International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 8 Issue 02 Series. II || Feb 2019 || PP 52-58

Comparative Analysis of Selected Flat Plate Collectors against Evacuated Tube Solar Collector

[1]Sani Aliyu and [2]Yusuf Abdulmalik
[1]Department of Physics, Usmanu Danfodiyo University Sokoto
[2]Department of Physics, Federal University Gusau
Corresponding Author: Sani Aliyu

Abstract: *Solar energy being the most reliable and abundant source of energy, it is necessary that new discoveries are made on how to collect, store and use this thermal energy. Over time, several investigations have been carried out on different types of Flat Plate Solar collectors in order to determine the system with the optimum performance efficiency compared to the expensive Evacuated Tube collector. This work is focused on determining the type of Flat Plate collector that can compete with Evacuated Tube and also determine the tilt angle that is most favorable for optimum performance of a passive Evacuated Tube collector. In the analysis, Flat Plate collectors with different glass covers were tested; from double-glazed to triple-glazed alongside Evacuated Tube, whose angle of tilt was changed from* 15° *to* 30° *to* 45°. *Each system was tested over a period of three days at Sokoto Energy Research Centre, Usmanu Danfodiyo University, Sokoto. The results showed that the Evacuated Tube supersedes the Flat Plate collectors, with the highest efficiency obtained to be* 54.7% *at a tilt angle of* 45°, *at angle* 30° *the efficiency obtained was* 27%, *and* 24.2% *was obtained at an angle of tilt of* 15°. *As for the Flat Plate collectors, the collector with Triple glass cover performed better, with highest average efficiency obtained to be* 14%. *Whereas, for the Flat Plate collector with double-glazed cover has the efficiency of* 11.1% *was obtained. The low performance of the flat plate collector when compared to that of the Evacuated tube collector can be attributed to the nature of the local glass and the lagging materials used in constructing the Flat Plate collectors. In the other hand, the Evacuated Tubes which are imported and are of high cost, perform very well as a result of the selective coating in concentric tubes and also the glass used in manufacturing them has high transmittance. The work will go a long way to help limit the scope of future researchers in terms of Evacuated tube solar collector performance testing, carried out in the same location. This is so, because the optimum tilt angle for the location have been determined among the three perfect angles used as case study.*

Keywords: - *Flat plate collector, evacuated tube collector, angle of tilt, glass cover, passive system, efficiency.*

Date of Submission: 17-02-2019 Date of acceptance: 03-03-2019

I. Introduction

The need for renewable energy sources cannot be over-emphasized, as most of the world's sources of energy are currently fossil fuels (Vendan et. al., 2012). The sun being the most abundant and reliable source of renewable energy generated from nuclear fusion of hydrogen into helium (Nosa et. al., 2013) has to be harnessed for domestic, agricultural and industrial uses.After the oil crisis which emanated about 36 years ago (Nosa et. al., 2013; Ruchi et. al., 2012), researchers have focused on developing alternative energy sources and means to collect, store and use them. As part of the daily needs, water heating is of great concern to all families across the world which uses hot water for numerous domestic activities such as cooking, bathing, washing, etc. About 20% of an average American family's energy consumption is in water heating (Ruchi et. al., 2012; Patel et. al., 2012).

Solar water heaters are devices used to heat water by simply using energy obtained from the sun. the sun reaching the earth surface in form of electromagnetic radiation (Munish and Sharma, 2014) is therefore received by solar thermal collector.

Eze and Ojike (2012) were able to obtain thermal efficiency of a single-gazed flat plate collector to be 42%. The performance of flat plate collector over different geometric absorber plate was analyzed by Amrutkar et. al., (2012) and the efficiency of 55%-70% was obtained. Mishra and Saikhedkar (2015) reached a conclusion that evacuate tube collector has efficiency of 25-40% more than flat plate collector.

The aim of this work is to bring the efficiency of locally constructed flat plate collector as close as possible to the efficiency of industrially manufactured evacuated tube collector.

II. Theoretical Consideration

2.1 Comparison Between Flat Plate Collector and Evacuated Tube Collector

Flat plate collector is a thermal collector used for water heating at low ambient temperature, it is slightly less efficient as than Evacuated Tube collector (Vendan et. al., 2012). But for the purpose of low temperature applications Flat Plate collectors are more efficient when considering the maintenance and price for purchase. The Flat plate collector is cheaper and less technical to construct.

