A short review on solar concentrator for energy generation in tropical coastal belt

Emetere M.E.1,2, Emetere J.M.3, and Ometan O.O.1,4

1Department of Physics, Covenant University Canaan Land, P.M.B 1023, Ota, Nigeria.
2Department of Mechanical Engineering Science, University of Johannesburg, South Africa
3Department of Mathematics, Federal University of Technology, Minna, Nigeria
4Department of Physics, Lagos State University, Lagos Nigeria
Corresponding Author; emetere@yahoo.com

Abstract-
The use of solar photovoltaic (PV) panel in highly convective tropical regions along the coastal belt has been reported to have low efficiency. Hence, the lifespan of the PV panel is endangered by different solar spectral absorbed by the solar cells. In this research, the solar collector was reviewed with the aim of recommending designs for solar farm operator or standalone user. It is recommended that solar collector could improve the use of solar energy to about 34% in highly convective tropical regions along the coastal belt.

Key words: solar, energy, solar irradiance, meteorology, solar concentrator

1. Introduction

The focus on meeting the energy needs of populace around the globe have taken centre stage with scientists at the forefront. The need to use one technological device or the other has influenced the rising energy needs even in remote villages. The common source of energy in the developing countries is the use of fossil fuel for automobiles, generators etc. Unfortunately, fossil burning has led to huge anthropogenic emissions. Air pollutions have led to climatic change, acid rain, global warming etc [1-3]. In recent years, the growing concerns on environmental hazards have redirected the focus of energy experts and researcher to friendly and efficient energy options or alternative [4].

In recent times, the renewable energy options have received huge patronage by governments, industries, and individuals. This is because it is environmentally friendly and its sources are naturally available. The wind and solar energy is the most widely patronized forms of renewable energy around the world. Its technology is flexible both for grid or standalone users around the world. In recent year, solar energy is preferred in the tropical climatic region because solar energy is abundant and environmentally friendly. Based on the above, there are huge investments on solar device for domestic and public use. Broadly, there are two (2) major techniques used in harnessing solar energy which are currently in use, they include; solar photovoltaic (PV) and solar thermal processes [7]. The challenges of the use of solar PV in tropical regions located in the coastal belt are enormous. For example, Lagos Nigeria is a typical example of tropical location along the coastal belt. The uses of solar PV panel have been hugely inconsistent. The hype on the use of solar PV panel have doused by the low lifespan and energy output of PV panels [8]. Hence, fossil fuel generators are gradually replacing renewable energy options. However, while the PV companies keeps improving on their products to Nigeria, it is observed that the use of solar collector may be a better option for local farmers, domestic energy
users and small businesses. In this review, the focus is on solar collectors. This device is believed to be relevant in highly convective tropical regions close to the coastal belt.

2. Principles of Solar Thermal Systems
Solar thermal systems are gradually influencing the energy markets as it makes use of heat from the sun to generate electricity. Hence, the emphasis on the use of solid-state device to generate electricity from the sun is gradually becoming obsolete because of this technology known as concentrator solar power (CSP) technology. The algorithm presented in Figures 1 & 2 illustrates the principles guiding the adoption of CSP technology.

![CSP algorithm for heat engine](image1)

Figure 1: CSP algorithm for heat engine [9]

![CSP algorithm for heat transformation](image2)

Figure 2: CSP algorithm for heat transformation [10]

From the above algorithm, it is shown that the CSP takes its source from solar radiation (which is abundant in the tropics). The concentrators redirect the captured solar radiation into a device
known as heat engines. A range of solar collectors that provide heat that is then applied in numerous applications such as; heating water for domestic uses and other numerous projects, captures sunlight.

A solar collector is an essential component of a solar thermal system (STS) because it's the key component that converts solar radiation energy into thermal energy. The useful heat is then transported from the absorber to circulating fluids (which may be water most time). The circulating or transition fluid is stored in a tank or an advanced storage system [5]. In other words, the solar collectors and thermal energy storage are the main components in the solar thermal system.

One of the criteria for selecting solar concentrator is the performance that is largely based on its optical properties. The reflection of the collectors must be superb to transmit heat waves among others. Heat wave is a period of excessively hot air, which may be accompanied by high humidity.

3. Advances in solar collectors

By literature, the two main types of solar collectors are non-concentrating (stationary) collectors and concentrating collectors [6]. The optimal operation for typical solar collectors is presented in Table 1. The difference between the two concentrators is traceable to its functionality due to its peculiar designs. For example, stationary collectors have the capability of heating water up to 100°C, while concentrator collectors could go beyond 100°C. By the name, non-concentrating collector requires no tracking device for intercepting and absorbing solar radiation. They are also known as flat plate collectors. Hence it is financially affordable and easier to operate in remote rural areas. Above all, it is easy to maintain and cost little to repair. This is evident in the market report on non-concentrating collector that its annual production is estimated to reach 500GW by 2020, from 40 GW in 2013 [11]. This makes its market the fastest growing one in solar devise businesses.

