DESIGN AND CONSTRUCTION OF A PORTABLE SOLAR WATER HEATER

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Abstract – Solar thermal water heaters are an old technology used a century ago in California. Theyare now used extensively, in updated form, in many countries. According to government and industry estimates, well-functioning solar water heaters can theoretically displace 50 to 80 percent of the output of a natural gas-fueled household water heater, depending how hot water usage aligns with production and storage capacities. In so doing, they offer tremendous potential for reducing greenhouse gas emissions, fuel consumption, and energy bills. Such performance holds promise for California given its climate change and energy efficiency policy goals, since 40 percent of the natural gas used in California households is used to produce hot water. However, absent programs, only a specialty market for solar water heaters has developed. To encourage wider deployment, the California Solar Initiative—Thermal program offers financial incentives for systems qualifying under a carefully crafted set of specifications. The program has had some limited success since its inception in 2010.

Within that context, this research assessed the performance and potential future use of natural gas-displacing solar water heaters in single-family homes in California, attending to a wide range of sociotechnical considerations. This project documented high diversity in user satisfaction and perceived system performance, and a qualified decrease in project costs to below $5,000 per installation. Solar water heating is a technology in progress, not universally suitable but instead appealing to varied niches shaped by household sensibilities, abilities, and hot water use levels. Thus, recent evolution provides a counterpoint to the pessimism, even as serious difficulties remain. The suitability of solar water heating for California households is not purely a matter of cost effectiveness within a typical energy efficiency framework, but alsoof evolving performance, perceptions, and values in light of ongoing and aspirational energy and social transitions ahead.
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***Key Words*:** Solar thermal water heating, renewable energy, domestic hot water, residentialnatural gas use, sociotechnical energy analysis, energy futures

1. INTRODUCTION

The world relies heavily on fossil fuels for most of its energy demands, and this has caused a lot of harm to the Earth. The increase of green-house gas levels in the atmosphere is largely due to the combustion of fossil fuels as a source of energy. This has caused global warming which has led to climate change, floods, forest fires, rising sea levels and the melting of glaciers. These are just some consequences of the over-reliance on fossil fuels for our energy demands. Solar energy provides an alternative and environmentally friendly energy source to the fossil fuels used for our energy needs. Over the last few decades, solar energy systems have gained more recognition because they can provide energy at a low long-term cost and minimal environmental damage. Researchers have developed several techniques forharnessing solar energy, these techniques include applications for space heating, water heating, electricity generation and many others.Solar energy is generated by the fusion reaction of hydrogen atoms in the sun. This fusionreaction results in the release of high-energy particles called gamma rays. Gamma rays are transmitted as electromagnetic radiation to the Earth, which is at about 150 million kilometres from the sun. Electromagnetic radiation comes in three forms: infrared rays, visible light, and ultraviolet rays. Solar energy reaching the Earth's surface can be harnessed directly by usingphotovoltaics (solar cells) and solar concentrators. Photovoltaics are used for electricity generation, while solar concentrators are used as a source of thermal energy. The utilization of solar energy collectors (concentrators) to transform radiation into heat energy is the basisof the solar water heating technology. A simple solar water heater consists of a collector, a tank, and the flow channel through which the working fluid is transported Records show the solar water heater (SWH) was first invented in the Roman empire around 200 B.C.E (Gong & Sumathy, 2016). The Romans had a simple system, they used thesolar heating concept to heat their public baths to enable a reduction in using coal and the labour required. These systems were not self-sufficient, but every innovative idea starts somewhere, and the solar water heating concept began here. After the Roman empire collapsed, humans forgot the concept of using the sun to heat water for over a millennium. Itwas in the late 18th century (1767) that a Swiss natural scientist, De Saussure, re-introduced the concept of using solar energy for water heating (Gong & Sumathy, 2016). He built an insulated box with two glass panes covering the surface, the bottom of the box was painted black to increase solar radiation absorption. This is the prototype for all solar water heaters. De Saussure found that whenever the insulated box was exposed to solar radiation, the insidesreached temperatures greater than water's boiling point. He had shown the green-house effect for the first time by doing this (Perlin, 2008). De Saussure hoped researchers would find hisinnovative device useful, but it took over a century for this to happen.In 1891, Clarence Kemp, an American manufacturer, patented the world's first commercial SWH called Climax (Gong & Sumathy, 2016). It was a simple system in which he put the black coated metal tank in an insulated box which had comparable designs to that of De Saussure's. This metal tank served as both the solar energy collector and storage. The major issue with Kemp's invention was that the water was stored and heated in the same tank. Hence, whenexposed at night and in poor weather, the water sometimes cooled down to an undesired temperature. William J. Bailey solved this drawback in 1909 by developing a system which had the collector and the tank separate from each other. The solar collector he built comprised fluid tubes connected to a black-coated metallic plate in a box with a transparent surface. The storage tank for the system was placed above the collector. It was the first system in history that transported the working fluid using the thermosyphon principle. This principle made it possible for water to circulate without the use of a mechanical pump. William Bailey's company was called the Day and Night SWH Company, emphasizing the advantage his solar water heating system had over that of Clarence Kemp's. By the 1920s, the discovery of natural gas and oil in southern California led to the emergence of gas water heaters. This crippled the solar water heating industry. Reductions in electricity cost and the copper scarcityduring the second world war replaced whatever was left of the solar industry.