2.1.1 Flat Plate Collectors

A flat-plate collector (FPC) is the heart of a solar water heating system and it is commonly used for harvesting solar thermal energy at low ambient temperatures (Struckmann, 2008). It consists of: a selectively coated flat-plate absorber plate, a transparent cover (usually double-glass cover) to reduce top heat-losses from the absorber plate (Manikandan and Sivaraman, 2016), heat-transport fluid (HTF) to remove heat from the absorber plate, tubes for the flow of the HTF, a heat insulating support to reduce heat loss from the collector, and a protective casing to ensure the components are free from dust and moisture (Anand et. al., 2011).In addition, flat plate collectors do not have optical concentration of sun light and they are generally stationary and produce a temperature below 90℃ (Anand et al., 2011). The absorber plate maybe made of copper, steel, galvanized iron, aluminum sheets or plastic (Amrutkar et al., 2012).

A flat plate collector collects both direct component of solar radiation and diffuse solar radiation, and their total solar irradiance is used as the basis for flat plate collector performance calculation (Sadik, 2013). They are usually fixed permanently in a particular position and hence require no tracking of the sun (Kaligorou, 2004).In this research, the Flat plate collectors used have different number of glass cover; single, double and triple.

Figure 1 Flat Plate Solar Water Heater with a Single-Glass Cover at Sokoto Energy Research Centre.

2.1.2 Evacuated Tube Solar Collectors

Evacuated glass tubes (Figure 2) have concentric tubes with vacuum in between so as to serve as good insulator, thereby not losing much heat during the heating process. Creating vacuum helps to prevent the tubes from cooling down in colder weather conditions and diffuse heat supply can therefore be continued even if there is no sunlight striking the collector, due to trapped heat within the evacuate tube. Thus, the advantage of the sealed glass evacuated tube is that it serves as heat store, providing a stable supply of heat to the manifold even during partial sunshine weather (Mishra and Saikhedkar, 2015).

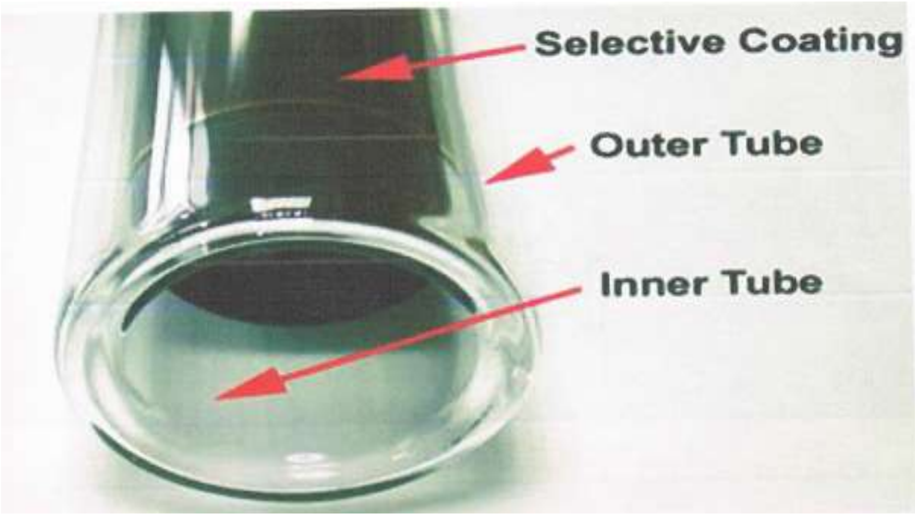

Figure 1 Evacuated tube solar collector (Mishra and Saikhedkar, 2015)

Figure 1 shows evacuated tube solar collector. Each evacuated tube is made from extremely strong borosilicate glass with high chemical and thermal shock resistance. The outer tube is usually transparent, thereby allowing light rays to pass through with minimal reflection. The outer side of the inner tube is coated with a sputtered solar selective coating as seen in Figure 2 which features excellent solar radiation, absorption and minimal reflection properties (Siddharth et. al., 2011). The top end of the concentric tubes is fused together and the air present in the annular space of the glass is evacuated to eliminate conductive and convective heat losses. Wind and low temperature have less effect on the function of evacuated tubes when compared to flat plate solar collector due to insulating properties of the vacuum (Mishra and Saikhedkar, 2015). Most concentrated solar systems use evacuated tubes because of its good thermal properties.

