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SOLAR CONCENTRATORS' DEVELOPMENTS IN NIGERIA: PROSPECT AND CHALLENGES

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Abstract
Solar radiation has been identified as the largest renewable resource on earth. Solar energy can be applied in different ways and also many different methods for collecting the solar energy from incident radiation are available. The use of concentrators in the forms of solar energy collectors in order to concentrate sunrays for better usage is on the increase world wide. To this effect, different types of solar concentrators have being developed over the years for various applications. They have proved to be effective way to provide the energy needed for cooking to people with less access to other energy sources. The present study reviewed the various solar concentrators developed in Nigeria such as the parabolic fresnel concentrator, paraboloid solar cooker, parabolic trough collector, conical concentrator, compound parabolic solar concentrator and solar tracking bi-focal collectors. It identified their level of performance and limitations, and made suggestions for further improvement. The needs for support by adequate funding through research grants and patronage by governments, corporate bodies and individuals was emphasized. Awareness on the various types of solar concentrators available and their areas of applications needed to be intensified in order to achieve a sustainable development.

Keywords: energy, solar, collector, concentrator, development, performance.

In most rural households in the third world countries, fuel wood is still a major source of domestic energy source. Excessive cutting down of trees for fuel wood causes environmental depletion, and using fuel wood for cooking produces smoke, raising the risk of lung cancer and eye damage. In order to achieve a sustainable development and solving the energy problem facing the world especially the third world countries, various researches on alternative energy source especially in area of renewable energy that would compliment or replace the conventional energy source for cooking in developing countries are ongoing.

Exploitation of renewable energy resources has been in the forefront of campaign throughout the world for the supply of significant proportion of the world energy needs. Solar radiation has been identified as the largest renewable resource on earth, and this energy source is more evenly distributed in the Sunbelt of the world than wind or biomass, allowing for more site locations (Muller-Steinhagen, 2003).

Solar energy is the energy generated by harnessing the power of solar radiation. The maximum intensity of solar radiation at the earth's surface is about 1.2 kW/m^2 but it is encountered only near the equator on clear days at noon. Under these ideal conditions, the total energy received is from 6 - 8 kW h/m^2 per day (Halacy, 1980; Androsky, 1973; Spillman et al., 1979). Solar energy can be applied in different ways and also many different methods for collecting the solar energy from incident radiation are available. The use of sunlight directly as an energy source has proved in the past to be less economical than the use of these other sources of concentrated sunshine in the forms of solar energy collectors. Solar collectors developed over the year can be categorized as concentrating or focusing collectors, flat plate collectors, solar ponds and photovoltaic panels (David, 1979; Garg, 1982).

This study examines various developments in solar concentrators in Nigeria. It identifies, describes and reports on various categories of solar concentrators developed, their prospect and the challenges. In this way, this paper is significant in attempting to present ways of addressing the issues of sustainable development through the development of solar cookers for the use of those in the third world countries.

SOLAR RADIATION AVAILABILITY IN NIGERIA

It is normally estimated that areas of the world lying between latitudes 35^{o}N and 35^{o}S of the equator and which have at least 200 hours of bright Sunshine per year are ideal for the utililization of the sun's energy. Nigeria, located between latitudes 4^{o}N and 14^{o}N of the equator is very much within this area. The abundance of solar energy is best quantified in terms of the available average irradiation, and hours of sunshine and frequency of overcast. A reasonable amount of work has been done to quantify and predict the status of solar radiation availability in Nigeria by research centers, institutions and various individuals (Sambo and Doyle, 1980; Sambo, 1986; Layi Fagbenle, 1990; Ojosu, 1989; Onyegegbu, 1993; Layi Fagbenle and Karayiannis, 1994; Layi Fagbenle, 1995).

Results of these various studies show that the country is endowed with reasonable amount of solar energy. Summary given by Aliyu (1998) shows that the Total annual solar energy received is 5x10^{12} kWh, Range of mean daily radiation is 15.4 – 22.6 MJ/m^2 – day, Range of mean daily sunshine is 3.5-7.0 hrs, and Range of Mean daily overcast is 1.5 – 5.5 hrs. These values are high on the average for the whole country but relatively higher in

the Northern part of the country. These have made solar energy to generate and attract attention in Nigeria, hence, the on going local research efforts to utilize the solar energy resource.