In the 1970s, about half a century later, the SWH got global attention again, revitalized bythe OPEC embargo which caused a major oil crisis and a hike in oil prices. Ever since, the solar water heating industry has expanded all over the world. Growing concerns about the planet's increasing carbon emissions, global warming and climate change have flared up interest in the solar water heating industry. As of 2018, the SWH market was valued at over a billion dollars, the yearly installation is expected to surpass three million units by 2025 (Gupta, 2019).

Problem Statement

Considering the epileptic nature of electric power supply in Nigeria, the reliance on solarapplications for water heating will lead to better reliability of service for hot water needs and will have minimal negative impact on the environment. This would reduce the reliance on electric heaters, which have higher operational costs and depend on fossil fuels as a primaryenergy source.

Motivation for the Study

A lot of research has gone into the solar energy field over the past few decades. This is mostly because of the increased world-wide acknowledgement of the environmental effects that the use of fossil fuel as an energy source comes with. This current study would result in the design and construction of a portable solar water heating system which would provide hot water. The use of locally sourced materials would reduce the financial resources required compared to the importation of these materials. With Nigeria going through a recession and a pandemic which has further impacted the nation's economy, the availability of locally made solar water heating systems would help boost the local economy and curb the rate of importation.

Scope of the Study

This study is limited to the design and construction of a portable flat-plate solar water heating system operating on the thermosyphon principle. The application of the thermosyphon principle eliminates the need for an electric pump, thereby reducing the cost of the SWH. The material resources required for the construction of a flat-plate collector operating on the thermosyphon principle are readily available in Nigeria.

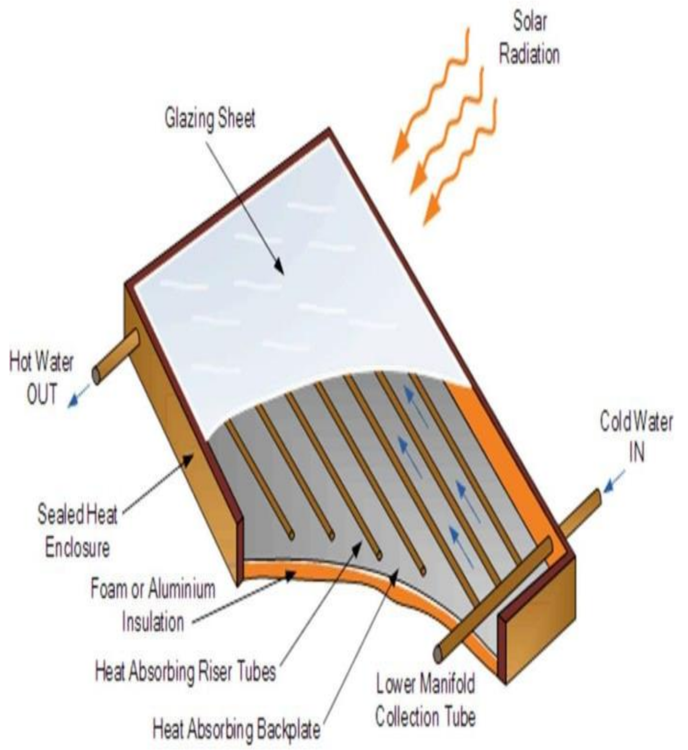
Aim and Objectives

The aim of this project is to design and construct a portable solar water heater. The objectivesare:

1. To design a portable solar water heater .
2. To construct the portable solar water heater.
3. To carry out the performance evaluation of the constructed solar water heater.
4. To obtain a baseline cost of a locally built solar water heater.

Operating Principles of a SWH Based on the Thermosyphon Principle

When exposed to sunlight, solar radiation passes through the transparent cover of the solarcollector and strikes the black-coated metallic plate which absorbs the incident solar radiation as heat. This causes an increase in the internal energy of the solar collector and causes it to become hot. The working fluid in the piping system, firmly bound to the black-coated metallic plate, absorbs this heat. This working fluid, then expands due to the heat addition, hence it reduces in density. Based on the thermosyphon principle, the heated fluid rises by natural convection, through the pipes at the top of the collector into the storage tank, while the cool fluid from the storage tank flows into the collector by gravity. Hence, the heated water gets transported due to an increase in both temperature and volume (Ogie et al., 2013). The cycle continues in this manner till the

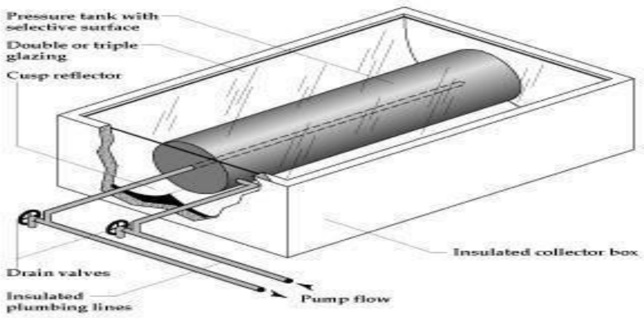


water in the storage tank is at the required temperature. Whenthe required temperature is achieved, the valves can be closed manually, or a thermostat canbe used to monitor and control the cycle. Figure 2.1 shows a typical flat-plate collector.