Figure 3 Evacuated Tube Solar Water Heater tilted at 45° at Sokoto Energy Research Centre.

2.2 Determination of Collector Thermal Efficiency

Collector efficiency is obtained by the ratio of the average heat output from the collector divided by the rate that the solar radiation strikes the collector i.e.

$$\eta = Q/A_c G_T \quad (1)$$

But $Q = mC_p(T_o - T_i)$ (2)

So, Equation (1) becomes:

$$\eta = mC_p(T_o - T_i)/A_c G_T \quad (3)$$

Where

η is the efficiency

m is the flow rate of the fluid in Kg/mins.
C_p is the specific heat capacity of the fluid $JKg^{-1}K^{-1}$.
T_o is the fluid outlet temperature from the absorber in ℃.
T_i is the fluid inlet temperature towards the absorber in ℃.
A_c is the area of the collector in m^2.
G_T is the beam radiation in Wm^{-2}.
Q is the quantity of heat in J.

III. Materials and Experimental procedures

3.1 Materials

The following is the list of the materials used in the course of the research:

- Digital Thermocouple Data Logger
- Thermo-Anemometer
- Pyranometer
- Stop Clock
- Evacuated tube collector
- Flat plate collector

3.2 Experimental procedures

In order to evaluate the performance of either the evacuated tube solar collector or any of the flat plate solar collectors, measurements of temperature (℃),wind speed (m/s), solar radiation intensity (Wm^{-2}), were recorded.

Both the Ambient temperature, the inlet and outlet temperature of each system was measured using a digital thermocouple, the wind speed was measured using a Thermo-anemometer. As for the solar radiation and pyranometer was used in measuring the solar radiation intensity.

Thermocouple Data Logger was used to measure the ambient temperature, the inlet and outlet temperature of each of the system. The thermocouple has a set of six wires to be connected to source of heat, meaning the wires can be connected to six different sources instantaneously and the temperatures will be displayed at the channel assigned to that particular wire. Each wire was taped to the source (the inlet pipe, outlet pipe) using a cello tape, while the ambient temperature was obtained by suspending one of the wires in the air.

The various temperatures were displayed on the screen of the Thermocouple data logger and recorded. Thermo-anemometer was used in measuring the wind speed at the same time that both temperature and solar radiation were measured. The thermo-anemometer was held up in the air at about two-meters (2m) high at the test site. The thermo-anemometer vane was pointed towards the direction of the wind, and this was easily known by the help of the wind turbines located around the site because the wind direction varies momentarily.

Pyranometer was used to measure the Solar radiation intensity. The Pyranometer was placed in the midst of the different collectors, with the sensor facing the sky. The location of the Pyranometer was monitored and altered, because when left at a particular position near the collectors, there will be shading by either of the systems. Hence, before recording the value of Solar radiation intensity, the sensor must be observed and noted if it is facing the sky without interruption.

The test was carried out over a period of three days for each of the systems, starting from 10am in the morning to 4pm in the evening.

IV. Results and Discussion

The performances of the Evacuated Tube solar collectors are shown in Figures 1, 2 and 3, where the Inlet, Outlet and Ambient Temperature is plotted against the Beam Radiation.

The performance of the three different Flat plate collectors are shown in Figure 4, 5 and 6 , where the Inlet, Outlet and Ambient Temperature is plotted against the Beam Radiation.

