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Design, Construction and Performance Evaluation of V-Trough Solar Concentrator System for Steam Generation

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Abstract: *This paper presents the design, construction and performance evaluation of v-trough solar concentrator system for steam generation. The developed v-trough solar concentrator is a solar thermal collector wherein the intensity of the sun light is boosted by the v-trough solar reflector coupled to the thermal absorber tube. The planar v-trough reflectors increased the solar concentration ratio by raising the intensity of solar radiation level received by any 1m^2 of the absorber which in turn raised the thermal efficiency of the absorber tube and water outlet temperature. To minimize the heat losses due to convection and radiation the absorber tube was enclosed in a transparent glass envelope. The V trough concentrator was designed with the view to reduce the construction using cheaper reflector materials, simple design and easy construction technique. An experimental-theoretical investigation into the performance of the adapted modified arrangement of a v-trough concentrator was carried out. Experimental study and statistical analysis of the v-trough solar steam generation system were conducted by heating up the cold water to produce steam. Five sets of data obtained between 0900 hrs and 1600 hrs for five days were collected and analyzed. The results revealed that the highest thermal efficiency attained by the v-trough solar concentrator system was 23.8% while the highest fluid (water) outlet temperature evident was 120.9^{o}C which is good for steam generation. It was also observed that, "daily solar radiation distribution is associated with higher or low function of the concentrator, thus increasing solar radiation improves its performance and overall functionality."*

Key wards; *Design, construction, v- trough, solar concentrator and reflectors*

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I. Introduction

Energy is a critical driving force for achieving massive industrialization, rapid economic growth, sustainable social development and viable political independence. Every aspect of modern life is largely dependent on it. Almost all political, social, agricultural, industrial, commercial, as well as residential services ranging from mining, construction, manufacturing, information communication, transportation, water supply, health care services delivery, education, food security and preservation, trading, finance, insurance, banking, housing, security, administration, subsistence agriculture, cooking, lighting, heating, cooling, drying, as well as professional/technical services, require energy. It isan absolute need that human race can't get away from.

In physics, energy is defined as the ability or capacity to perform work. Energy sources are classified into renewable (non-conventional) and non-renewable (conventional) energy sources. Renewable energy sources are inexhaustible sources of energy that are derived from natural processes that are replenished over and over on a human timescale e.g. sunlight. While non-renewable energy sources are the exhaustible sources of energy that cannot be replenished constantly e.g. fossil fuels.

Energy has emerged as one of the most significant and universal concerns society will face in this century and presently, the world relies on conventional fossil fuels to produce about 86% of its energy needs (Sergeant and Peumans, 2009). However, the combustion of fossil fuels generates greenhouse gases (GHG), major gases responsible for global warming, which is detrimental tophysical and biological environments (Sergeant and Peumans, 2009). Recent studies have shown that shifting from conventional fossil fuels to renewable energy sources such as solar would significantly reduce by greater amount such potential health risks and help in reverting climate change (Sergeant and Peumans, 2009, and Mekhilef et al., 2011).

Nasir, (2004) observed that solar energy currently represents the world's most abundant inexhaustible, non-polluting and free energy source that could be used economically to supply man's increasing energy demands. Mekhilef et al., (2011) noted that among all the renewable energy sources, solar power attracted more attentions as a greatest promising option in achieving sufficient energy supplies to meet the world's growing energy demands. Muhammad-Sukk et al., (2010) posited that solar energy technology offers great potential in terms of supplying the world’s energy but, however, ascertained that in spite of the world's abundant sunlight, its current contribution to the world is still limited and related the main factor to high initial cost of building the collecting systems. Today solar energy resources play a vital role in providing free and more affordable energy for domestic and industrial applications (Mekhilef et al., 2011).Solar energy is the form of energy that emanates from the sun and its applications can be classified into solar thermal and solar photovoltaic applications (Wu et al., 2010). Conversion of solar radiation into useful energy has been practiced for many generations (Kalogirou, 1998). The easiest way of harnessing the solar energy is to directly convert it into useful thermal energy (Chong et al, 2012). Here, solar energy is easily captured as low grade heat and is commonly being used for water heating, space heating, drying etc. (Mathur and Kandpal, 1983).

Solar photovoltaic and solar thermal conversion technologies as the two solar energy conversion techniques in use today convert solar energy directly into electrical energy (electricity) and thermal energy (heat) respectively (Wu et al., 2010). In recent decades, a number of solar energy collectors (the basic solar energy conversion elements) for various applications have been fabricated and experimentally studied while more are currently under development (Kocher et al., 2011). Literature revealed that the early commercially and widely produced solar energy conversion elements for solar photovoltaic and solar thermal applications are photovoltaic cells and flat-plate collectors (Kocher et al., 2011). A flat-plate collector is basically a solar thermal collector with a blackened surface and sometimes with an optical transparent cover oriented at a suitable angle to the sun's rays used to harness solar thermal energy above ambient temperature and below 90.0^{o}C. Flat-plate collector uses the fact that the solar radiation flux that reaches the earth’s surface peaks at approximately 1000 W/m^2 depending on many factors.When a flat-plate collector is a perfect black body and is used to collect this energy, the equilibrium temperature T of the blackbody absorber may be given as

$$\delta_{sb} T^4 = 1000 \text{ W/m}^2 \text{ …….. (1)}$$

From equation (1) the equilibrium temperature thus work out to be about 365.0^{o}K or 90.0^{o}C (neglecting all the losses). If heat is removed from the collector by flowing water or air the collector and fluid temperatures will be reduced and a high performance flat plate collector can heat the working fluid up to about 80.0^{o}C. It may therefore, be noted that with a simple conventional flat plate collector temperatures up to the boiling point of water (100.0^{o}C) are not possible. However, when the temperature required for a particular application is high and exceeded 90.0^{o}C, the amount of radiation on the collector surface has to be increased, that is, the intensity of radiation level received by any 1m^2 of the absorber has to be raised to achieve the desired temperature (Mathur and Kandpal, 1983). Since the incident solar flux (1000 W/m^2) cannot be changed, the energy received on a larger area isfocused or concentrated on a smaller absorber area. This technology is known as solar concentration and a device designed for this purpose is called solar concentrating collector or simply solar concentrator (Muhammad-Sukk et al., 2010).

