The Prospects of a Promising Solar Thermal Concentrator (Fresnel Lens) for Cooking, Heating and Electricity Generation

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Abstract: - Approximately 2.7 billion people do not have access to reliable energy services[1] Communities in developing countries most especially Africa derives over 80% of its energy for domestic use through fuelwood,one of the consequences of over-dependence on fuelwood and fossil fuels is global warming [2] In the absence of a significant reduction in global emissions from current levels between now and 2050, global temperatures could rise by 4°Cthis change in temperature comes with high uncertainties that would experience increased frequency of high-intensity tropical cyclones, irreversible loss of biodiversity, including coral reef systems, unprecedented heat waves, severe drought, major floods and new risks that threaten our ability to anticipate and plan for future adaptation[3] These serious concerns draw the attention to the need to consider a new, significant, efficient, inexpensive, simple and safe alternative and sustainableenergy technology for domestic and industrial needs which is environmentally friendly at lower cost.This paper present an evaluation study of parabolic concentrator which is the most mature concentrated solar thermal power system and currently utilized by multiple operational large-scale CSP farms around the world against the unpopular Fresnel lens concentrator, which up till now no full-scale thermal systems using Fresnel lenses are known to be in operation as commercial power plant. The preliminary experimental result shows that the highest stagnation temperature recorded at the receivers of 50cm aperture parabolic trough, 50cm diameter 3mm thick Fresnel lens and 25cm 3mm thick fresnel lens with no load were found to be about 170°C, 900°C and 250°C respectively. This indicates that the Fresnel lens technology is very promising, a small standalone system for both cooking and electricity generation with high efficiency, easy to re-fabricate at a lower costcan be actualized, modification is on-going to actualize this system, which will reduce the overall cost and thereby reducing fossil fuel consumption which in return reduces CO_2 emission.

Key-Words: -Fresnel lens, global warming, solar thermal concentrators, solar cookers

1 Introduction

Approximately 2.7 billion people do not have access to reliable energy services and 1.5 billion do not have access to electricity, as the rate of connections will not be able to keep pace with population growth, at the same time, global greenhouse gas emissions are soaring. (UNDP, 2012).

Communities in developing countries most especially Africa derives over 80% of its energy for domestic use through fuelwood, but the use of fuelwood and fossil fuel has been found to be very detrimental to socio-economic life of the people, as well as environmental degradation. One of the consequences of over-dependence on fuelwood and fossil fuels is global warming and deforestation, where trees are cut indiscriminately to meet basic needs of the teaming population (Ardayfio-Schandorf, 1993).

In the absence of a significant reduction in global emissions from current levels between now and 2050, global temperatures could rise by 4°C, and possibly 6°C by 2100, there is a narrow 7-10 year window remaining during which the energy sector must be decarbonized in order to avoid catastrophic climate change scenarios.

Most importantly, a 4°C world is so different from the current one that it comes with high uncertainties that would experience increased frequency of high-intensity tropical cyclones, irreversible loss of biodiversity, including coral reef systems, unprecedented heat waves, severe drought, major floods and new risks that threaten our ability to anticipate and plan for future adaptation needs. A 4°C world can, and must, be avoided (J. Y. Kim, Nov 2012).

Heat wave see temperature rise to 40°C in Brazil and Argentina (Aljazeera, Dec 2012).

These serious concerns draw the attention to the need to consider a new, significant, efficient, inexpensive, simple and safe alternative and sustainableenergy technology for domestic and industrial needs which is environmentally friendly at lower cost.

An energy source that meets such sustainability requirements is "solar thermal technology", which is a technology for harnessing limitless solar energy for thermal energy (heat).This paper present an evaluation study of parabolic concentrator which is the most mature concentrated solar thermal power system and currently utilized by multiple operational large-scale CSP farms around the world against the unpopular Fresnel lens concentrator system, which up till now no full-scale thermal systems using Fresnel lenses are known to be in operation as commercial power plant.

Finally modification is on-going to actualize a solar thermal concentrator system that is much cheaper, smaller in size and simple for re-fabrication by local artisans across the globe, the systemwill reduce the overall cost of solar thermal technologies (solar cookers and concentrators for electricity generation) thereby reducing fossil fuel consumption, in return reduces CO_2emission,however this will help disseminate the technology much easier and faster at a lower cost when compared with a more expensive and complicated parabolic trough system.