: Typical flat-plate solar collector

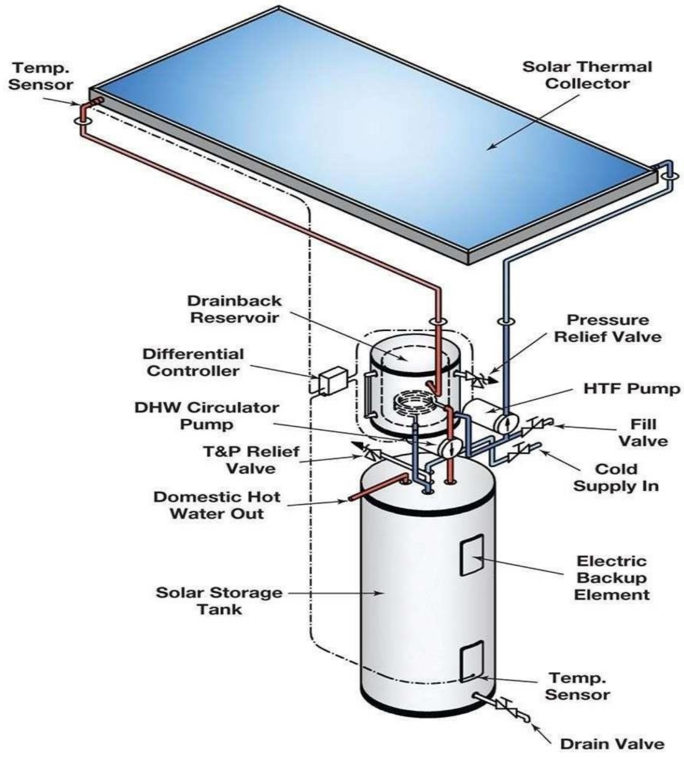
Batch System

Another name for this is integral-collector storage system. It is just one or more black- painted storage tanks inside an insulated box with a glass cover. The water gets heated inside the tank, and then either gravity or natural convection (the tendency of a hot fluid to rise) transports the water from the tank to the desired destination (Layton, 2009). Figure 2.2 below shows a batch system.

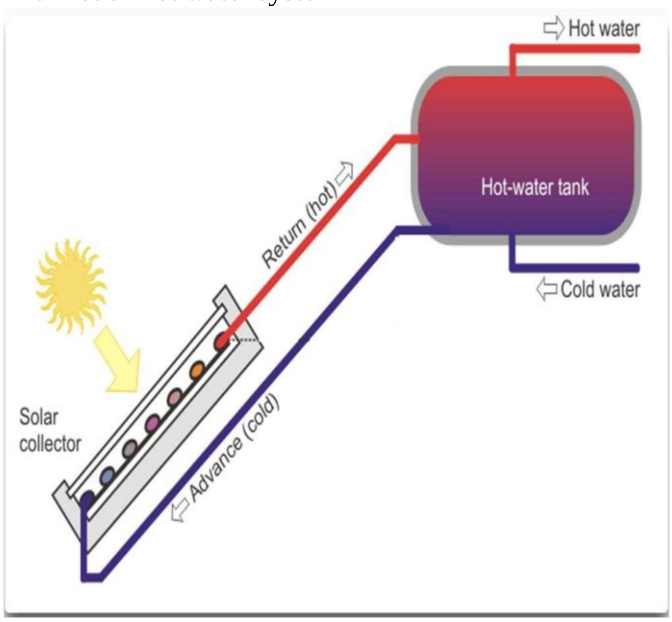


Thermosyphon System

The thermosyphon system works on the thermosyphon principle, enabling the flow of water without a mechanical pump. In this system, the storage tank is separate from the solarcollector. The solar collector must be installed below the storage tank for the thermosyphon effect to work properly. Cold water from the tank flows down by gravity to the bottom headerof the solar collector. It flows into the pipes attached to the absorber plates and gets heated due to the solar radiation incident on the absorber plate. It expands and becomes less dense than the cool water in the storage tank. Natural convection transports this heated water in the collector pipes into the storage tank through the pipes at the top of the collector. Cold water from the tank simultaneously descends to the pipes at the bottom of the solar collector, and the cycle continues



Drain back hot water system



Thermosyphon solar heating system

Drain back System

This system is similar to the indirect system except that it uses water as the heat transferfluid. When the pump is turned off, the water is drained from the pipes to prevent freezing. In addition to the components an indirect system has, the drain back system has a reservoir where the heat transfer fluid is stored (Heat Streamer, 2016). As seen in Figure 2.6 below, there are two pumps. The HTF pump is used to circulate the heat transfer fluid while the DHW pump is used to circulate the domestic hot water

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MATERIALS AND METHODS

Design and Dimensioning of the SWH

The SWH was designed and dimensioned to enable the selection of materials suitable for the design needs. The key components considered during the design process are the flat-platecollector, the storage tank, and the flow channel.