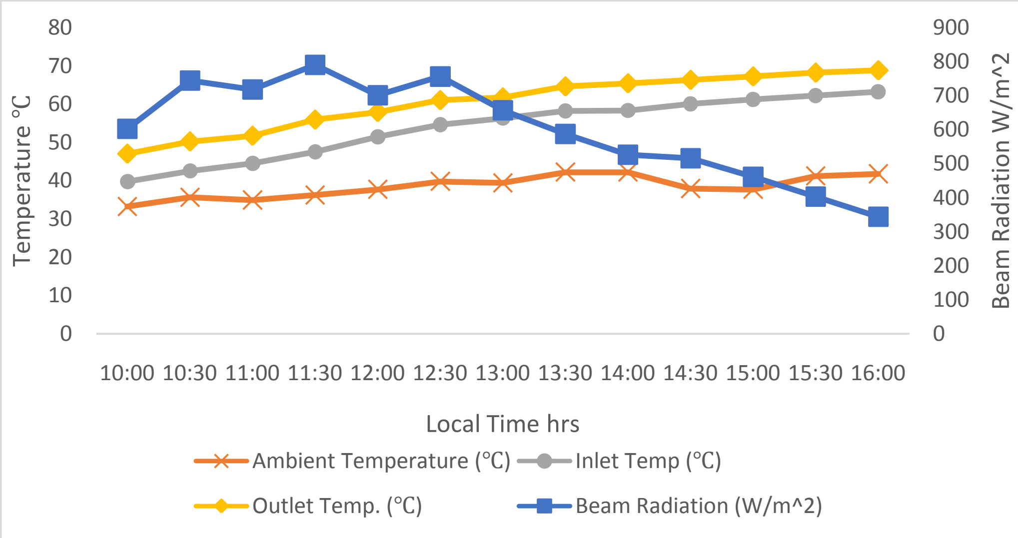

Figure 1 Temperature Variation with Beam Radiation for Evacuated Tube at 45^0

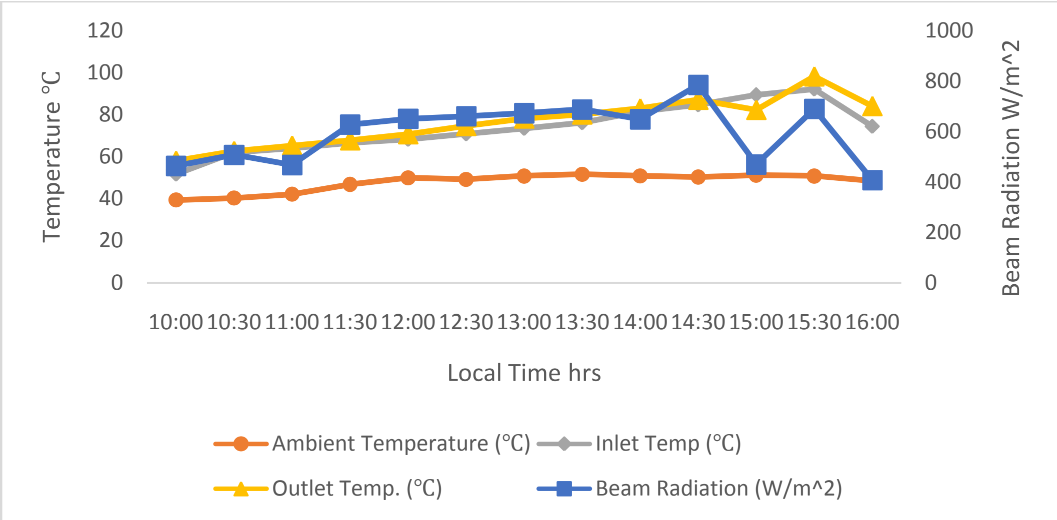

Figure 2 Temperature Variation with Beam Radiation for Evacuated Tube at 30^0

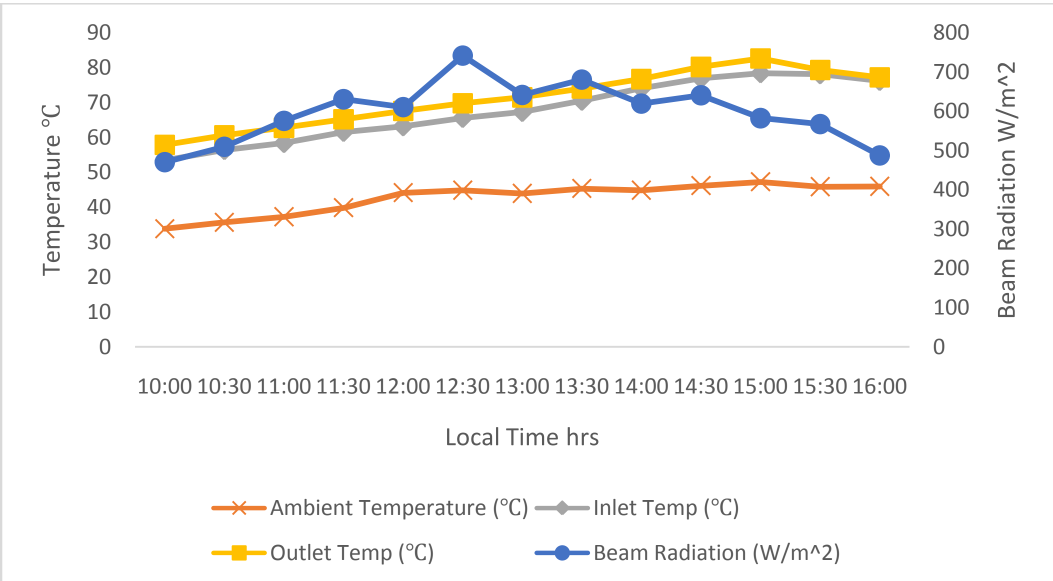

Figure 3 Temperature Variation with Beam Radiation for Evacuated Tube at 15^0

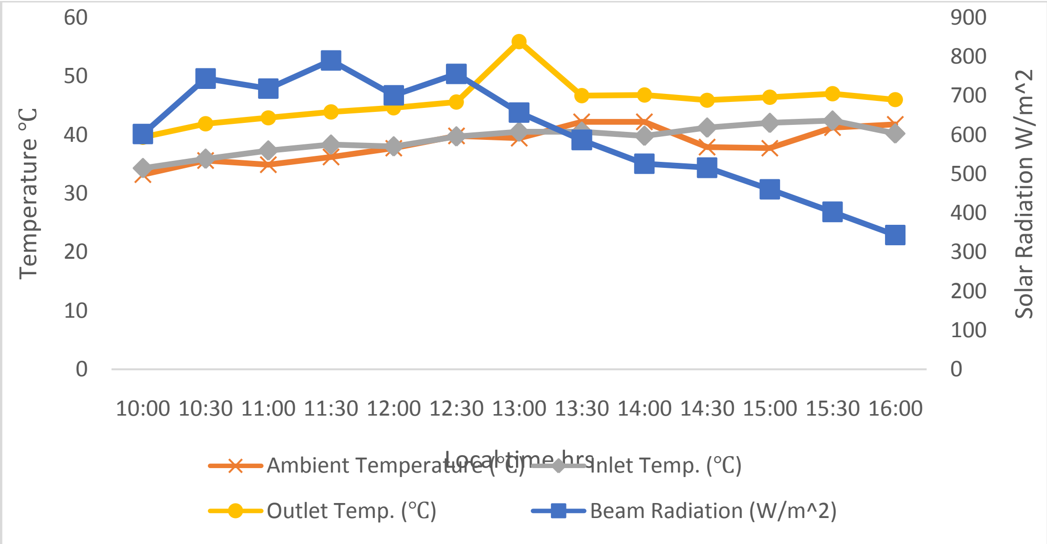

Figure 4 Temperature Variation with Beam Radiation for Triple-glazed Flat Plate

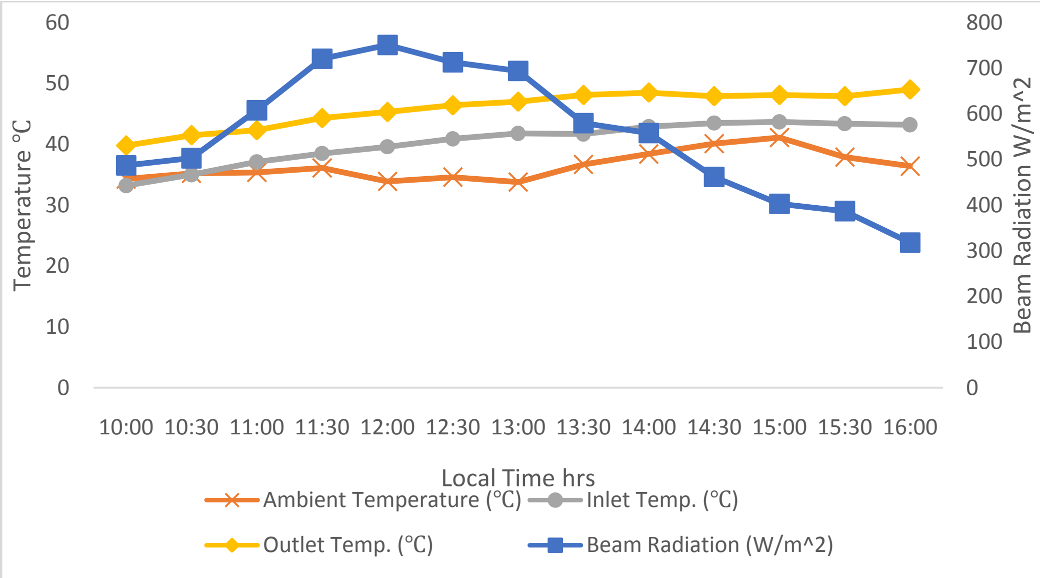

Figure 5 Temperature Variation with Beam Radiation of Double-Glazed Flat plate

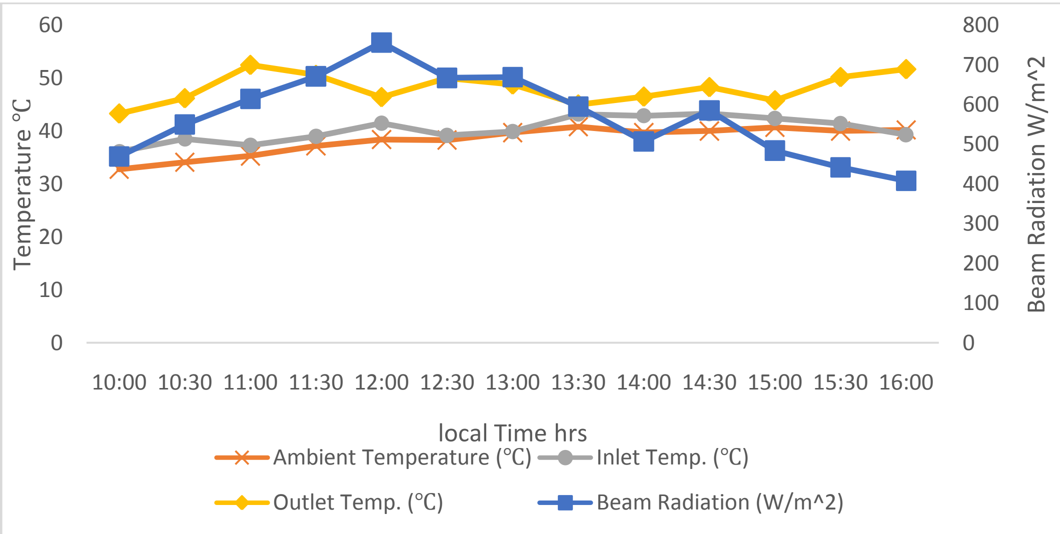

Figure 6 Temperature Variation with Beam Radiation for Single-glazed Flat Plate

It can be seen in Figures 1, 2 and 3 which both represent the results obtained from the evacuated tube collector that the outlet temperature is very high when compared with that of the flat plate collectors in Figures 4, 5 and 6.