2 OVERVIEW OF HIGH AND MEDIUM TEMPERATURE CONCENTRATORS

For years, several researches werecarried out by researchers to design, simulate and evaluatedifferent solar thermal concentrators across the globe with a view to remedy the identified problems highlighted above (mainly global warming), but most of the available high temperature solar thermal electricity generation technologies (parabolic trough, tower, dish stirling, Fresnel reflector, chimney and large community solar cookers)turn out to be excessively large and heavy, occupying large land mass running into tensto hundreds ofmeters per system, highproduction costmakes it very difficult for local communities to afford,this hinders energy accessibility to so many communities in dare need for their lively hood across the globe. On the other hand small medium temperature solar cooker systems: (box, dish, parabolic and plat plate)are very unpopular due to their low efficiency and inconveniency in cookingand material cost when compared withthe traditional use of fuel wood. This however necessitate the research to try to find out an efficient, compact and simple system (for high and medium temperature) that meets the needs of Industries and the general populace for cooking/heating and electricity generation at a very much lower cost using solar thermal technology.

2.1High temperature solar thermal concentrators (electricity generation) over view

Generally high temperature solar thermal concentrators are devices that produce heat from about 100°C – 1000`s °Cfrom sunlight, which is subsequently converted into electricity and are differentiated base on the optical principle they used for energy concentration

2.1.1 Parabolic trough

This is a one axis system made in a parabolic shape with huge parabolically shaped mirror, (which is expensive to manufacture)or other reflector materials on the inner surface usually joined together running into meters (1-600m) with a coated absorber tube filled with working fluid (oil) running along its axis from end to end, the oil is heated to about 400°C and in turn heats up water to steam for electricity generation ina rankine cycle, for now it stands to be the most mature CST technology across the globe with a concentration ratio of around 80-100x,with solar to net efficiency of 14% annually. The largest operational solar power system at present is one of the SEGS plants and is located at KramerJunction in California, USA, with five fields of 33 MW generation capacity each

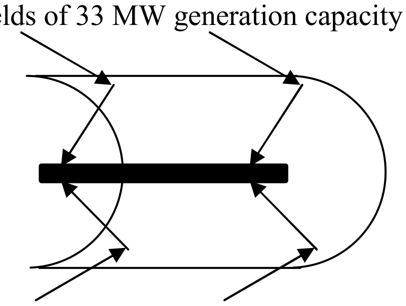


Fig. 1 Parabolic Trough

2.1.2Solar power tower

This is more like a furnace with several array of dual axis tracking heliostat reflecting the solar radiation at the central receiver on top. Steam is heated to 500 °C to drive turbines that are coupled to generators which produce electricity, the temperature generated can reach up 1300°Cthus producing superheated steam for turning generators to produce electricity attaining a higher efficiency of 25% than trough, the system occupy large space up to about 150hecters(1,500,000 m^2) to 320 hectares (3,200,000 m^2) of land. The expected largest tower system is Ivanpah Solar Power Facility developed by Bright Source Energy in the United States of America with the installed capacity of 392MW expected to be completed in 2013.

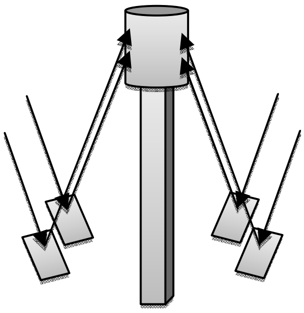


Fig. 2 Solar Power Tower (central receiver heliostat)

2.1.3Solar dish

The solar dish is a parabolic reflector that turn on two axes to track sunand concentrate onto a thermal receiver/stirling engine positionedat the focal point of the concentrator. Temperatures can rise up to 1,000°C with concentration ratio up to 1,000x.In connection with a stirling engine, these systems could be used as stand-alone with solar to electric efficiency of about 30% which is the highest among CST systemsitcan be used to generate electricity in the kilowatts range.