Design Assumptions

The following assumptions were made in the design and dimensioning of the SWH:

1. Flow inside the tubes is laminar and uniformly distributed.
2. The radiation incident on the collector is uniform.
3. The numerical parameters assumed in the system design and dimensioning include:

- Total heating time, t= 5 hours
- Number of flow cycles, n= 5
- Ambient temperature, T_i= 22 ^{0}C'
- Desired outlet temperature, T_o= 70 ^{0}C
- Collector efficiency, η= 58 %
- Storage tank diameter to height ratio,=3

Design Process

Determination of Hot Water Demand and Storage Tank Volume

The daily hot water demand is required for the design of a solar water heating system. Considering a domestic setting of a couple without any children where hot water is used for bathing, 15 litres of water is estimated to meet each individual's demands. The daily hot water demand is used to determine the storage tank volume as seen in Equation

$$V_{St} = [(P * HWD)] * 1.2$$

Where V_{St} is the storage tank volume in litres, P is the number of people and HWD is the daily hot water demand for a single person in litres. The equation is multiplied by a factor of 1.2 to account for unforeseen circumstances. From this, V_{St} is calculated to be 36 litres. Hence a storage volume of 36 litres would meet up with the daily hot water demand.

Taking ^{H} = 3, the required storage tank diameter and length is calculated using

$$V_{St} = \pi d_{St}^{2} H$$

Where d_{St} is the storage tank diameter in m and H is the storage tank length, d_{St} is calculatedto be 0.25 m and H is determined to be 0.75 m.

Determination of Thermal Energy Required

The amount of thermal energy required to heat up 36 litres of water is given by:

$$Q_{St} = (m\, C_w\, (T_o - T_i))\, /3600$$

Where Q_{St} is the amount of thermal energy in kWh required to heat up the total volume of water from the inlet temperature T_i to the desired outlet temperature T_o, m is the total mass in kg of the water to be heated and C_w is the specific heat capacity of water in J/kg ^{0}C. Since mass is a function of volume and density, Equation 3.3 can be rewritten as:

$$Q_{St} = (\rho\, V_{St}\, C_w\, (T_o - T_i))\, /3600$$

Where ρ is the density in kg/m^3 of the fluid being heated, in this case water, T_i is assumed to be 22 ^{0}C and the desired output temperature is 70 ^{0}C. From Equation 3.4, Q_{St} = 2 kWh

Determination of Design Month

From an observation of Table 3.1, June, July, and August have the lowest values of irradiance yearly. The use of irradiance values from these three months in the system design would enable for better performance during other months of the year. Hence, they were selected asthe design months. Their average values gives an irradiance (I) of 4.5 kWh/m^2/day as the design value.

Month	Global horizontal irradiance (Ghi) (kWh/m^2/day)
January	5.49
February	5.46
March	5.66
April	5.32
May	5.33
June	4.97
July	4.4
August	4.14
September	5.02
October	5.27
November	5.91
December	5.38

Material Selection

The selection of the materials used for the components of the SWH are based on the design specifications, material availability and cost, material properties, component function and the manufacturing processes involved.

Storage Tank

The material selected for the storage tank is stainless steel. It is readily available and resistant to hot water corrosion (Exergia, 2009). Stainless steel is costlier than other suitable materials like galvanized mild steel, but it requires low maintenance, has easy formability, is temperature resistant and is environmentally friendly (Eagle Stainless, n.d.). Its easy formability means it can be easily rolled into a cylindrical shape and its high temperature resistance makes it suitable for hot water storage.

Storage Tank Insulation

Fibre glass of 0.020 m thickness was used to insulate the storage tank against heat loss to the environment. From the design calculations, 0.023 m is the required thickness but due to a lack of market availability, fibre glass of 0.020 m thickness was used. It is cheap, readily available, has low thermal conductivity and is non-combustible (Barry, 2018). Mild steel wasused as the enclosing chamber for the tank and fibre glass insulation. It has good weldability.

Flat-plate Collector

The flat-plate collector has various components with different functions, hence the materialsused for the various components are based on their different functions.

The Absorber Plate

The absorber plate's main function is to absorb the solar radiation incident on the flat-plate collector. Copper, mild steel and aluminium all have high thermal conductivity and absorptivity, but aluminium is selected due to it being lighter than mild steel and its cost beingrelatively lower than that of copper. It is also corrosion resistant, ductile and a good reflector of visible light and heat (Liji Thomas, 2019).

.2.1.1 Absorber Plate Coating

Coating the absorber plate is important as it increases the amount of the incident solar radiation absorbed by the plate. Absorber plates are usually coated with black paint, they canalso be pre-treated to ensure good adhesion with the paint. Selective coatings reduce the heatloss from the absorber plate, they are highly effective in absorbing solar radiation but do not emit thermal radiation at a high level. Due to the lack of availability of good selective coatings like black chrome, plain black paint was used with the aid of a spray paint machine.

The Collector Flow Channel

For the piping system tubes, copper is selected because it is tough, and does not fail easily under tension or compressive stress, this makes copper suitable for tube forming or wire drawing (Azom, 2005). The tubes are attached to the absorber plate by welding, fastening or tight fitting the tubes into shaped sheet fins of the absorber plate (Exergia, 2009). The methodused was fastening the tubes to the absorber plate with bolts

Transparent Cover

The requirements for the transparent cover are that it should have low reflectance, low absorptance, and high transmittance. The material that fits this requirement is glass; it transmits a high amount of the solar radiation incident on the collector and suppresses the convective and relative losses from the top of the solar collector plate. Tempered glass with low iron content is used in many solar collectors due to its strength, safety, and higher collector efficiency. It is highly efficient and also has a higher mechanical strength comparedto common glass (Exergia, 2009). Common glass was used due to the expensive cost of tempered glass.