According to Nasir (2004) the solar concentrating collector utilizes optical systems like reflectors, refractors, etc. to increase the intensity of solar radiation incidents on solar energy-absorbing surfaces and generate high temperature for applications requiring energy delivered at temperatures quite higher than 90^{o}C. Because they operate at high temperatures, solar concentrating collectors can be used to generate steam for industrial processes and electrical power generation. Some common concentrating collectors include v-trough concentrators, parabolic trough concentrators, compound parabolic trough concentrators, parabolic dish concentrators, central receiver systems, circular Fresnel lens concentrators, linear Fresnel lens concentrators etc (Mathur and Kandpal, 1983).

A v-trough is a type of solar thermal concentrating collector that is consists of a v-shaped array of long linear planar reflectors or a combination of compound parabolic reflectors with planar reflectors (usually coated silver or polished aluminium) which concentrates sunlight onto a receiver tube running along its base at the focal line. Sunlight is reflected by the reflector and concentrated on the absorber tube. The tube is usually filled with heat transfer fluid (HTF) usually water or oil. The absorbed sunlight warms the heat transfer fluid flowing inside the absorber tube which generates steam directly or the HTF is driven through a heat exchanger to indirectly produce steam that can be used in an industrial process or electricity generation.

The present research is to design and construct a v-trough solar concentrator system and evaluate its thermal performance characteristics with sole aim of coming out with an efficient, clean, cost effective and affordable steam generation technology for industrial process and electrical power generation using readily available materials.

II. System Design

This system was designed with optimum efficiency to achieve the objectives of the researchat low cost using readily available materials. The system is designed to consist of four plane mirror facets: The two upper reflectors with a dimension of 20.0 cm (width) x 100.0 cm (length) x 0.4 cm (thickness) each are inclined at an angle of 165°each relative to a base reflector of dimension 14.0 cm (width) x 100.0 cm (length) x 0.4 cm (thickness). The lower edges of thebase reflectors were then inclined at an angle of 90.0° to each other forming a v-shaped trough(see Figure 1.1).

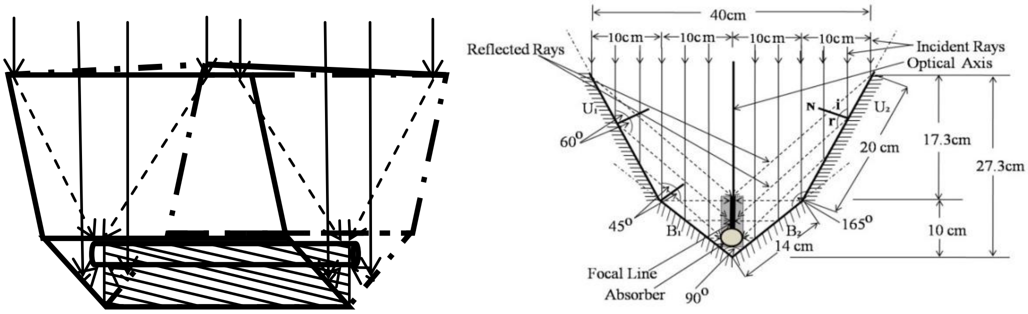

Figure 1.1: Ray Diagram Showing VTC of Four Plane Mirrors

Next is the supporting wooden frame which is a subsystem carrier with self supporting structural capability designed to support the reflecting surface platform, radiation receiver unit, and the receiver support arms. The v-shaped frame is made from a few plywood boards joined together. It's 1.0 m long and has a window (aperture) of 100.0cm by 40.0 cm across as illustrated in Figure 1.2.

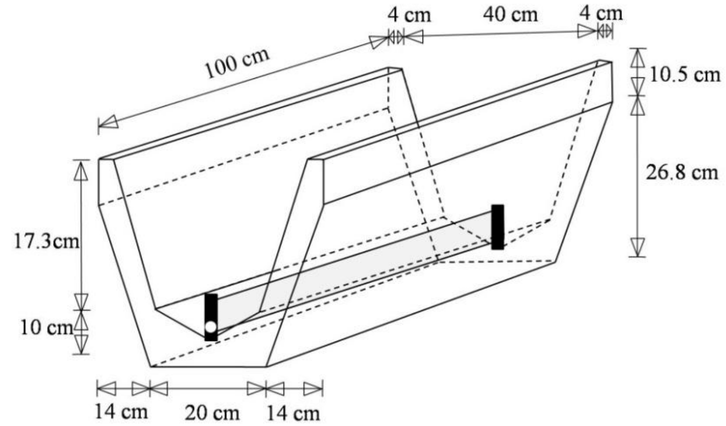

Figure 1.2: Three dimensional sketch of the third adapted design

The mirror reflecting surface platform unit is mounted on a v-shaped supporting wooden frame. The thickness of the mirror is small (0.4 cm) and therefore the mirrors are quite light. For protection, each mirror is designed to be supported from behind with a ply wood board protector of the same dimension as the mirror. The placement of the mirrors on the platform of supporting wooden frame is symmetrical with reference to the concentrator axis.

Then thesolar radiation absorberwhich comprises of a copper tube, a glass envelope and rubber cork seals on both ends of the glass envelope at the entrance and exit of the tube was designed. It was made up of a copper pipe of 9.525 mm diameter and 10.0m long. To enable a time delay so as to achieve the required temperature, a 500.0 cm copper pipe was bent and folded severally into serpentine shape of about 100.0 cm long and 10.0 cm high as shown in Figure 1.3.