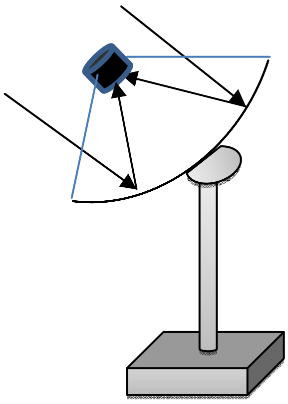


Fig. 3 Solar Dish

2.1.4Concentrated linear fresnel reflector

This is a new technology compared to the trough, tower and dish systems, it utilizes mirrors arrange in strife in a form of Fresnel lens structure with the aim of reducing cost of curved mirror production as in the case of trough it also look like a trough in the way the mirrors are arrange linearly to also reflect to a linear coated tube with working fluid, in other way it is just like the tower where the mirrors (heliostat) are arranged with individual one axis tracking system to track the sun. An example of Fresnel concentrator power plant is Puerto Errado 2 (PE2) which was built in the region of Murcia by the German company Novatec Solar with mirror surface area of about 300,000m² and a total capacity of 30MW it started operation in 2012 as the world's largest Fresnel CSP power station..

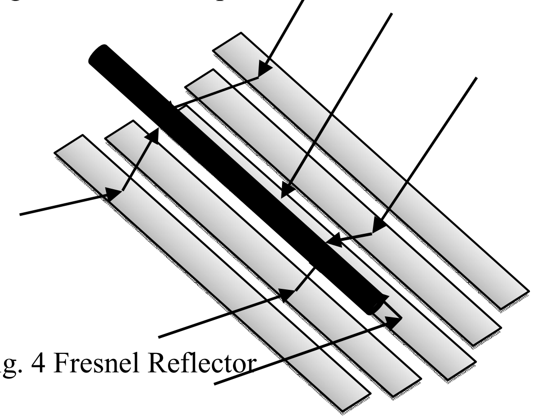


Fig. 4 Fresnel Reflector

2.1.5 Solar chimney

This is a system designed to trap and heat air at ground level under a transparent collectorroof (about 130meters in diameter) made of glass or special plastic which can as well serve as a greenhouse for growing plants, the air when heated tried to find a way of escaping through a chimneyof about 1000 meters height by chimney effect, the effect drives the installed wind generator in between the chimney base and the roof top,unlike other concentrators described above utilizing only direct irradiance this system make use of global irradiance.Both the size of the collector and chimney affect the output of the system and the roof can serve as energy storage.

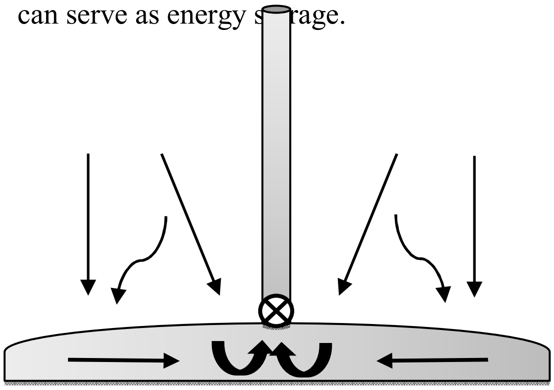


Fig. 5 Solar Chimney

2.1.6 Summary

These high temperature concentrator systems are very expensive, occupies very large area of land mass and the technology involve is advance beyond the local communities capability, there is the need to have an alternative concentrator design that is smaller, cheaper, easy to re-fabricate and saferhence introduced in this paper.

2.2 Medium temperature Solar concentrators (solar cookers) overview

KlemensSchwarzer et al 2006 classify solar cookers based on the type of collector and the place of the cooking as follows:
(a) Flat plate collector with direct use–type A
(b) Flat plate collector with indirect use–type B
(c) Parabolic reflector with direct use–type C
(d) Parabolic reflector with indirect use–type D

