volume (1): Issue (1))

A.R. El Ouederni et. al. (2008) in this paper a parabolic solar concentrator has been experimentally studied. The experimental devise consists of a dish of 2.2 m opening diameter. Its interior surface is covered with a reflecting layer and equipped with a disc receiver in its focal position. The orientation of the parabola is assured by two semi-automatic jacks. Experimental measurements of solar flux and temperature distribution on the receiver have been carried out. These experimental results describe correctly the awaited physical phenomena.

M. Ouannene et. al. (2009) designed, built and studied a parabolic solar concentrator. The characteristic equations and the experimental results showed that the favorable conditions of getting better solar concentrations are; first is the best hour of getting maximum solar energy is 13h: 30 to 14h: 30 and second is the concentrator is more effective if the solar tracking is perfect.

Pelemo et al. (2002) have noted the importance of materials used as shells for solar cooker. For their concentrators, the shell of the cooker were developed using various combinations of paper pulp with starch, sawdust and resins, and concrete cement. They considered cement mixed with sawdust and reinforced with palm fibers as a better alternative and more suitable for their environment. In their work, two types of materials were considered for use as the reflective material. These are aluminum sheet and glass mirrors. They concluded that both materials are suitable as

www.ijmer.com Vol.2, Issue.3, May-June 2012 pp-1381-1385 ISSN: 2249-6645

reflective materials in Ile-Ife environment even though they have different years of effective service durations.

Ajiya et al. (1995) designed and constructed a parabolic solar cooker at University of Maiduguri, Nigeria. The design was based on point focus using small square glass mirrors fixed on abricated parabolic dish as the reflecting surface. The parabolic is then placed on a mounting with some kind of steering arrangement that can be used to track the sun manually as it transverses its path from east to west. Blackened flat plate placed at the focal point serves as the absorber on which cooking pot is placed. Locally sourced materials were used for fabrication of the various parts. Testing revealed that the parabolic solar cooker performed at about 30% efficiency in Maiduguri environment.

Mshelbwala et al. (1996) carried out modification on Ajayi work in order to improve its efficiency. He introduced "L" shaped flat bars to replaced the blackened flat plate for the support of the cooking pot, and painted the bottom of cooking pot black. This modification made the bottom of the cooking pot to be the receiver thereby causing direct heating of the pot without any intermediary as was in the original design. Heat loss due to conduction between the flat-plate and cooking pot was eliminated by the new modification. Analysis of the data collected from the experimental tests carried out on the modified cooker revealed an efficiency of 46.6% which is an improvement on the earlier design.

Asere et al. (2003) carried out the design, construction and testing of a compound parabolic solar cooker (CPC).The temperature of up to 90^0C was obtained while highest instantaneous efficiency of the cooker for the clear day was 44%. The effect of spherical scatters on the thermal performance of the CPC was found to be quite high even when the particles are assumed to be non-absorbing. And in order to boost the energy available for cooking, the need of energy storage in the CPC system has been suggested.

Hasan et.al. (2003) simply designed and the low-cost parabolic-type solar cooker (SPC) was made and tested. The energy end energy efficiencies of the cooker were experimentally evaluated. The experimental time period was from 10:00 to 14:00 solar time. During this period, it was found that the daily average temperature of water in the SPC was 333 K and the daily average difference between the temperature of water in the cooking pot and the ambient air temperature was 31.6 K. The energy output of the SPC varied between 20.9 and 78.1 W, whereas its energy output was in the range 2.9–6.6 W. The energy and energy efficiencies of the SPC were in the range, respectively, 2.8–15.7% and 0.4–1.25%.

Lifang Li et.al. (2011) parabolic concentrator mirrors are an important component of many solar energy systems, particularly solar mirror collectors. Precision parabolic mirrors are expensive to fabricate and to transport. Here, a new concept for designing and fabricating precision parabolic mirrors is presented. Mirror precision is important and conventional methods to fabricate precision parabolic mirrors are complex and costly. The reflectivity of the surface materials is an important factor in the optical efficiency. In solar energy applications, back silvered glass plates, anodized aluminum sheets and aluminized plastic films serve as reflectors. They are widely commercially available. Films are usually adhered to a supporting material such as aluminum. However, the supporting material must be held with a precision parabolic shape by some supporting structures.