Collector Casing

Mild steel was used for the collector casing; this is due to it being cheap and light. The collector frame holds the absorber plate, piping system and the transparent cover. Mild steel also lasts long when exposed to environmental conditions (Exergia, 2009).

Collector Casing Insulation

Styrofoam of 25 mm thickness was used to insulate the bottom and sides of the collector. TheStyrofoam was cut into the required sizes and fitted into the collector casing. It is cheap, readily available and has good insulation properties (Ogie et al., 2013).

SWH Structural Support

Angle iron made from mild steel were used for the SWH support because it is affordable, easy to work with, strong, available in multiple sizes and requires little maintenance.

Construction of the Solar Water System

Collector Casing

The collector casing was fabricated from mild steel of 2 mm thickness. A higher thickness of mild steel would reduce the ease of machinability. The bottom dimension of 1040. by 840 mm, the side dimensions of 1040 by 100 mm and 840 mm by 100 mm was marked using a scriber, try-square and chalk. This dimension was cut out from the plate using a filingmachine, bent to shape with the aid of a clamp and welded with an electric arc welding machine using mild steel electrodes. The casing was filed to remove rust and painted. A 25mmthick layer of Styrofoam was used to insulate the bottom and sides of the collector casing. The collector casing is shown in Figure 3.1 below

Absorber Plate

Aluminium plate was the material used for the absorber plate. The area of the absorber plate is equivalent to the collector area of 0.76 m2. The absorber plate was painted black to increase its heat absorptivity. Figure 3.2 shows the absorber plate in the collector

The Flow Channel

The internal flow system was constructed using copper pipes. From the design calculation, the required pipe diameter is 11.3 mm, but due to a lack of market availability, the closest alternative of 12.7 mm copper pipe was used. Water was passed through the pipe with one end closed to ensure there

were no leakages. The copper tubing was then painted black and fitted firmly on to the absorber plate.

The Transparent Cover

e Glass with a thickness of 4 mm and dimension of 1035 by 835 mm was used as the transparent cover. It was bound to the top of the collector casing with silicon. The edges of the casing holding the glass were covered with 2mm thick angle irons welded together to form a covering frame. The space between the covering frame and the glass was filled with rubber and had silicon applied to ensure tightness. Figure 3.4 shows the transparent cover.

Glass installed on collector frame

The Storage Tank

The storage tank was fabricated from stainless steel of 1.5 mm thickness. The tank capacity of 36 litres was fabricated from a cut out plate dimension of 75 mm by 50 mm. The plate was rolled with a rolling machine and welded using stainless steel electrodes. The side plates were marked and cut out. The holes for the flow channel pipes on the side plates were also marked and cut open. Stainless rods of 30 mm diameter were drilled to a diameter of 17 mm, step turned and internally threaded to enable easy attachment of the angle valves. They were then welded over the holes for the flow channel pipes on the side plates. The storage tank was filled with water and checked for leakages.

The Storage Tank Insulation

The storage tank was insulated with fibre glass of 20 mm thickness. The fibre glass was put into the enclosing chamber, then the storage tank was placed inside

The Supporting Frame

The supporting frame was constructed from angle irons of 4 mm and 2mm thickness with a one and half inch wideness.

The frame was constructed to enable for adjustment of theollector and wheels were attached to allow for easy movement of the system. The frame was constructed with a distance of 490 mm between the bottom of the storage tank and the top of the collector to ensure that the water flowed properly

Fabricated solar water heater

RESULTS AND DISCUSSION

4.1 Results

The data required for the performance analysis of the SWH can be seen below. The experiments were conducted in two sets on three different days. The first set during the late rainy season and the second set during the dry season. Using the average flow rate of 0.0025 kg/s and the other readings obtained during testing, the instantaneous system efficiency was calculated using Equation 3.5 for each set of data.

Table 4. 1 Readings for the first day of experiments (23/09/20 readings)

Time (h)	Ambient Temp. (⁰C)	Inlet Temp (⁰C)	Outlet Temp (⁰C)	Irradiance W/m^2	Efficiency (%)
10:00	25.00	25.00	27.00	565	4.89
11:00	27.00	30.00	30.50	603	1.15
12:00	28.00	30.00	31.10	704	2.16
13:00	28.00	30.00	50.00	826	33.45
14:00	28.00	32.00	65.00	681	66.95
15:00	29.00	30.00	37.00	543	17.81