DEVELOPMENTS IN SOLAR ENERGY CONCENTRATORS IN NIGERIA

Based on the available literature and materials, a number of researchers have carried out various works on concentrating solar collectors in Nigeria some are reported below.

Parabolic Fresnel Concentrator: 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.

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. The fresnel concentrator performed satisfactorily despite a 34.3% reduction in reflective area compared to a paraboloid of the same diameter.

Paraboloid Solar Cooker: Pelemo et al. (2002a) have carried out the design, construction and performance test of focusing type solar. Basic paraboloid equation were used in the design after due consideration of all necessary environmental factors. The performance of the concentrator cooker constructed was found satisfactory in Ile-Ife environment. The layout is shown in figure 1.

Pelemo et al. (2002b) 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 reflective materials in Ile-Ife environment even though they have different years of effective service durations.

Pelemo et al. (2003) also demonstrated the application of solar concentration for water boiling and distillation in a Nigeria environment (Ile- Ife). Concentrator with rotatory paraboloid reflector was used in their work because of its capacity of delivering high focal temperature, large power and short cooking time couple with the simplicity of determining the focal spot. The concentrator was constructed based on the parabola whose focal point was 70cm. The concave part forming the reflector was obtained by sticking small pieces of glass mirrors onto the surface using coal tar. Tracking of the sun by the concentrator was done manually. Water boiling and distillation was achieved with the solar concentrator at Ile-Ife. In Bauchi, Nigeria, Dahiru et al. (2007) have carried out the development of a paraboloidal concentrating solar cooker with manually tracking device and tested under hazy weather condition. Maximum temperature of 91^{o}C was attained during water boiling test. The layout of the solar cooker is shown in figure 2.

Parabolic Trough: Sulaiman et al. (1989) have designed and tested a low-cost cylindrical collector for steam generation which still requires further improvement. Also Ahmed (2001) carried out the design, fabrication and performance evaluation of an improved parabolic trough solar concentrating collector using slat-mirrors in Ahmadu Bello University (A.B.U.) Zaria, Nigeria. The design was based on parabolic trough concept and a prototype collector of aperture area of 1.2m^2 was constructed. The sun tracking mechanism consisted of two angle-iron bar structures freely connected to convert linear displacement of a satellite dish jack arm bolted in between them into an angular motion of the collector as to align the sun rays. Performance evaluation based on water heating shows that the collector using slat-mirrors is over 75% efficient against its evaluation when collector with continuous curved surface is considered. The maximum flow temperature attained by the collector was 58^{o}C, while the maximum hourly and daily efficiencies were evaluated to be close to 50% using data collected during tests in Zaria environment. The layout of the solar collector is shown in figure 3.

Conical Concentrator: In order to improve on existing work on conical concentrator, another design and development of a solar conical concentrator was carried out by Daudu (2002). He designed and constructed an axicon concentrator of 100cm aperture, cone height of 46cm and vertex angle of 90^{o}. The cone was developed from steel sheet of 0.6mm thickness and the inner surface aligned with 63 designed triangular plane mirror strips. Each strip is 5cm wide on the upper side and 1cm wide on the vertex side of the cone. Two absorbers of diameters 8cm and 6cm, and heights of 46cm and 47cm respectively were also designed and fabricated. The absorbers were painted black, filled with water and placed at the centre of the axicon mounted on an improvised mounting of modified common satellite stand. The sun tracking could only be achieved by adjusting an adjustable leg of the mounting stand manually at interval, which in turn tilts the axicon collector to the desired direction i.e. direction facing the sun. Rollers wheels were provided for the legs for easy movement of the unit as well as for azimuthally changes. When located in the sun, the temperature as high as 106^{o}C were recorded. The layout of the conical concentrator is shown in figure 4.

Compound Parabolic Solar Concentrator: Asere et al. (2003) have carried out the design, construction and

testing of a compound parabolic solar cooker (CPC). The temperature of up to 90^{o}C was obtained while highest instantaneous efficiency of the cooker for the clear day was 44%. The layout of the compound parabolic cooker is shown in figure 5. 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 (Habou et al. 2003).