Table 1: Optimum operation for typical solar collectors [12,27]

| Collector               | C   | \(\eta_{opt}\) | \(\varepsilon_r\) | \(T_{r, opt}\) (K) | \(\eta_{sys}\) |
|-------------------------|-----|---------------|-------------------|---------------------|----------------|
| Flat plate collector    | 1   | 0.8           | 0.25              | 401                 | 0.1449         |
| Evacuated tube collector| 1   | 0.7           | 0.10              | 451                 | 0.1777         |
| Compound parabolic collector | 3   | 0.6           | 0.10              | 527                 | 0.2079         |
| Parabolic trough collector | 30  | 0.75          | 0.10              | 884                 | 0.4400         |
| Solar dish collector    | 100 | 0.75          | 0.10              | 1110                | 0.5011         |

Due to the specific energy requirements in tropical climate locations along coastal belts, the preferred solar collector is the concentrating solar collector. The coastal belt is characterized by solar shading (Emetere et al. 2018), high rainfall, low clear sky and low sunshine hour. A typical example is illustrated below- using meteorological dataset over Lagos between 1984-1987 (Figures 3-4).
The variability of the sunshine hour and solar irradiation as presented in the figures above reveal that the best way of tracking the solar irradiance in the region is using concentrating solar collector. The design of concentrating solar collectors mainly comprise of concave reflecting surfaces that capture and focus solar beam radiation onto a smaller receiving area, thereby increasing the radiation flux [13, 27]. Hence, in the following subsections, the emphasis will be on the concentrating solar collector.

4. **Parabolic Trough Systems**
Parabolic trough systems are the most common technology that is commercially available in the open market [11]. A parabolic collector (Figure 5) has the capability of focusing and reflecting the sun radiation to the absorber within wide limits. The geometry of the mirrors in the parabolic
concentrator is such that every small pieces of the mirror are arranged in such a way to allow light travel from all directions.

The essential segments of an parabolic trough framework incorporate the collector tubes, bended mirror gatherings (concentrators) and the heat transfer fluid (HTF). The collector is the segment where solar energy is converted to thermal energy [14]. The absorber is a significant piece of a solar power plant that has huge impact on its performance. The sun powered beams are caught by a bended mirror that reflects the sunlight and center it onto the absorber tube, it is put at the mirror's center line, the activity of the absorber is to assimilate the approaching warmth and exchange it to the flowed liquid. The absorber is normally made of a straightforward material; for example, electro-synthetically stored dark chrome is generally utilized because of its capacity to oppose high temperatures [15].

In order to reduce heat loss, there must be a vacuum in the absorber tube. Presently, the vacuum technique is applied in the absorber tube of parabolic trough systems. The parabolic geometry of the curved concentrator mirrors are meant to converge solar radiation onto the pipe called receiver tube. The optical reflectivity of the curved mirrors is essential to efficiently focus the solar energy. Hence, the mirrors normally have a support structure in form of metal, glass or
plastic plate to ensure firmness. A thermal insulating material is preferred to avoid over heating of the mirrors. Excessive heat transfer by conduction can lead to cracking of the mirror. The final casing is made up of highly reflective material (usually silver or aluminium) [14].

5. Solar Power Tower
Solar power towers produce power from sun-based radiation by centering the concentrated sunlight based radiation (Figure 6) onto a pinnacle-mounted recipient (heat exchanger). Solar power towers are of two types: the external type and cavity type. The sun powered power tower framework comprises of a beneficiary likewise alluded to as the Helioestat Field Collector [17], which is mounted on a pinnacle together with a field of hundreds to thousands of heliostats (enormous two-hub sun following individual mirrors) which center occurrence sunlight based radiation onto the focal recipient (safeguard) at the highest point of a pinnacle as appeared in the figure beneath. The solar receiver (absorber) on the solar power tower framework is for the most part in the state of a cylinder; the cylinder is produced using a metallic compound material covered with a retaining paint. Amid this procedure, presenting the absorber to the concentrated warms the moved liquid at the absorber and reflected sun based motion; the liquid temperature regularly achieves 700 K [18].