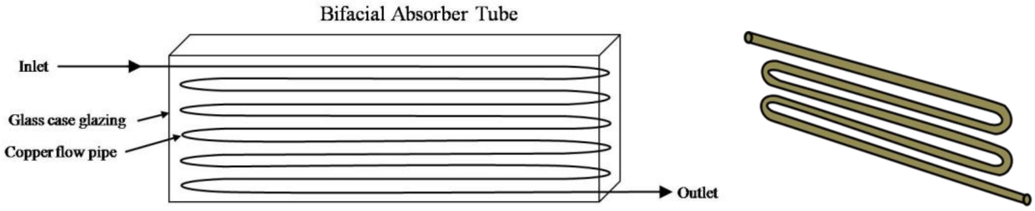

Figure 1.3: The bifacial serpentine absorber configuration

The exposed surface area of the copper tube was coated with heat resistant enamel black paint as to maximize the solar absorptivity and overall thermal conductivity of the tube. The serpentine copper tube is surrounded by a rectangular-shaped transparent concentric glass cover with a glazing to absorber air space thickness (an annular gap) of 5.0 mm. The evacuated glass casing was used as glazing to insulate the space around the absorber tube for inhibiting cool air from flowing into this space that could cause the convective loss. The vacuum between the glass and copper pipe also reduces the rate of heat loss due to radiation. The rubber corks are incorporated to achieve an air-tight enclosure.The absorber tube is placed parallel to the symmetrical axis of the concentrator and at a focal plane (focal region) of 100.0 cm long and 10.0 cm height from the base. This means that the position where the maximum solar concentration is achieved coincides with the pipe position because the total incoming solar radiation is focused to this focal region. The VTC system designparametersare shown in Table 1.1.

Table 1.1: Design Parameters/Specifications of the Third System

Parameter	Nomenclature	Value	Unit
Collector Gross Area	A_g	0.6800	m^2
Aperture Area	A_a	0.4000	m^2
Absorber/Receiver Area	A_r	0.1497	m^2
Collector Aperture	A	0.4000	M
Collector Height	H	0.2730	M
Acceptance Angle	θ_{max}	60^o	^{o}
Focal Height	F	0.1000	M
Receiver Diameter	D	9.5250	Mm
Glass Envelope gap	D_g	5.0000	Mm
Concentration Ratio	C	2.7000	

III. System Construction

The system construction consists of four main phases, namely the construction of wooden frame, the construction of v-trough reflecting mirror system, the construction of solar-radiation absorption system and the finishing process.

(a) Construction of Supporting Wooden Frame

The construction of the system components commenced with fabrication of a 100.0 cm long by 37.3 cm high by 48.0cm wide, v-trough supporting frame (see Figures3.25 – 3.33). A sheet of 4" x 6" x ½" plywood and long logs of 1" x 1" edging square wood blocks were purchased from Kara market in Sokoto.

To begin with, the plywood framing panels for the sides, top and bottom were measured and marked according to the design dimensions using a T-square, angle guide and measuring tape. The pieces were cut off at the marks using hand saw and coping saw as illustrated in Figure 2.1.

The side angle panels were measured and marked according to the design specifications setting the cutting angle for the upper-to-base reflectors to 165.0° and for the base-to-base reflectors to 90.0° and were trimmed using coping saw.

Figure 2.1: Plywood framing panels and edging square wood blocks

The siding board pieces of two 100.0 cm by 10.5 cm plywood panels and two 100.0 cm by 30.5 cm were held in place by two plywood angleforms (see Figure 2.2), each having a groove cut into v shape. This was done by pushing the pieces of plywood panels and attaching them together with 1" nails forming the non-mirror back of the trough. Precise positioning of the nails is not required, but they should be firmly fixed and little bit away from the border of the panels.

The edges were joined together using long logs of 1” x 1” edging square wood blocks and top bond adhesive glue between the joints for tightness and durability before nailing. The side angles are placed with the v-shaped edge being the head and vertically facing the interior (see Figure 2.2).

Figure 2.2: Angle view of the assembled back of the frame

The two upper pieces of 100cm by 20cm and two lower pieces of 100cm by 14cm reflector carrier plywood boards were then attached to the top edges of the frame forming the v-trough mirror support system where the reflective surfaces will reside (see Figures 2.3 and 2.4).

The lower base pieces were precisely fastened at the centre of the angles, the top side of the upper pieces are fixed to two 100.0 cm by 4.0 cm plywood pieces attached to the upper corner of the back. Precise and accurate joint angles are ensured during fixing.

Figure 2.3: Assembling frame’s top

Figure 2.4: Complete assembled frame

Next, holes for fastening the absorber are drilled on two wooden arms cut off according to the dimensions. The two holes at the ends are for fixing pipes, and are of diameter 10.0mm each, which is slightly bigger than the diameter of the pipes (9.525 mm). This helps for the adjustment of the positioning of the absorber. The arms' positions were strictly symmetric with respect to the centre of the trough. The frame was then painted in blue-green colour (see Figure 2.5).

Figure 2.5: Angle view of painted frame

(a). Construction of Reflecting System

The reflecting surface which is the active collector surface was constructed of two upper100.0cm by 20.0cm and two lower100.0cm by 14.0cm of second surface plain mirrors. The placement of the mirrors on the platform was symmetrical with reference to the trough axis(see Figure 2.6). The mirrors were secured to the frame with evo-stik gum.

Figure 2.6: Mounted v-trough reflectors

The total incoming solar radiation is focused on a 10.0cm by 100.0cm focal plane which is parallel to the collector axis. The thickness of the mirror is small (0.4 cm) and therefore the mirrors are quite light.

(b). Construction of Solar Radiation Absorption System

The Solar Radiation Absorption System is the heat receiver and was constructed of a9.525 mm diameter by 500.0 cm long copper pipe. To enable a time delay so as to achieve the required temperature, the pipe was bent and folded severally into serpentine shaped passage of about 100.0 cm long and 10.0 cm high by compact-filling it with fine dry sand to avoid kink, crush, collapse and pleat in the process of bending (see Figure 2.7).

Figure 2.7: Copper Pipe Bent into Serpentine Shaped Passage

The exposure area of the serpentine copper tube was painted black as to maximize the solar absorptivity and overall thermal conductivity as well as to minimize radiative heat loss of the tube as shown in Figure 2.8.