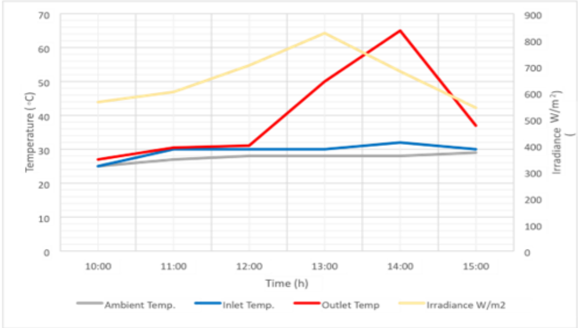

Figure 4. 1 Temperature against irradiance for day one

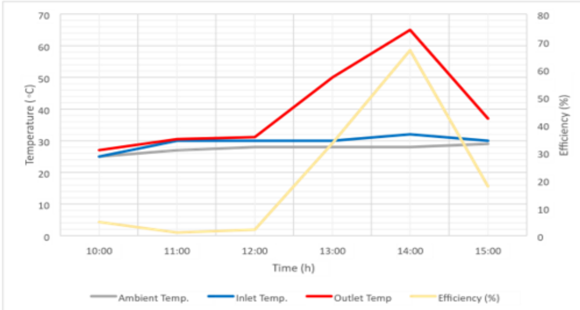

Figure 4. 2 Temperature against efficiency for day one

From Figure 4.1, it is seen that the outlet temperature slowly rises for the first few hours, but then increases rapidly from midday till its peak at two pm. It is important to note that the irradiance levels peak an hour before the outlet temperature peaks. From Figure 4.2, the highest efficiency is observed at the time when the output temperature peaks. It can be deduced that the outlet temperature and the efficiency have a close relationship.

Table 4. 2 Readings for the second day of experiments (25/09/20 readings)

Time (h)	Ambient Temp. (⁰C)	Inlet Temp (⁰C)	Outlet Temp (⁰C)	Irradiance W/m^2	Efficiency (%)
10:00	26.00	26.00	28.00	519	5.32
11:00	26.00	26.00	46.80	604	47.58
12:00	27.00	27.00	53.00	615	58.41
13:00	28.00	27.00	50.10	749	42.61
14:00	27.00	30.00	61.00	683	62.71
15:00	27.00	32.00	53.80	493	61.09

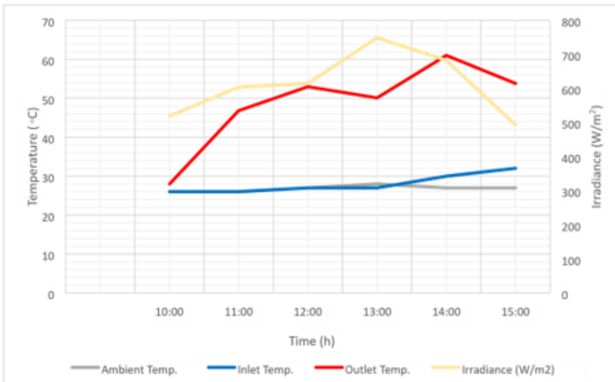

Figure 4. 3 Temperature against irradiance for day two

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14:00	32.00	46.50	60.30	671	28.41
15:00	32.00	46.70	55.60	460	26.73

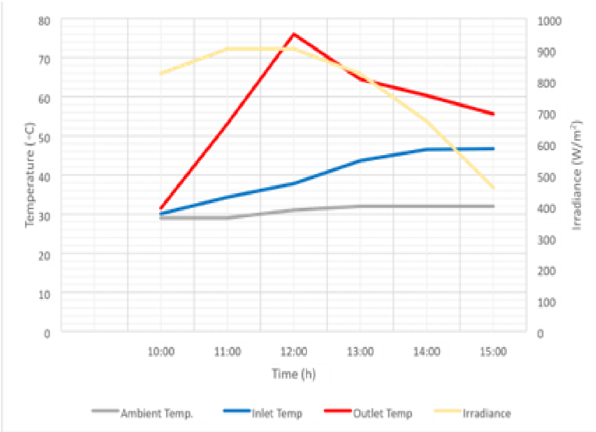

Figure 4. 9 Temperature against irradiance for day five

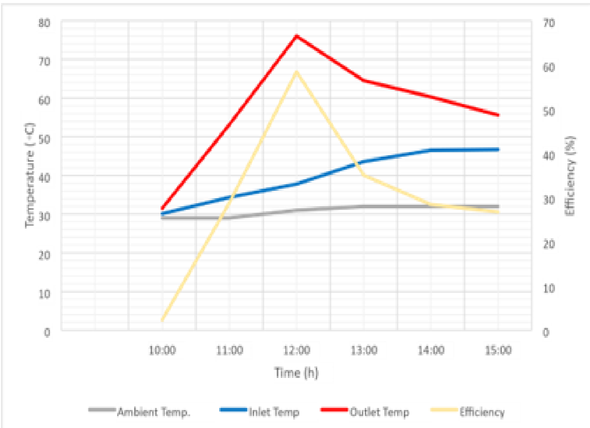

Figure 4. 10 Temperature against efficiency for day five

›r day five, Figure 4.9 shows that the irradiance rises between ten and eleven am, then stays ›nstant till twelve pm after which it gradually falls. This trend is unsimilar to those observed ı the previous days of testing. The outlet temperature peaks at twelve pm similar to day four. gure 4.10 shows that the efficiency and the outlet temperature both peak at the same time ıd have similar trendlines. This shows a correlation with results from day four.