![Solar power tower surrounded by large number of heliostats](image)

Figure 6: Solar power tower surrounded by large number of heliostats [19, 27]

Global Market Insights [20] has projected that concentrated solar power market will witness growth in Middle East and Africa. This development may likely raise the investment on CSP to USD 4 Billion by 2025.

6. Dish-Stirling System
Dish-stirling systems are mainly used for stirling engine turbines and its operates by temperature gradient generated by the sun. The Stirling engine is known for its higher efficiency than steam engine, quiet operation, and the ability to use almost any heat source. It is more expensive than the parabolic concentrators. Hence, it may not be the best option for low-income standalone users. However, it may be very useful for small enterprise because its less expensive as the solar power tower and can be applied in smaller units, such as supplying remote villages or towns
[21]. Hence, medium agro businesses can adopt the use of this technology to improve upon its energy demand. Dish-Stirling systems are made-up of many reflective mirrors (like the parabolic dish) and a dish-mounted receiver at its focal point as presented in the Figure 7. The design of the dish-stirling systems keeps metamorphosing based on the need to increase its efficiency. Hence, its market prospect is huge but unstable due to the cost of its maintenance.

Figure 7: A dish collector and its mounted receiver [22]

The prices of concentrated solar power is presented by Market Research Report [23] as shown in Figure 8 below. This shows that the market prospects of dish concentrators (comparatively with other types of concentrator) are relatively low. Hence, since the emphasis of this is research is based on cost and efficiency of solar concentrator, it is essential to discuss on the principles of placing stationary collectors for maximum energy generation.
Figure 8: Concentrated solar power market [23]

7. **Stationary Collectors**

Stationary collectors are collectors that are stationary. This means that there are solar tracking collectors. This type of solar collector under focus are permanently fixed in one position and do not track the sun. The design of stationary collectors must meet the basic requirement of good performance and a good return on investment. Hence, it is expected that the stationary collector must be correctly sized and geometrically oriented. Based on the technicality of acquiring appropriate orientation, it is salient to consider site evaluation. This factor is very important to ensure maximum functionality of the collector. The stationary collector is the main component of Solar Water Heating (SWH) systems used in the domestic applications [24]. Solar Water Heating (SWH) mainly depends on the geographical location, due to the fact that it’s more effective in places of abundant sunlight. Nevertheless, SWH systems also have the potential to function effectively well in countries with less sunlight. A study that was carried out by the Energy Saving Trust, based on field trials in the U.K and Ireland that encompassed 100 sites across both countries, indicates that SHW’s can perform well when the system is used appropriately [25, 27]. In classification in accordance to their system application, stationary solar collectors are categorized into two i.e. heating purposes and combined heat and electricity purposes. Hence, the orientation of the solar collector is very important. According to Enerworks [26], the orientation of the solar collector should be such that the roof angle is equivalent to latitude of location i.e. within the range of plus or minus 15° (Figure 9). This means that if the roof angle is made steeper, it enhance higher performance during winter and allows deposited snow to drop-off more effectively. During summer, shallow roof angle is expected to improve upon collector performance. In the tropic, solar collector may be kept constant but requires regular cleaning due to high dust or particulate deposition.

![Figure 9: Orientation of stationary collectors](image)

8. **Conclusion**
The versed use of solar collector is impressive as it has been shown to have different designed that are properly situated to address energy needs in highly convective tropical regions that is located along coastal belt. Solar collector design that was discussed in this review can suite any size of standalone users. Based on the above discovery, the burdens associated with under utilized solar PV panel will become a thing of the past.

Acknowledgements
The authors wish to thank the host institutions for the partial sponsorship of this work.