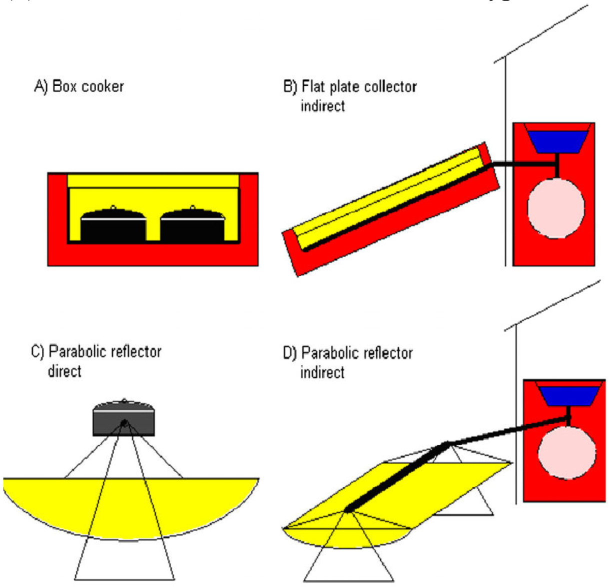


Fig. 6 Solar Cookers

2.2.1Flat plate collector with direct use–type A

This is a direct system with a flat plate collector (A), the cooking pot is placed directly in the collector most of these cookers are the box type with maximum temperature of about 80°C -120°C.

2.2.2Flat plate collector with indirect use–type B

In the indirect system (type B), the energy is transported from the collector to the cooking place by a heat-transfer medium the heat pipe and in this case also the temperature range is about 80°C - 100°C.

2.2.3Parabolic reflector with direct use–type C

While in type C, a parabolic reflector concentrates the sunlight on the cooking pot and the temperature is usually high running into hundreds depending on the size of parabola and easily burn food because it does not have any temperature control.

2.2.4Parabolic reflector with indirect use–type D

Similar to type B, type D uses a heat-transfer medium and a trough as a concentrator

2.2.5 Summary

Most of these medium temperature concentrator systems (solar cookers) took several minutes in some cases hours to raise the stagnation temperature to about 100°C or more, most of these cookers can only reach a maximum temperature of about 150°C, some of their disadvantages include inconveniency in cooking, inefficiency and hazard of burning these factors make them very unpopular therefore there is the need to have an alternative concentrator design that is smaller, cheaper, easy to re-fabricate and safer hence introduced in this paper.

3 ExperimentalSetup

An experiment was set up to compare and evaluate two types of concentrators (Fresnel lens and parabolic trough) with a view to design and develop an efficient, compact, and simple system that meets the needs of Industries and the general populace for cooking /heating and electricity generation at a very much lower cost.
The system was setup as can be seen in the diagram below with a Fresnel lens on top of a rig and a copper plate receiver attached to a thermocouple sensor; two separate lenses (50cm and 25cm) were used to collect several data (stagnation temperature Ts, ambient temperature Ta and global solar irradiation W/m^2) throughout the experiment with the rig. On the other side is a 50cm parabolic trough also attached to a thermocouple in one case and three thermocouples in another case through its linear copper receiver as can be seen in the result presented below, all the two concentrator types are connected to a data logger for data collection at interval of 5secs. In both cases one axis tracking is used for the experiment.