Figure 2.8: The Exposure Area of the Serpentine Copper Tube Painted Black

The tube was housed into arectangular-shaped transparent glass casing and evacuated of air or as little as high-vacuum technique can be achieved using rubber cork seals on both ends of the glass envelope at the entrance and exit of the tube; so that the vacuum between the glass and copper tube reduces the rate of convective heat loss.The glass glazingwhich surrounds the heat absorber tube was also used as to insulate the space around the absorber tube for inhibiting cool air from flowing into the space that could cause the convective loss (see Figure 2.9). The presence of glass also reduces the heat loss due to conduction.

Figure 2.9: Glazed Blackened Bifacial Serpentine Copper Tube

The absorber tube was placed parallel to the symmetrical axis of the concentrator and at a focal line of the v-trough and held in place by two receiver support arms. This means that the position where the maximum solar concentration is achieved coincides with the pipe position (see Figure 2.10).

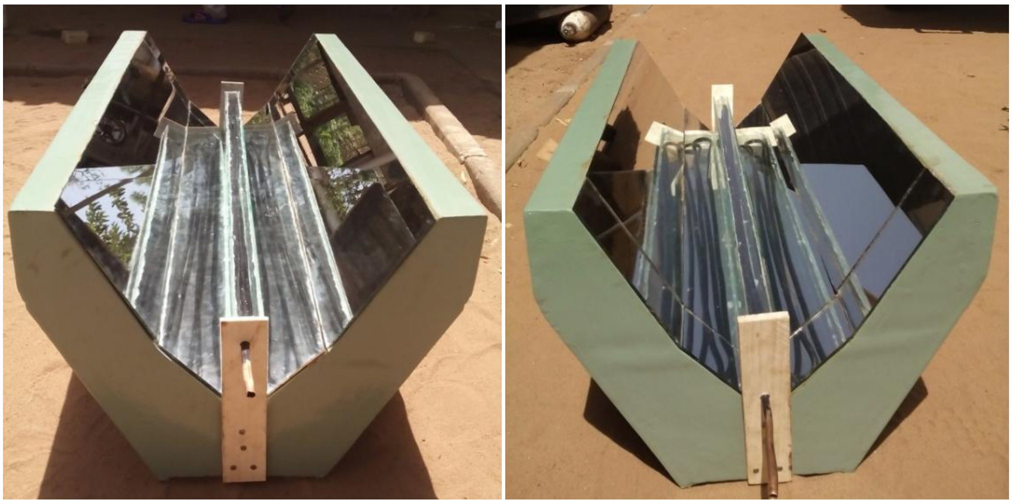

Figure 2.10: Completed V-trough Concentrator

IV. System Testing And Evaluation

System Experimental Testing: Data Collection

(a). Experimental Setup

After construction, the v-trough solar concentrator system for steam generation was installed outdoorand the measurement system was assembled at Sokoto Energy Research Centre, UsmanuDanfodiyo University test area (see Figure 3.3). The system was tested between May 25, 2014 and May, 31 2014 to evaluate its thermal performance characteristics under different prevailing natural weather conditions.

Though ideally the v-trough reflector should be north-south facing and inclined at the angle equal to the local latitude. However, the v-trough concentrator was mounted in a fixed position and horizontally along east-west orientation facing the equator to avoid system's diurnal tracking of the sun and seasonal tilt adjustments as well as to prevent casting shadow on the concentrator's reflecting surfacesince the local latitude for Sokoto is only 13^{o}N, but this resulted in the time available for testing being restricted by the acceptance range of incidence angles within sunshine hours between 0900 hrs and 1600 hrs daily.

In the setup, the outlet of the cold water tank was connected to the inlet of the solar absorber unit, while the outlet of the solar absorber was connected to the inlet of an insulated hot water thank. The absorbers ends were thenconnected between the cold and hot water tanks as shown in Figure 3.1.

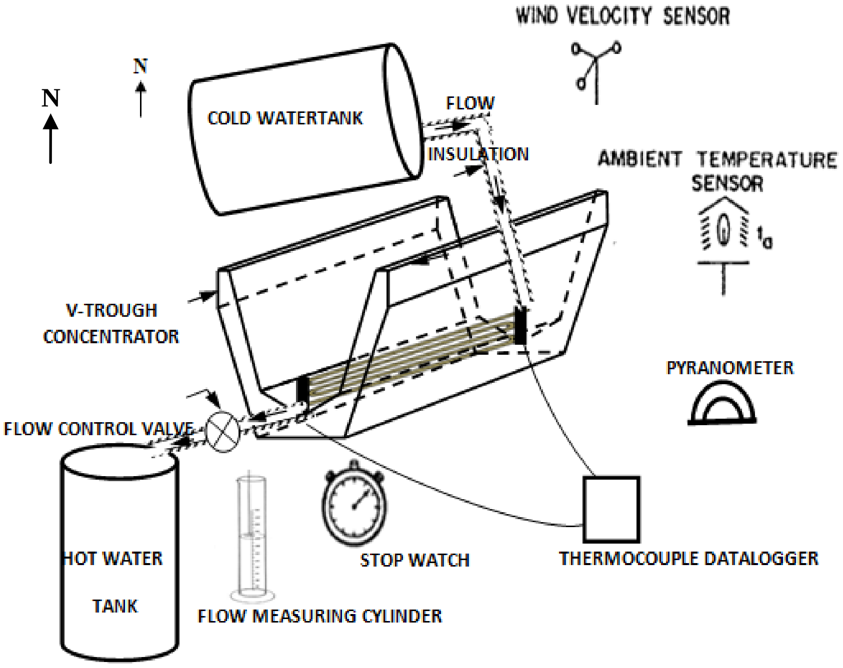

Figure 3.1: Schematic Diagram of the Test Loop/Experimental Flowchart

The water tank was elevated 20.0 cm above the absorber level and away from the reflector system in such a way that water can flow downstream to the absorber and tank shadow falling on the reflector system can be avoided.

A high temperature resistance connecting rubber pipe of 1/2 inch diameter was connected from the base of the cold water tank to the inlet of the copper absorber, which provided water to absorber. However, to measure the mass flow rate a flow meter was connected at the outlet of the absorber to the hot water tank.