Solar Tracking Bi-Focal Collectors: A solar tracking bi-focal collector system shown in figure 6 has been designed, constructed and tested for the purpose of heating water by Abdulrahim (2008). The collectors were made of two paraboloid concentrators, each having an aperture area of 1.53m^2, aperture diameter of 1.4m, depth of 0.145m, focal length of 0.84m, receiver diameter of 0.3m and a concentration ratio of 22. For the construction of the solar collectors, mild steel- sheet and square pipe were used as the shell support for the reflecting surfaces, while the concave parts forming the reflectors were obtained by sticking small pieces of glass mirrors on to the surface of the shell using glue (Abdulrahim et al., 2011a & 2012a).

The tracking mode adopted is the mechanical clockwork system using chains and sprockets. Framework support structure was provided for the solar collector system and the water supply system comprises of an elevated tank, structural support, pipe networks, fittings and hoses (Abdulrahim et al., 2012b). Performance evaluation of the solar collectors carried out in Maiduguri revealed that minimum outlet water temperature of 42^{o}C was recorded during the month of December, while the temperature rose to 78^{0}C in March and September (Abdulrahim et al., 2011b). The highest temperature attained during the test period was 83^{0}C when using a modified receiver to heat 8 liters of water at the focal zone of the collectors in March (Abdulrahim et al., 2011c).

PROSPECT AND CHALLENGES OF SOLAR CONCENTRATORS DEVELOPMENT AND UTILIZATION

From the foregoing, it was found that the designs of these various concentrators were carried out by able individuals in Nigeria, and the materials used in the construction were sourced locally as well as the fabrication technology. Also, most of the developed Solar Concentrators were carried out by individuals or groups with or without support from their various institutions and research centers. Government intervention of full support in funding relevant researches in this area is yet to be fully felt. It was also found that public awareness on the potential of Solar Concentrator utilization for cooking and heating is still low. So, it is yet to be a popular means for house hood cooking/heating.

CONCLUSIONS AND RECOMMENDATIONS

Past work on solar focusing collectors in Nigeria employed the use of polish parabolic curved surface to form the focusing surface of the collectors while in some cases small pieces of mirror plates were placed on the parabolic curved surface. The tracking modes range from manually tracking to automated mode of tracking. Attention has also been given to support system for the collectors when necessary. The solar concentrators developed have a wide range of applications such as water heating, steam generation, water distillation, solar refrigeration and cooking of food items. A common theme arising from the available literature is the need for further improvement of these developed solar concentrators. Supports in form of research grants, and patronage of these developed solar concentrators is highly recommended by the various level of government and nongovernmental organization (NGO). The populace is to be made aware of the available solar concentrators developed so far and their potential in meeting the energy required for sustainable development

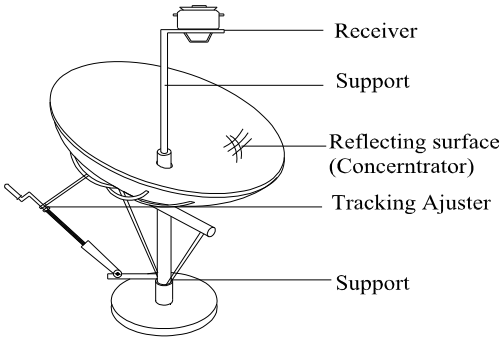


Figure 1: Focusing-type Solar cooking device (Pelemo etal.,2002a)

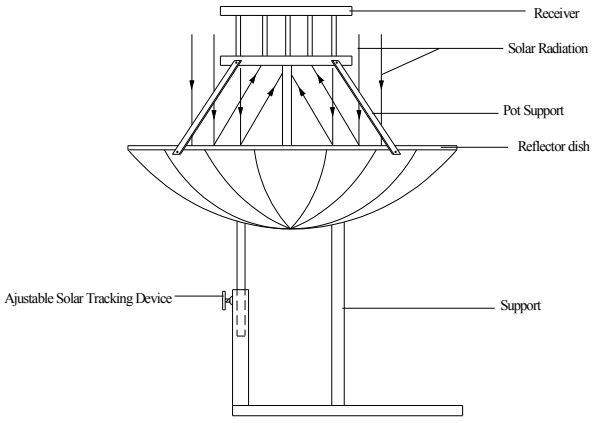


Figure 2: Concerntrating Solar Energy Cooker (Dahiru etal.,2007)