Reference

[1]. M. E. Emetere, (2017). Impacts of recirculation event on aerosol dispersion and rainfall patterns in parts of Nigeria, GLOBAL NEST JOURNAL 19 (2), 344-352
[2]. ME Emetere and ML Akinyemi (2017). Documentation of atmospheric constants over Niamey, Niger: a theoretical aid for measuring instruments, Meteorological Applications 24 (2), 260-267
[3]. Moses E Emetere, ML Akinyemi, (2017). A Simple Technique to Evaluate Aerosols Loading in the Atmosphere of Binkolo-Sierra Leone, Journal of Informatics and Mathematical Sciences, 9(2): 339-345
[4]. EPA (2019). Energy Efficiency Reference for Environmental Reviewers, https://www.epa.gov/sites/production/files/2014-08/documents/energy-efficiency-reference-for-environmental-reviewers-pg.pdf (accessed 30th May, 2018).
[5]. Kalogirou, S.A. Solar thermal collectors and applications. Prog. Energy Combust. Sci. 2004, 30, 231–295.
[6]. Tian, Y. (Yuan) and Zhao, Changying (2013) A review of solar collectors and thermal energy storage in solar thermal applications. Applied Energy, Vol.104 . pp. 538-553. doi:10.1016/j.apenergy.2012.11.051
[7]. Larroueturou, F.; Caliot, C.; Flamant, G. Influence of receiver surface spectral selectivity on the solar-to-electric efficiency of a solar tower power plant. Solar Energy 2016, 130, 60–73.
[8]. Moses E. Emetere, Marvel L. Akinyemi, and Etimbuk B. Edeghe, (2016). A Simple Technique for Sustaining Solar Energy Production in Active Convective Coastal Regions, International Journal of Photoenergy 2016, 3567502, 1-11, http://dx.doi.org/10.1155/2016/3567502
[9]. José J.C.S. Santos, José C.E.Palacio, Arnaldo M.M. Reyes, Monica Carvalho, Alberto J.R.Freire, and Marcelo A.Barone1, Advances in Renewable Energies and Power Technologies, Volume 1: Solar and Wind Energies, Pages 373-402 (2018)
[10]. Lovegrove K., and Pye J., Fundamental principles of concentrating solar power (CSP) systems, Concentrating Solar Power Technology, Pages 16-67 (2012).
[11]. Mordor (2018). Non Concentrating Solar Collectors Market, https://www.mordorintelligence.com/industry-reports/global-non-concentrating-type-solar-collector-market-industry (accessed 30th May, 2018).
[12]. Bellos E., and Tzivanidis C.. A realistic approach of the maximum work extraction from solar thermal collectors, Appl. Syst. Innovat., 1 (2018), p. 1
[13]. S. Kalogirou, Thermal performance, economic and environmental life cycle analysis of thermosiphon solar water heaters, Solar Energy, 83 (2009), pp. 39-48

[14]. Kulichenko, N., & Wirth, J. (2012). Concentrating solar power in developing countries: Regulatory and financial incentives for scaling up. Washington, D.C.: World Bank Publications.

[15]. Yang, Y.; Wang, Z.; Xu, E.; Ma, G.; An, Q. Analysis and Optimization of the Start-up Process based on Badaling Solar Power Tower Plant. Energy Proced. 2015, 69, 1688–1695.

[16]. M.K. Islam, M. Hasanuzzaman, N.A. Rahim, Modelling and analysis of the effect of different parameters on a parabolic-trough concentrating solar system, RSC Adv., 5 (46) (2015), pp. 36540-36546

[17]. Y Tian, CY Zhao., A review of solar collectors and thermal energy storage in solar thermal applications, Applied Energy, 104 (2013), pp. 538-553

[18]. Guédez, R.; Topel, M.; Spelling, J.; Laumert, B. Enhancing the Profitability of Solar Tower Power Plants through Thermoeconomic Analysis Based on Multi-objective Optimization. Energy Proced. 2015, 69, 1277–1281

[19]. Sargent & Lundy LL Consulting Group, (2013), https://sargentlundy.com (accessed 30th May, 2018).

[20]. Global Market Insights (2019). Concentrated Solar Power Market to hit $4 billion by 2025: Global Market Insights, Inc. https://www.globenewswire.com/news-release/2019/03/25/1759910/0/en/Concentrated-Solar-Power-Market-to-hit-4-billion-by-2025-Global-Market-Insights-Inc.html (accessed 30th May, 2018).

[21]. Quaschning, V. 2004. Technical and economical system comparison of photovoltaic and concentrating solar thermal power systems depending on annual global irradiation, Sol. Energy, vol. 77, no. 2, pp. 171-178.

[22]. Eduardo F. Camacho, Manuel Berenguel Soria, Francisco R. Rubio, Diego Martinez, Control of Solar Energy Systems, pp. 239.

[23]. Market research report (2017). Concentrated Solar Power Market Analysis. Report ID: GVR-1-68038-996-8

[24]. Kalogirou, A.S., 2004. Environmental benefits of domestic solar energy systems. Energy Conversion Manage., 45: 3075-3092.

[25]. Kalogirou, A.S. and P. Christos, 2000. Modelling of a thermosyphon solar water heating system and simple model validation. Renewable Energy, 21: 471-493.

[26]. Enerworks, (2019). Solar Collector Installation Manual. https://enerworks.com/downloads/Module-4-Solar-Collector-Installation-Manual.pdf?x59561 (accessed 30th May, 2018).

[27]. Ramadan Mawi Yahia Kazuz, Hybrid Solar Thermo-Electric Systems for Combined Heat and Power, PhD thesis, Cardiff University. Pg. 14-44.