The maximum outlet temperature as in Figure 1 was obtained for evacuated tube collector at 45° by 4: 00pm (1600hours) as 68.8℃, but in Figure 2, the maximum outlet temperature was recorded as98.2℃ and the temperature of 82.5℃ was obtained as the maximum outlet temperature for the evacuated tube collector tilted at angle 15°. The outlet temperature of the most efficient evacuated tube which is the evacuated tube tilted at 45° is the least among the results of the three evacuated tube collector readings. The efficiency is so because the formula for calculating efficiency as in Equation (3) is dependent on other parameters especially temperature difference. This temperature difference can be seen to be regular in equation (3), thereby making it more efficient.

As for the flat plate collectors, the maximum outlet temperature reached is 55.9℃ as seen in figure 4. This value was obtained from the triple-glazed flat plate collector, and as a result making it the most efficient flat plate collector.

V. Conclusion

After comparing the performances of various Flat Plate solar water with different numbers of glass covers against Evacuated tube, it was found that the Evacuated Tube performed much better for water heating for rice parboiling. The temperature of evacuated tube increased faster than that of the Flat plate collector, although, this can be attributed to the selective coating materials used in manufacturing the Evacuated tubes (Mishra et al., 2015). And as for the Flat plates, the collector with Triple glass cover performed best, when compared to the Single and Double-glazed cover systems with the highest efficiency of up to 14%.