The measuring sensors were assembled before testing the system as follows. The CHINO-AL3000-6ch AL3765-N00 model digital thermocouple data logger for measuring the absorber temperatures, (t_r), inlet temperatures, ($t_{f,i,}$) and outlet temperatures, ($t_{f,e}$) was fixed in position at different points of the constructed system. The mercury-in-glass thermometer for measuring ambient air temperatures, (t_a) was fixed at the surrounding of the test area and shaded from the direct sun shine. A METEON Digital Display CMP 3 Pyranometer fitted with shadow ring as well as without shading for measuring the global components of solar radiation, and the diffuse components of solar radiations were respectively fixed in place. An AM-4812 Digital Anemometer for measuring the wind speed so as to observe the effect of wind on the performance of the collector was fixed around the test area. The experimental set up and measuring instruments were as shown in Figure 3.2.

Figure 3.2: Diagram of the Test Loop/Experimental Setup

(b). Test Measurements and Instrumentation

The experimental investigation into the performance of v-trough concentrator was carried out and all responses of the measuring instruments were accordingly recorded. At this point 16 sets of experimental runs at time intervals of 30 minutes within sunshine hours between 0900 hrs and 1600 hrs daily were conducted for five days and the data were daily recorded. Temperatures at different points of the constructed system were collected, fromthe thermocouple data logger. The inlet and outlet water temperatures were measured by placing two thermocouple terminalsat the entrance of the cold water and theexitof the hot water to the absorber respectively. The absorber temperatures were also recorded by fixing the third thermocouple terminal at the absorber surface. The ambient air temperatures were measured by placing a mercury-in-glass thermometer at the surrounding of the test area (see Figure 3.2). The test was done at constant water flow rate of 0.050 kg/s. The mass flow rate, $\dot{m}$ was determined using volumetric measuring cylinder.

The diffuse components of solar radiation were recorded using a shadow ring fitted Kipp and ZonenMETEON Digital Display (080689 CMP 3 Pyranometer model)with sensitivity of 16.86µv/w/m^2 and the global components were measured using a Kipp and ZonenMETEON Digital Display (080631CMP 3 Pyranometermodel)without shading ring of 18.63µv/w/m^2 sensitivity.

To observe the effect of wind on the performance of the collector, wind speed was measured at each point using AM-4812Digital Anemometer. The wind speed (air velocity) was measured by subjecting the Vane Probe of the Anemometer around the test site.

The following data points (parameters) were obtained: Absorber temperature, (t_r), ambient air temperature (t_a), water inlet temperature to the absorber ($t_{f,i,}$), water outlet temperature from the absorber ($t_{f,e}$), water mass flow rate (ṁ), wind speed (v_w), intensity of diffuse solar radiation(G_d), intensity of global solar radiation (G_G),and beam components of solar radiation (G_b). Water outlet temperatures were also recorded.

Performance Evaluation: Data Analysis

The researcher employed a simple and suitable method to evaluate the performance of the collector. The twocollector performance characteristic parameters evaluated arecollector thermal efficiency, η_g; and collector outlet temperature, $T_{f,e}$.The collector thermal efficiency, η_g,isthe ratio of solar radiation captured by the collector to the incident solar radiation as shown by equation (2).

$$\eta_g = \dot{m}c_p \frac{(t_{f,e} - t_{f,i})}{A_g G_{bp}}] \qquad \dots \dots . \dots (2)$$

V. Results And Discussion

Experimental (Measured) Test Results

The results obtained from the experimental testing of the adaptedv-trough solar concentrating collector carried out between May 25, 2014 and May 31, 2014 at SokotoEnergy research Centre are presented below.

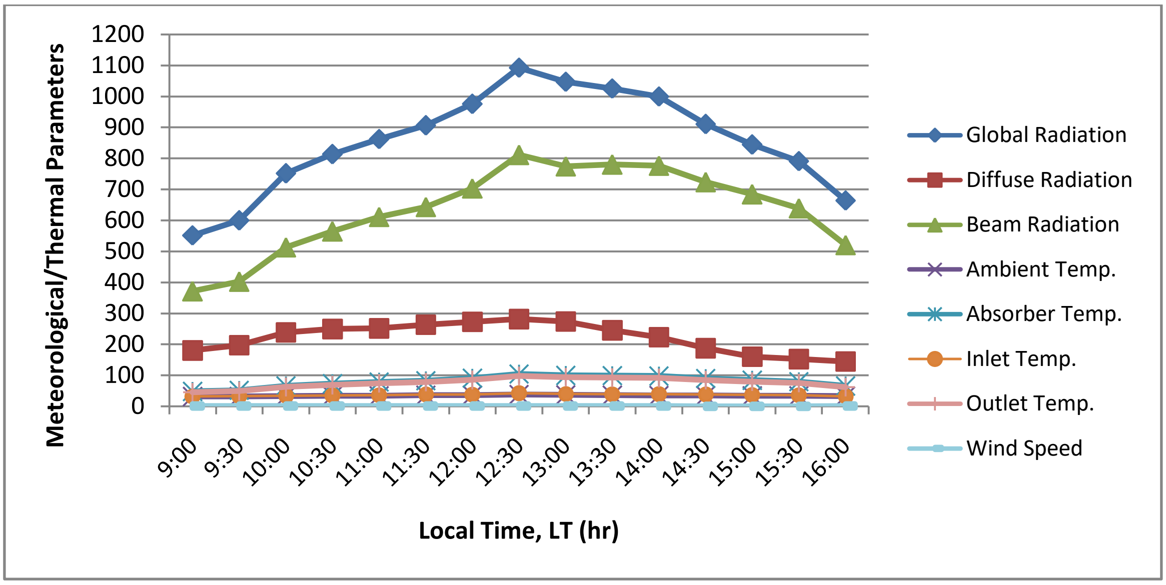

Figure 4.1: Trending of Various Meteorological/Thermal Parameters with Time for Day 1