C. E. Kennedy at.al. (2005) Concentrating solar power (CSP) technologies use large mirrors to collect sunlight to convert thermal energy to electricity. The viability of CSP systems requires the development of advanced reflector materials that are low in cost and maintain high specular reflectance for extended lifetimes under severe outdoor environments. Durability testing of a variety of candidate solar reflector materials at outdoor test sites and in laboratory accelerated weathering chambers is the main activity within the Advanced Materials task of the CSP Program at the National Renewable Energy Laboratory (NREL) in Golden, Colorado. Test results to date for several candidate solar reflector materials will be presented. These include the optical durability of thin glass, thick glass, aluminized reflectors, front-surface mirrors, and silvered polymer mirrors.

The development, performance, and durability of these materials will be discussed. Based on accelerated exposure testing the glass, silvered polymer, and front-surface mirrors may meet the 10 year lifetime goals, but at this time because of significant process changes none of the commercially available solar reflectors and advanced solar reflectors have demonstrated the 10 year or more aggressive 20 year lifetime goal. CSP technologies are capital intensive and, for the first truly commercial systems, about half of the total capital cost of a power plant will be invested in the solar collectors. This makes reducing the cost of solar collectors critical to achieving energy cost targets compatible with economic viability, depending on the technology.

Dr. Steven F. Jones et.al. (2001) FSEC comments that aluminized Mylar was used in the development of the solar funnel. He reported that aluminized Mylar was a good reflective material but was relatively expensive and rather hard to come by in large sheets.

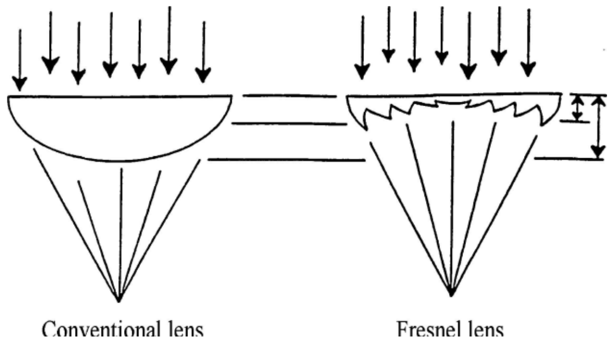
Mohammed S. Al-Soud et. al. (2010) a parabolic solar cooker with automatic two axes sun tracking system was designed, constructed, operated and tested to overcome the need for frequent tracking and standing in the sun, facing all concentrating solar cookers with manual tracking, and a programmable logic 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 2008 – showed that the water temperature inside the cooker's tube reached 90^{0}C in typical summer days, when the maximum registered ambient temperature was 36 ^{0}C. It was also noticed that the water temperature increases when the ambient temperature gets higher or when the solar intensity is abundant. This is in favor of utilizing this cooker in many developing countries, which are characterized by high solar insulations and high temperatures. Besides cooking, the proposed cooker could be utilized for warming food, drinks as well as to pasteurize water or milk.

A.K.Agrawal et,al. (1991) a two axis tracking system is described for the focusing of sunlight in parabolic type reflector used in solar thermal devices like solar cooker. This system consists of worm gear drives and four bar type kinematic linkage and accurate focusing of reflectors at low cost

C.Saravanan et. al. (2011) paper presents the hardware design and implementation of a system that ensures a perpendicular profile of the solar panel with the sun in order to extract maximum energy falling on it. Renewable energy is rapidly gaining importance as an energy resource as fossil fuel prices fluctuate. The unique feature of the proposed system is that instead of taking the earth as its reference, it takes the sun as a guiding source. Its active sensors constantly monitor the sunlight and rotate the panel towards the direction where the intensity of sunlight is maximum. The light dependent resistor's do the job of sensing the change in the position of the sun which is dealt by the respective change in the solar panel's position by switching on and off the geared motor. The control circuit does the job of fetching the input from the sensor and gives command to the motor to run in order to tackle the change in the position of the sun. With the implementation of the proposed system the additional energy generated is around 25% to 30% with very less consumption by the system itself. In this paper, an improvement in the hardware design of the existing solar energy collector system has been implemented in order to provide higher efficiency at lower cost.