Table 4. 6 Readings for the sixth day of experiments (30/10/20 readings)

Time (h)	Ambient Temp. (°C)	Inlet Temp (°C)	Outlet Temp (°C)	Irradiance W/m²	Efficiency (%)
10:00	30.00	30.50	33.20	816	4.57
11:00	30.00	31.70	59.80	916	42.38
12:00	32.00	34.20	79.30	940	66.29
13:00	33.00	39.80	73.50	884	52.67
14:00	34.00	40.10	65.70	750	47.16
15:00	34.00	43.40	60.20	551	42.12

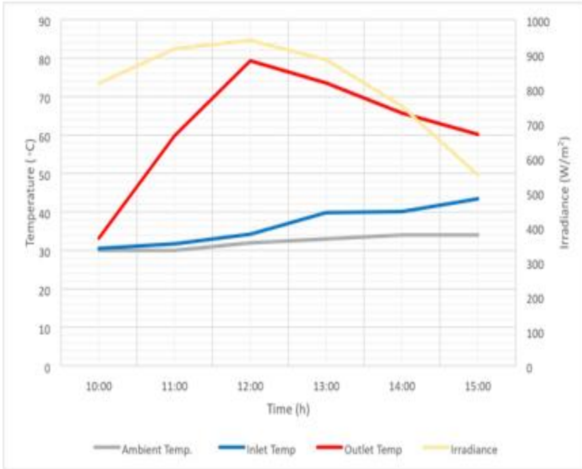

Figure 4. 11 Temperature against irradiance for day six

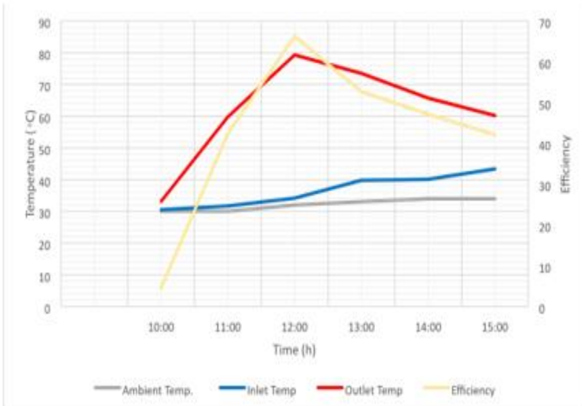

Figure 4. 12 Temperature against efficiency for day six

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From Figure 4.11, The outlet temperature reaches a peak of 79.3^{0}C at noon. This is the highest observes compared to the previous days of testing. The irradiance levels also peak at noon, following with the trend from day four and five. For Figure 4.12, the relationship between the efficiency and the outlet temperature is similar to that of day four and five. The maximum efficiency observed on the last day's testing was 66.29%.

Table 4. 7 Outlet temperature for the six days of testing

Time (h)	Day One	Day Two	Day Three	Day Four	Day Five	Day Six
10:00	27.00	28.00	24.80	30.30	31.50	33.20
11:00	30.50	46.80	42.10	50.10	53.10	59.80
12:00	31.10	53.00	48.50	77.40	76.00	79.30
13:00	50.00	50.10	57.10	74.50	64.50	73.50
14:00	65.00	61.00	53.00	70.80	60.30	65.70
15:00	37.00	53.80	50.10	63.30	55.60	60.20

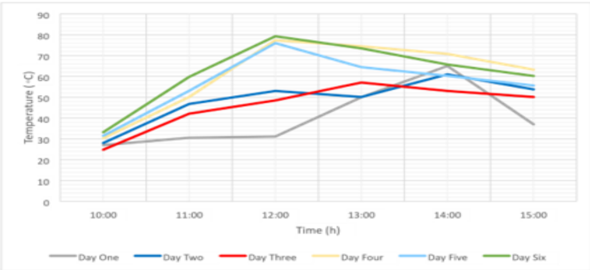

Figure 4. 13 Outlet temperature for the six days of testing

Figure 4.13 shows a significant difference in the outlet temperatures for day one to three compared to those for day four to six. The testing for day one to three was during the late rainy season while those for day four to six was during the dry season. The peak outlet

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Using a specialised machining technique called electro magnetic abrasive finishing (EMAF), metallic workpieces can have high-quality surface finishes. EMAF removes material from the workpiece surface using abrasive particles and an electromagnetic field, producing a smoother and more uniform finish.

For items in a variety of applications, including aerospace equipment, medical devices, semiconductors, vehicles, tools, and dies, among others, a highquality surface with a low value of surface roughness and high dimensional accuracy is needed. The production of components with complicated shapes for various applications requires the use of sophisticated materials, such as alloys of hard materials, glass, ceramics, and composite materials. These materials are challenging to finish because of their extreme hardness and toughness, as well as the goods' intricate shapes. The finishing process is the last step in the manufacture of components, and it accounts for around 15% of the overall production expense. Abrasive finishing is a method for precision surface finishing that shows promise. In order to complete the intricate shapes shows promise.

Discussion of Results

It is seen from the overall results that that the irradiance levels and the output temperature are closely related. For the first three days of testing during the late raining season, an outlet temperature of 65 ^{0}C was the highest temperature observed. However, for the last three days of testing during the dry season, the maximum outlet temperature observed was 79.3 ^{0}C. This clearly shows that the system performs better during the dry season. The system was designed with a desired output temperature of 70 ^{0}C and the collector area used was 0.76 m^2 obtained in section 3.1.2.4 during the design process. The total volume of water heated up was 36 litres.(Ekpo & Enyinna, 2017) designed a solar water heater to provide 75 litres of water at 60 ^{0}C daily. From their design, the collector area required was 1.464 m^2. However, they used an area of 2.3m^2 during the construction of their system and obtained a maximum output of 76 ^{0}C. Comparing the two results shows that although (Ekpo & Enyinna, 2017) used a larger collector area, their peak outlet temperature was slightly lower than the peak value obtained in this work. This shows that using a larger collector area would not necessarily improve performance, the irradiance available at the system site also plays a role on system performance.