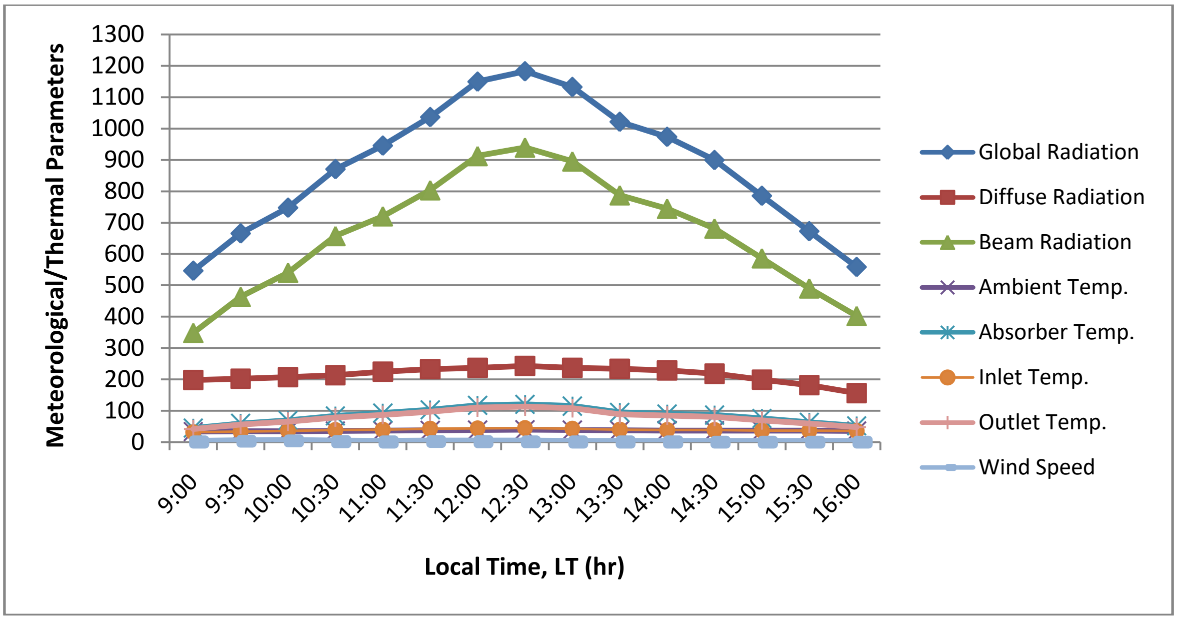

Figure 4.2: Trending of Various Meteorological/Thermal Parameters with Time for Day 2

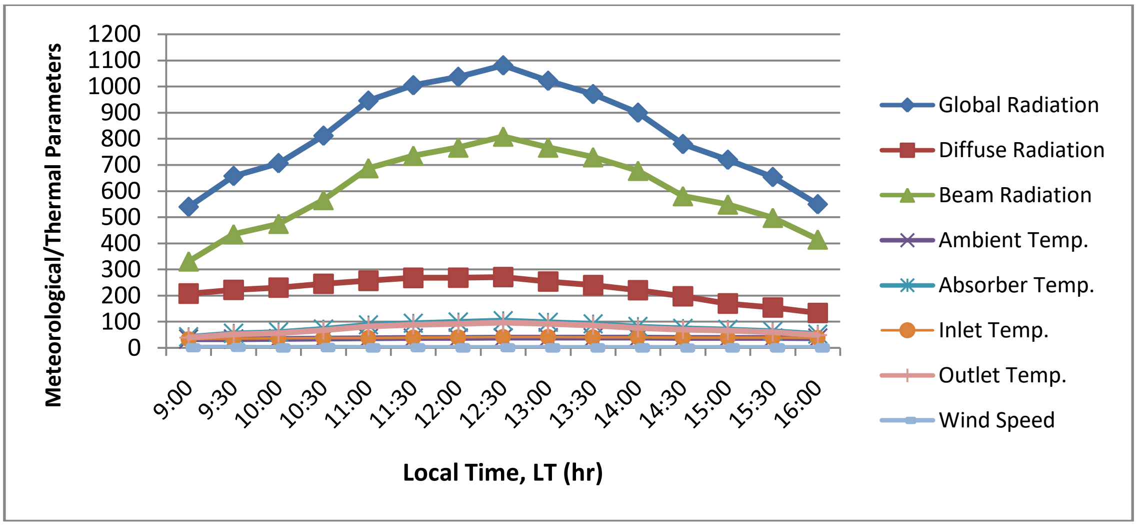

Figure 4.3: Trending of Various Meteorological/Thermal Parameters with Time for Day 3

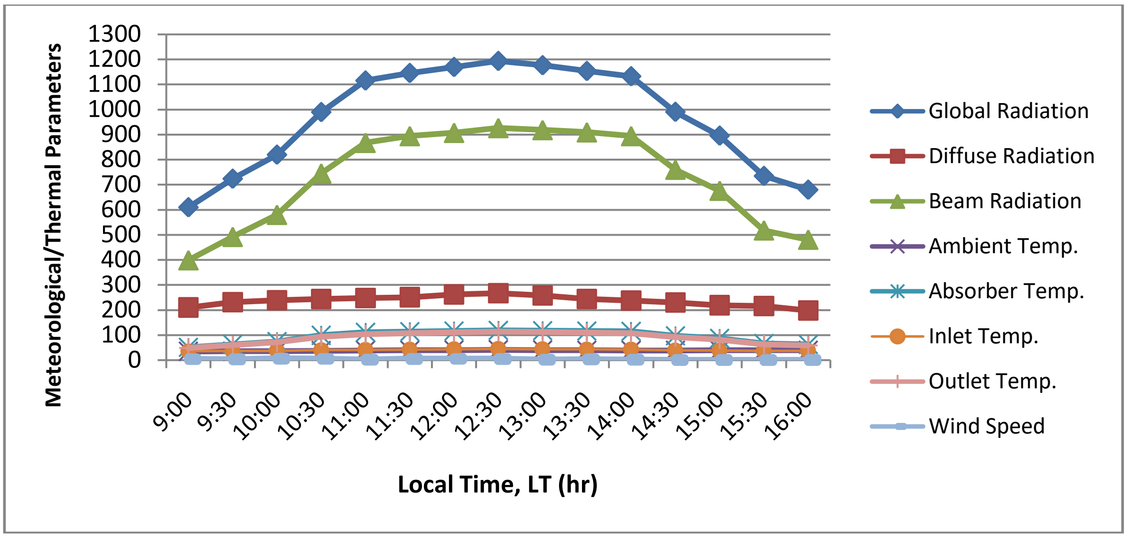

Figure 4.4: Trending of Various Meteorological/Thermal Parameters with Time for Day 4