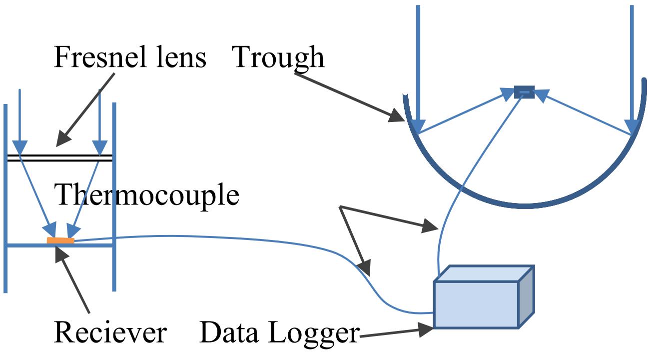


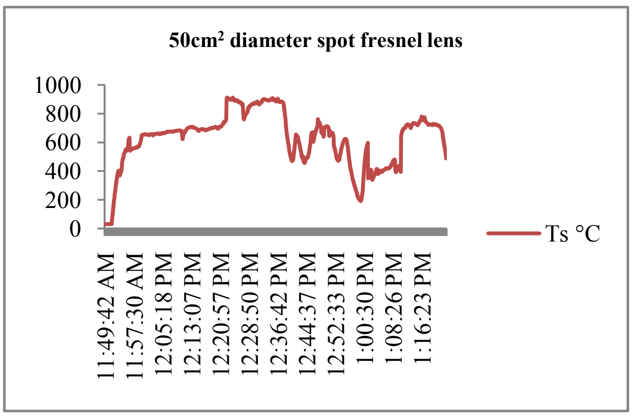
Fig. 7 Experimental setup

3.1 ANALYSIS OF RESULTS

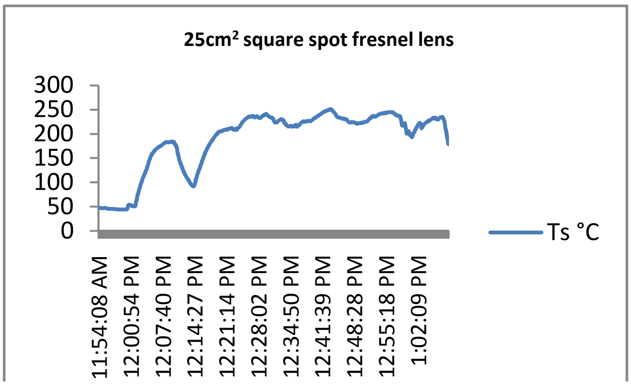
The preliminary result presented below represent various stagnation temperatures collected from the 50cm^2 Fresnel lens, 25cm^2 Fresnel lens and 50cm^2 parabolic trough for comparison, though with some tracking inefficiencies and heat losses from the receivers.

The results clearly shows that the stagnation temperature of parabolic is much lower than that of the Fresnel lens of equal geometric size, it did not match with the smaller lens that is almost half by its geometrical size compared to the parabolic trough, it is also clear that the stagnation temperature for the lens 50cm of the same geometrical size with the trough is almost four time (4:1) as can be seen clearly from the result.

This shows that Fresnel lens output in relation to its geometrical size is very encouraging and can thus be utilized for high temperature generation and higher efficiency.



(a)



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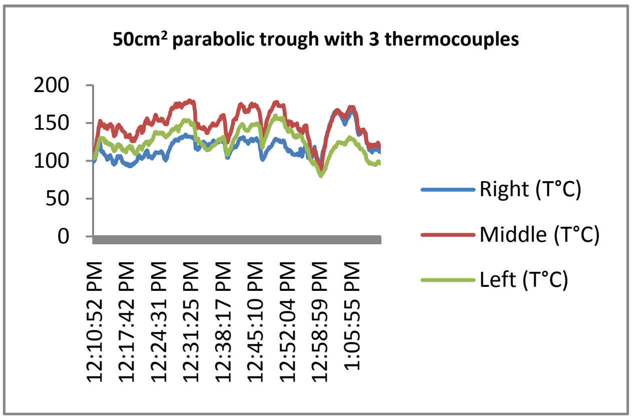
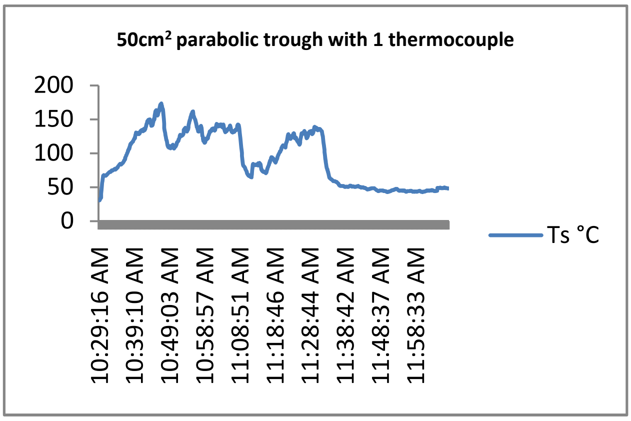


(c)



(d)

Fig. 8Graphs representing stagnation temperatures (a) 50cm^2 Fresnel lens (b) 25cm^{2}Fresnel lens (c) 50cm^2 parabolic trough with 3 thermocouples (d) 50cm^2 parabolic trough with 1 thermocouple

4 Conclusion

The preliminary data collected shows that there is great potential in using Fresnel lens concentrator as a small standalone system for both cooking and electricity generation with high efficiency, easy to fabricate at a lower costfor communities to afford. modification is on-going to produce a better and more efficient system using simple optics, which will reduce the overall cost and thereby reducing fossil fuel consumption which in return reduces CO_2emission.

Up till now no full-scale thermal systems using Fresnel lenses are known to be in operation as commercial power plant, it is time to give fresnel lens technologies a chance for possible integration into the solar thermal concentrator system for both heat and electricity generation considering its higher stagnation temperature generation capability as compared to a parabolic trough of the same geometrical magnitude.

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