The highest irradiance level of 940 W/m^2 was observed on day six, the highest outlet temperature of 79.3 ^{0}C was also observed on the same day and at the same time. The highest rise in outlet temperature was observed on day four with a temperature rise of 47.1 ^{0}C betweenten am and noon. It is noteworthy that day three had the lowest irradiance levels. The highest efficiency gotten from the system was 68.19 % on day four.

RECOMMENDATIONS

Conclusion

In this work, the design and construction of a 36-litre capacity portable solar water heater has been carried out. using relevant equations to size the major components of the system. The materials for the components were then selected with consideration to the design calculations, machinability, market availability and cost of the materials. The system was tested, and the following results were observed. From the first three days of testing during the late raining season, the highest outlet temperature recorded was 65^{0}C. For the last three days of testing during the dry season, the highest outlet temperature recorded was 79.3 ^{0}C. This difference clearly shows that the system performs better during the dry season when the irradiance levels are higher. The highest irradiance recorded was 940 W/m^2 on the sixth day of testing while the highest efficiency recorded from the system was 68.19% .

Recommendations

Due to time and financial constraints, the following are recommended as futuremodifications that should enhance system testing and performance:

1. Installation of a sensor to determine water level and control flow.
2. Installation of a flow meter to easily get flow rate of working fluid.

REFERENCES

1 Abdunnabi, M., Rohuma, I., Endya, E., & Belal, E. (2018). Review on solar water heating in Libya

2. Adefarati, T., & Bansal, R. C. (2019). Energizing Renewable Energy Systems and Distribution Generation. In Pathways to a Smarter Power System (pp. 29–65). Elsevier. https://doi.org/10.1016/b978-0-08-102592-5.00002-8

3. Alternative Energy Tutorials. (2015). Solar Flat Plate Collectors for Solar Hot Water. http://www.alternative-energy-tutorials.com/solar-hot-water/flat-plate-collector.html

4. API Energy. (n.d.). Active Vented System. Retrieved September 29, 2020, from https://apienergy.co.uk/product/active-vented-system-drain-back-solar-water- heatingsystem/

5. Atia, D. M., Fahmy, F. H., Ahmed, N. M., & Dorrah, H. T. (2012). Optimal sizing of a solar water heating system based on a genetic algorithm for an aquaculture system.

6. Mathematical and Computer Modelling, 55(3–4), 1436–1449.https://doi.org/10.1016/j.mcm.2011.1

7. Azom. (2005). Aluminium - Specifications , Properties , Classifications and Classes. https://www.azom.com/article.aspx?ArticleID=2863

8. Barry, C. (2018). thermal properties of glass fiber thread. B&W FIBERGLASS NEWS, 1. http://info.bwfiberglass.com/blog/the-thermal-properties-of-glass-fiber-thread

9. Dean, J. (n.d.). Domestic Hot Water Assessment Guidelines (Fact Sheet), Saving Energy In Commercial Buildings, NREL (National Renewable Energy Laboratory). Retrieved May19, 2020, from https://www.nrel.gov/docs/fy11osti/50118.pdf

10. Eagle Stainless. (n.d.). Characteristics of Stainless Steel. Retrieved September 27, 2020, from https://eagletube.com/about-us/news/stainless-steel-characteristics/

11. Ekpo, J., & Enyinna, P. (2017). Design and Construction of a Solar Water Heater for Environmental Sustainability. British Journal of Applied Science & Technology, 20(3), 1–15. https://doi.org/10.9734/bjast/2017/31820

12. Energy information administration. (2020). Where solar is found. https://www.eia.gov/energyexplained/solar/where-solar-is-found.php

13. Lilian, I. N., Daniel, O., & Joseph., O. (2018). Modeling the Solar Radiation Parameter over Abuja using Neural Networks. Undefined.

14.

15. Nshimyumuremyi, E., & Junqi, W. (2019). Thermal efficiency and cost analysis of solar water heater made in Rwanda. Energy Exploration and Exploitation, 37(3), 1147–1161. https://doi.org/10.1177/0144598718815240

16. O'Hegarty, R., Kinnane, O., & McCormack, S. (2014). A simplified procedure for sizing solar thermal systems; Based on national assessment methods in the UK and Ireland. EnergyProcedia, 62, 647–655. https://doi.org/10.1016/j.egypro.2014.12.428

17. Of, E. (2011). Dimensioning and Design of Solar Thermal Systems. Design, 31–36. www.aee-

18. Office of energy efficiency and renewable energy. (2013). Solar Radiation Basics. Energy.Gov. https://www.energy.gov/eere/solar/articles/solar-radiation-basics

19. Ogie, N. A., Oghogho, I., & Jesumirewhe, J. (2013). Design and Construction of a SolarWater Heater Based on the Thermosyphon Principle. Journal of Fundamentals of Renewable Energy and Applications, 3, 1–8. https://doi.org/10.4303/jfrea/235592

20. Osinowo, A. A., Okogbue, E. C., Ogungbenro, S. B., & Fashanu, O. (2015). Analysis of Global Solar Irradiance over Climatic Zones in Nigeria for Solar Energy Applications.Journal of Solar Energy, 2015, 1–9. https://doi.org/10.1155/2015/819307