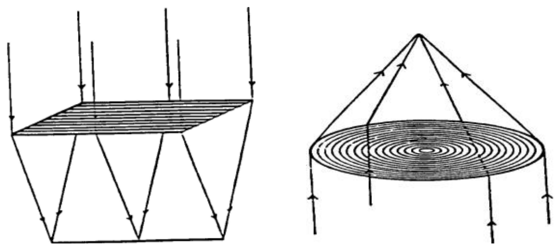
Selection of Fresnel lenses

Solar radiation is concentrated by reflection or refraction through mirrors or lenses. The mirrors can be plane, called heliostats, or parabolic; the lenses can be simple lenses or Fresnel lenses (FL). Concentrators are used to improve the solar energy caption in specific applications. In a lens, the refraction phenomenon is produced in the surface, while the bulk material between the two surfaces doesn't have any influence in the refraction. In 1748 Georges- Louis Leclerc had the idea of reducing lens weight and size acting on the lens surface, but it was a French mathematician and physicist, Augustin-Jean Fresnel, who built, in 1820 the first lighthouse using Leclerc's design. The FL is a flat optical component where the bulk material is eliminated because the surface is made up of many small concentric grooves (Fig. 1).



Each groove is approximated by a flat surface that reflects the curvature at that position of the conventional lens, so each groove behaves like an individual prism. There are two basic FL configurations: linear (Fig. 2) and circular (Fig. 3).

A linear FL has linear parallel grooves and the focus is a line. A circular FL has circular concentric grooves and the focus is a small circle. FL manufacture processes have developed. First designs were cut and polished in glass. In 1950 they started to be made by pressing hot glass in metal molds, and since the eighties they are made of plastics. Modern plastic FL, cheaper and lighter than a conventional lens of the same size, has high optical quality and no spherical aberration.



(Fig.2) (Fig.3)

(Cristina Sierra, Alfonso J. Va´ Zquez," High solar energy concentration with a Fresnel Lens," Journal of Materials Science (40), (2005), pp.1339 – 1343).

Cristina Sierra et. al. (2004) the high solar energy density achieved in our simple and cheap Fresnel installation has been used for several surface modifications of metallic materials. This equipment is a very useful tool to apply concentrated solar energy in the field of high and very high temperatures. These temperatures are achieved in a few seconds and usually the materials treatments are completed in minutes. Fresnel lens installation is a serious alternative to the conventional equipment for material treatment and even to the large solar installations. In this work we review the surface modifications produced by concentration of solar energy with a Fresnel lens.

Musa et al. (1992) carried out the design, construction and performance test of a parabolic Fresnel concentrator cooker using locally available materials. The design of the concentrator cooker was based on the Fresnel principle which consists of concentric parabolic rings – frustums of cones. These components were arranged on a flat structure having the same focus and properties for light perpendicular to their axis or revolution. Glass mirrors were used as the reflective material. The pot was placed on a grill fixed at the focal point of the concentration which is suspended such that it rotates freely about the focal axis. In this way, the pot remains stationary irrespective of tracking angle setting. The concentrator presents a smaller amount of area to the wind compared to a parabolic dish concentrator, thereby promising greater stability and pot accessibility. Tracking the sun with the concentrator is by manual adjustment at 20 minutes time interval for altitudinal change in the sun's position. Series of water boiling and controlled cooking tests carried out with the concentrator under various levels of atmospheric turbidity yielded very encouraging and satisfactory results. Though the Fresnel concentrator performed satisfactorily despite a 34.3% reduction in reflective area compared to a parabolic of the same diameter, the 20 minutes ritual needed for manual adjustment in order to track the sun proved to be a major disadvantage with this device.

Conclusion

The paper was focused on the Solar Energy high temperatures using parabolic solar concentrator, Fresnel lens, Reflecting materials and solar tracking. It identified their level of performance. 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.

To overcome this, there is change in material like anodized aluminum sheets, aluminized plastic films for concentrators. The use of Fresnel lenses will raise more temperature than conventional one and can be used in furnace heating. Solar energy concentrated by Fresnel lenses is a cheap and environmentally friendly energy source suitable for surface materials treatments .The current investigation introduced that with two axes sun tracking to resolve the problem of frequent tracking and standing in the sun, which are the main drawbacks of most concentrating solar cookers with manual tracking. The provision of two way tracking mechanism for a parabolic type solar concentrator permits accurate and effortless focusing of solar radiation on the receiving surface of the utensil placed at the focus of the reflector.

Acknowledgment

The author would like to acknowledge the Professor S. R. Karale for great support to this project.

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