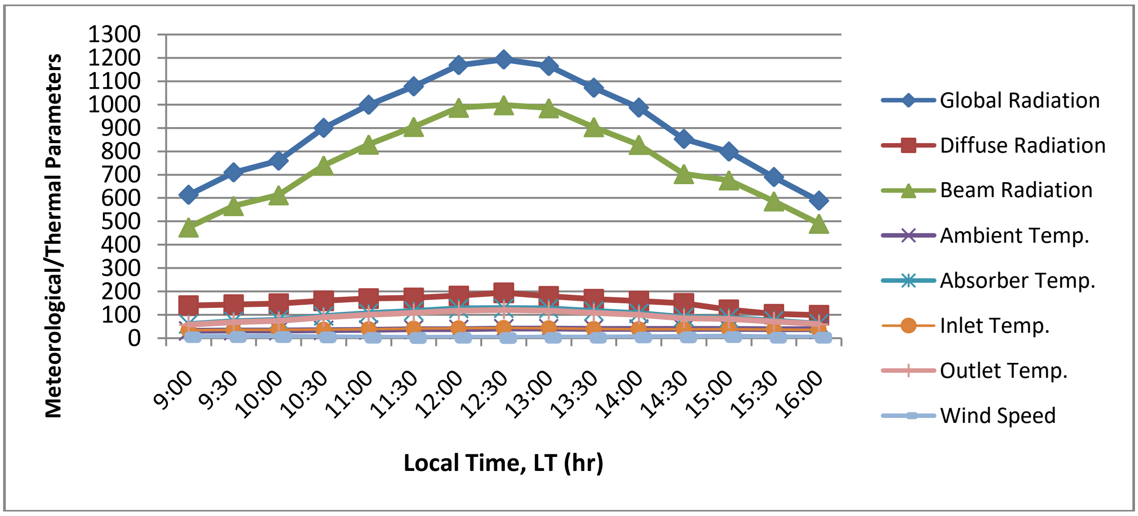

Figure 4.5: Trending of Various Meteorological/Thermal Parameters with Time for Day 5