The more the number of glass in the cover of Flat Plate collector, the better it will perform because of the green-house effect formed by the gap between the glasses, thereby trapping some amount of heat. Although there is still a large gap between the efficiency of the Evacuated Tube and the Triple-glazed Flat Plate Solar Water heater, but with better glass cover like the Anti-reflecting glass the locally made Flat Plate Solar Collector will compete with the foreign Evacuated Tube in Solar Heating.

The need to determine angle of tilt in which a passive Evacuated Tube collector will perform best cannot be over-emphasized, as the angle played a very important role in the performance of the system in the absence of tracker. The most suitable angle of tilt was found to be 45°.

References

[1]. Vendan, S. P., Shunmuganathan, L. P. A., Manojkumar, T., Shiva, C. T. (2012), Study on Design of an Evacuated Tube Solar Collector for High Temperature Steam Generation, International Journal of Emerging technology and Advanced Engineering, Vol. 2 (12), Pp. 2250-2259.

[2]. Nosa, A. O., Ikpomwosa, O. and Julius, J. (2013), Design and Construction Solar Water Heater Based on the Thermosyphon Principle, Journal of Fundamentals of Renewable Energy and Applications, Vol. 2, Pp. 51-59.

[3]. Ruchi, S., Sumathy, K., Erickson, P., Gong, J., (2012), Recent advances in the Solar Water Heating systems: A review, Renewable and Sustainable Energy Reviews, Elsevier, Vol. 19, Pp. 173-190.

[4]. Munish, K. and Sharma, V. K. (2014), Latest Evolutions in Flat Plate Solar collectors technology, International journal of Mechanical Engineering, Vol. 1(1), Pp. 7-11.

[5]. Eze, J. I. and Ojike, O. (2012), Analysis of Thermal Energy of a Passive Solar Water Heater, International Journal of Physical Sciences, Vol 7 (22), Pp.2891-2896.

[6]. Amrutkar, S. K., Ghodke, S. and Patil, K. N. (2012), Solar Flat Plate Collector Analysis, International Organization of Scientific Research Journal of Engineering, Vol 2 (2). Pp.207-213.

[7]. Mishra, D. and Saikhedkar, N. K. (2015), Evacuated Tube Solar Water Heating System- A Descriptive Study, International Journal of Innovative Research in Science Engineering and Technology, Vol. 3 (5), Pp.12627-12635.

[8]. Struckmann, F. (2008), Analysis of flat plate collectors, Project report: Department of Energy Sciences, Faculty of Engineering, Lund University, Sweden. Pp.2-3.

[9]. Manikandan, J. and Sivaraman, B. (2016), Comparative Studies on Thermal Efficiency of Single and Double Glazed Flat Plate Solar Water Heater, ARPN Journal of Engineering and Applied Sciences, Vol. 11 (9), Pp. 5521-5526.

[10]. Anand, B., Dass P. P. and Rajeev, J. (2011), Parametric studies of top heat loss coefficient of Double-glazed Flat plate solar collectors, MIT international Journal of Mechanical Engineering, Vol 1 (2). Pp.71-78.

[11]. Sadik, U. (2013), Construction and Performance Evaluation of Parabolic Solar Concentrator for Steam Generation, MSc. dissertation, Department of Pure and Applied Chemistry, Usmanu Danfodiyo University Sokoto (unpublished).

[12]. Kaligorou, S. A., (2004), Solar Thermal Collectors and Applications, Progress in Energy and Combustion science, Pp.235-247. Retrieved on 22nd September, 2016: www.elsevier.com/locate/pecs

[13]. Siddharth, A., Shobhit, C., Uduyakumar, R. and Muhammad, A. (2011), Thermal Analysis of Evacuated Tube Collectors, Journal of Petroleum and Gas Engineering, Vol. 2 (4), Pp. 74-82.

Sani Aliyu" Comparative Analysis of Selected Flat Plate Collectors against Evacuated Tube Solar Collector" International Journal Of Engineering Science Invention (Ijesi), Vol. 08, No. 02, 2019, Pp 52-58