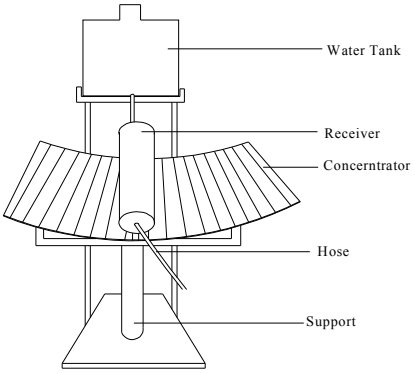


Figure 3 : Solar trough collector (Ahmed, 2001)

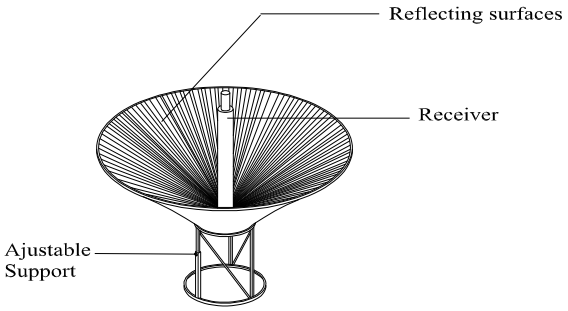


Figure 4: Solar Conical Concerntrator (Dauda,2002)

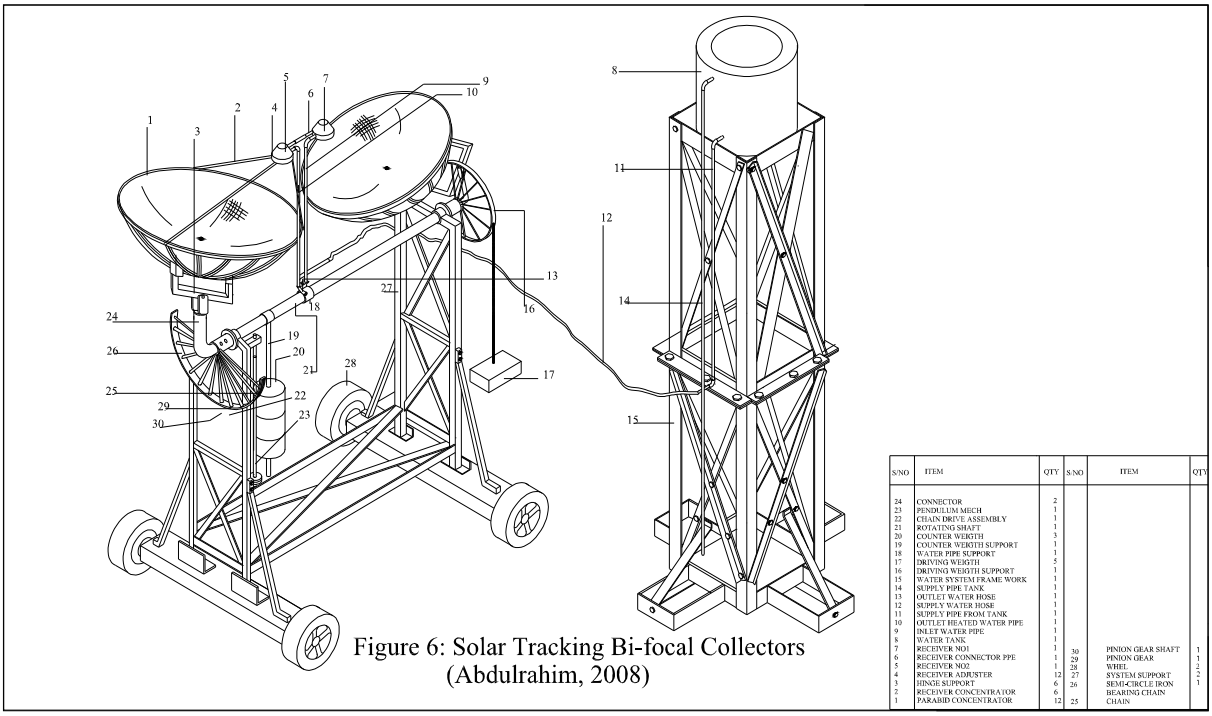


Figure 6: Solar Tracking Bi-focal Collectors (Abdulrahim, 2008)

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