Performance Evaluation (Derived) Results

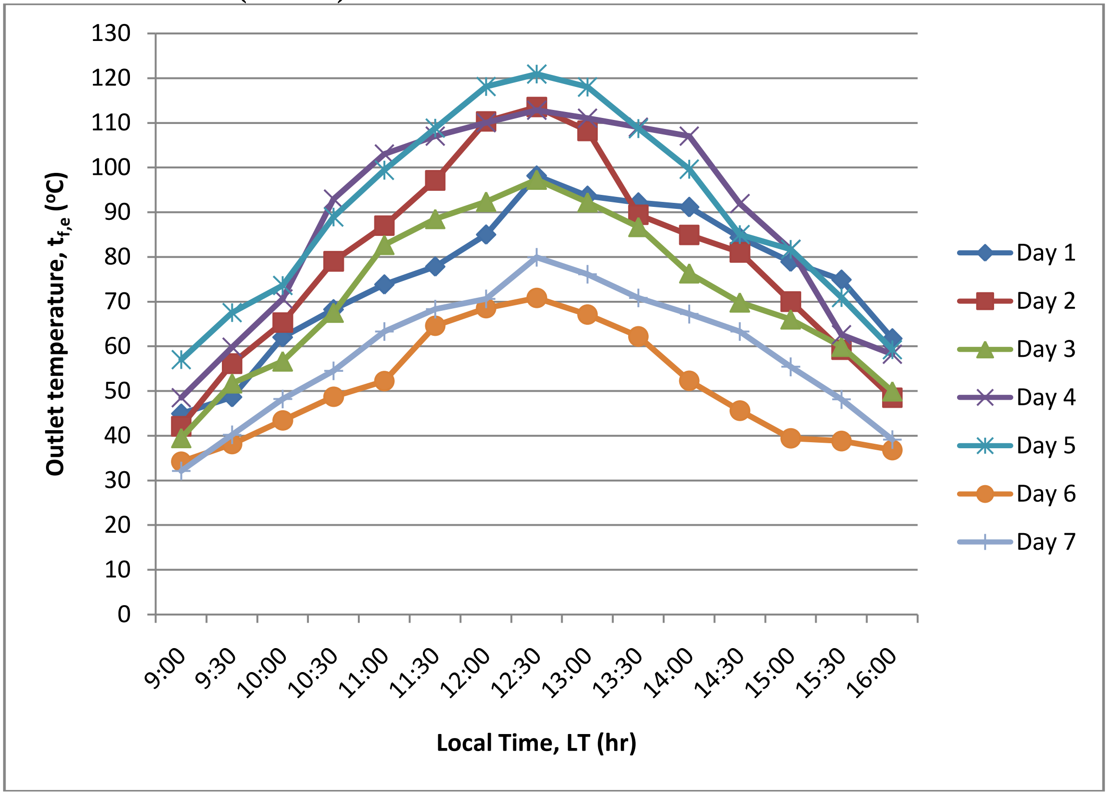

Figure 4.6: Graph of outlet temperature as a function of local time

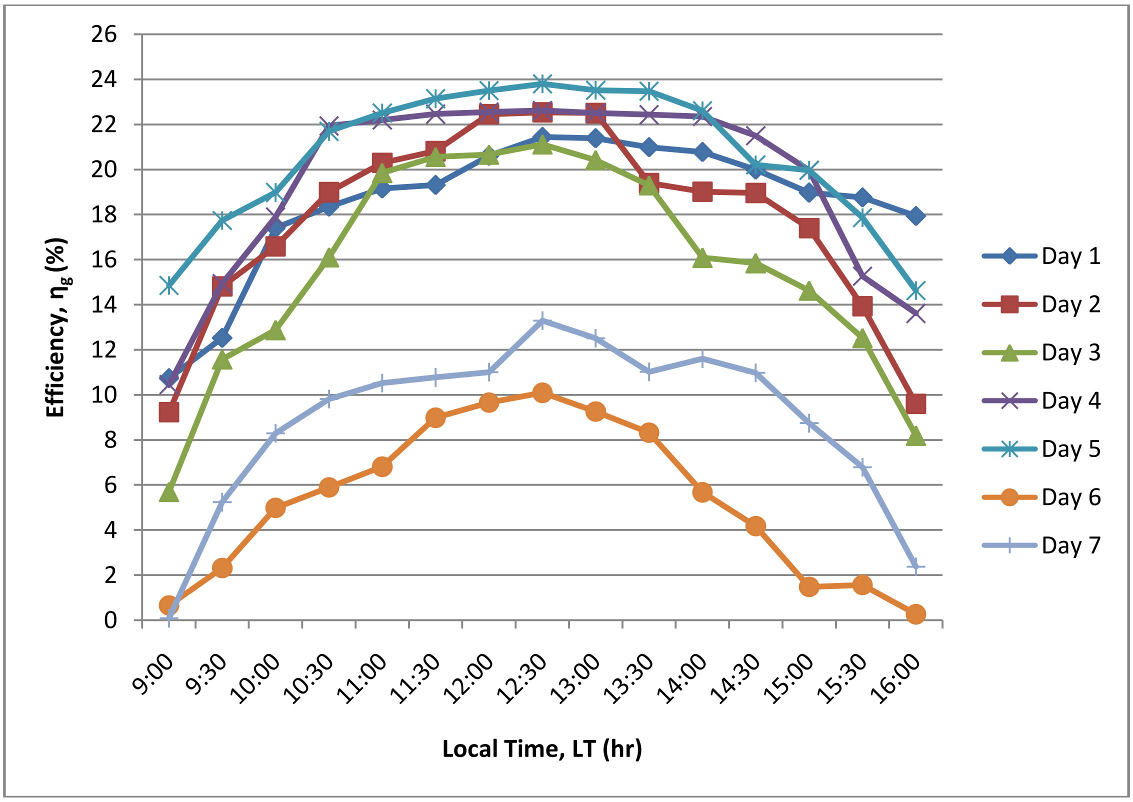

Figure 4.7: Graph of efficiency as a function of local time

VI. Discussions of results

Figures 4.1, 4.2, 4.3, 4.4 and 4.5 give test results of the system temperatures variation, hourly solar radiation collection, concentration and absorption of the collector for day 1, 2, 3, 4 and 5 (from 23rd May, 2014 to 27th May 2014). From these figures, it can be seen that the Insolation increased from low values at 09:00 hours to peak between 12:00 and 14:00 hours and then fell back to low values until 14:00 hours. This means that more radiations were collected, concentrated and absorbed by the collector between 12:00 and 14:00 hours. From the results, it also follow that the maximum fluid (water) outlet temperatures and the maximum absorber temperatures were obtained between 12:00 and 14:00 hours. With the proper thermal insulation and glazing applied to the collector, thermal losses from the water tanks, connecting pipes and the absorber were avoided and the fluid (water) outlet temperatures were successfully improved. This was evident by comparing the results of day 1 at 12:00 hour with that of day 5 at 14:30 hour, day 2 at 15:00 hour with that of day 5 at 15:30 hour, day 2 at 15:30 hour with that of day 5 at 16:00 hour, day 4 at 15:00 hour with that of day 5 at 15:00 hour, and day 5 at 09:00 hour with that of day 4 at 16:00 hour respectively. Though there was same solar Insolation and wide difference between the wind speeds in each set, but there were no significant differences between the results obtained. This showed that wind speed has no significant effect on the operation of the concentrator.

Figures 8 and 9 show the graphs of outlet temperature against local time, and efficiency against local time respectively. The fluid (water) outlet temperature and efficiency increase steadily and sharply with local clock time for the results of days 1, 2, 3, 4 and 5. The fluid outlet temperature and efficiency increases slowly from 9:00 to 10:30 hours and steadily attained peak values between the hours of 11:00 and 14:00, after which the temperature and efficiency decreases transiently (decay with time) as the sun moves down in the late afternoon. This shows that the collector performance was optimum in the late morning and early afternoon hours between 11:00 to 14:00, when the solar irradiance was higher and day hotter than the morning hours. The figures 4.6 – 4.7 show the maximum temperatures and efficiencies attained by the collector for Days 1, 2, 3, 4, and 5which are: 98.1^{o}C, 21.4%; 113.5^{o}C, 22.5%; 97.3^{o}C, 21.1%; 112.8^{o}C, 22.6%; and 120.9^{o}C, 23.8% respectively. The collector could have been more efficient would the atmosphere be clearer than experienced throughout the testing period. The results also show that the maximum water outlet temperature T_{max} andefficiency η_{max} for Day 2 and 4were high and have close values, but the results for Day 1 and 3 show considerable fall which were due to scattered clouds and suspended dust particles that made the atmosphere hazier, thereby absorbing some amount of radiation and scattering some (i.e. converting direct solar radiation to diffuse radiation), hence reducing (to a definite extent) the amount and intensity of the direct radiation reaching the collector surface. The result for Day 5 was the highest which was as a result of clear atmospheric condition experienced on that day.Although, the highest maximum efficiency, η_{max} (i.e. 23.8%) so far reached by the device was not so high, but itstillperformed up to expectation as the generation of steam start at the boiling point of water which is 100^{o}C. Since the highest maximum temperature, T_{max} attained by the collector (i.e. 120.9^{o}C) was on the average for steam generation.

VII. Conclusion

A v-trough solar concentrator system for steam generation was constructed according to the specifications designed by the researcher. Experimental studies and evaluation analysis were carried out to determine the system performance characteristic based on the temperature induced to the working fluid (water) by the collected, concentrated and absorbed solar radiation. The results revealed that the highest thermal efficiency attained by the v-trough solar concentrator system was 23.8%. The system was tested by heating up the cold water to produce steam. The highest fluid (water) outlet temperature evident was 120.9^{o}C which is good for the generation of steam.

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