A 100 Liter Capacity Solar Water Heater for a Household of Three Individuals

C.B. Ugwuodo[1]; E.C. Ugwuoke[2*]; E.N. Anike[1]; K.C. Onyeneho[3]; and F.C. Umunna[4]

[1]Department of Chemical engineering, Michael Okpara University of Agriculture, Umudike, Nigeria.
[2]Projects Development Institute (PRODA), Enugu, Nigeria.
[3]Department of Mechanical Engineering Technology, Akanu Ibiam Federal Polytechnic, Unwana, Afikpo, Ebonyi State, Nigeria.
[4]National Productivity Center, Enugu, Enugu State, Nigeria.

E-mail: emmychyugwuoke@yahoo.com*

ABSTRACT

Global energy consumption has increased steadily over the last few decades and has recently been marked by especially dramatic growth rates in many developing countries, such as China, India, and Brazil. Heating accounts for 40% to 50% of the world's energy demand and most of the energy supply for heating currently comes from fossil fuels. To reduce the consumption of fossil fuels for heating and the emission of greenhouse gases, solar energy has been accepted as one of the most promising alternative energy sources because it is free and environmentally clean. One of the most widely-known solar thermal applications is the solar water heating (SWH) system. According to the Renewable Energy Policy Network (2010), approximately 70 million houses use SWH systems worldwide. Namely, SWH systems have been recognized as one of the most cost-effective systems to many engineers, investors, and users.

The proper design of SWH systems is important to assure good performance and maximize the economic benefits of these systems. This experiment achieved rising the cold water temperature from 24°C to 51°C which is a significant increase. The ambient temperature varied from 24°C to 28°C. The outlet temperature of the heated water varied from 23°C from 8 am to 42°C at 6 pm on the same day. It was observed during the experiment that varying the color of the collector plate from red to black has great effect in the outlet temperature. As the Insolation increased from 10am to 3pm the outlet temperature of the water increased.

(Keywords: solar water heater, insolation, ambient temperature, collector, water)

INTRODUCTION

We are blessed with abundant solar energy at no cost. The solar radiation incident on the surface of the Earth can be conveniently utilized for the benefit of human society. One of the popular devices that harness the solar energy is solar hot water system (SHWS).

Renewable energy resources, of which the Sun is a good example, are those resources which undergo a faster replenishment rate within a relatively short time than the rate at which they are utilized or depleted [1]. The energy of the Sun is generated from the nuclear fusion of its hydrogen into helium, with a resulting mass depletion rate of approximately 4.7×10^6 tons per second [1]. The Earth's population currently needs 15 terawatts of power in total, but the solar radiation that reaches the Earth on a continuous basis amounts to 120,000 terawatts; hence, just a fraction of the Sun's energy reaching the Earth will cover the bulk of energy requirements [2].

About 36 years ago, the world experienced a major oil crisis which started a new way of energy thinking which focused on developing alternative energy resources, which would be renewable and environmentally friendly [3]. Several challenges such as the increase in oil demand accompanied with oil price rise, depletion of oil reserves, reduced availability of fossil fuels, ozone layer depletion, health hazards, relatively tangible problems of aesthetics to problems of environmental conservation, and global climate change and other air pollution issues caused mainly by burning of these hydrocarbon as a source of heat energy, has led to the drive to use environmentally friendly and renewable alternative sources of heat energy to eliminate or minimize these negative effects [3].

Presently, solar and other alternative energy resources are being harnessed for various applications such as power generation, air-conditioning, space heating, domestic hot water systems, etc. [4]. Solar energy being transmitted from the Sun through space to Earth by electromagnetic radiation must be converted to heat before it can be used in a practical heating or cooling system. Since solar energy is relatively dilute when it reaches the Earth, the size of a system used to convert it to heat on a practical scale must be relatively large. Solar energy collectors, the devices used to convert the Sun's radiation to heat, usually consist of a surface that efficiently absorbs radiation and converts this incident flux to heat which raises the temperature of the absorbing material [1]. A part of this energy is then removed from the absorbing surface by means of heat transfer fluid that may either be liquid or gaseous.

One of the simple forms of solar energy collectors built is the flat-plate collector. It differs in several respects from more conventional heat exchangers [3]. The later usually accomplish a fluid-to-fluid exchange with high heat transfer rates but with emitted radiation as an unimportant factor. Focusing systems have the following challenges which are absent in flat-plate collectors: complications of optical characteristics of concentrator, non-uniform fluxes on the absorbers, wide variation in shape, temperature and thermal loss characteristics of absorbers, and introduction of additional optical factors into the energy balance. Flat-plate collectors unlike focusing systems are designed for applications requiring energy delivery at moderate temperatures up to perhaps 80 °C above ambient temperature.

They have the advantages of using beam and diffused solar radiation, not requiring orientation toward the Sun, no significant optical loss terms, and requiring little maintenance. In a review of solar water heating systems for domestic and industrial applications carried out by Ogueke, et al. [5] , water heating systems were grouped into two broad categories (passive and active), each of them operating in either direct or indirect mode. They reported their performances, uses and applications, and factors considered for their selection. The active systems generally have higher efficiencies, their values being 35%–80% higher than those of the passive systems [1]. They are more complex and expensive. Accordingly, they are most suited for industrial applications where the load demand is quite high or in applications where the collector and service water storage tank need not be close to each other or for the applications in which the load requires more than one solar collector.

On the other hand, the passive systems of which this work is an example are less expensive and easier to construct and install. They are most suitable for domestic applications and in applications where load demand is low or medium. Chuawittayawuth and Kumar [6], in their work, presented details of experimental observations of temperature and flow distribution in a natural circulation solar water heating system and its comparison with the theoretical models. The measured profile of the absorber temperature near the riser tubes (near the bottom and top headers) conformed well with the theoretical models. The values at the riser tubes near the collector inlet were found to be generally much higher than those at the other risers on a clear day, while on cloudy days, these temperatures were uniform [3]. The mean absorber plate and mean fluid temperatures during a day were estimated and compared with theoretical models. The temperature of water near the riser outlets was found to be fairly uniform especially in cloudy and partly cloudy days at a given plane during a day. The temperature of water in the riser was also found to depend on its flow rate. Measurements of glass temperature were also carried out in the work.

Michaelides, et al. [7] presented experimental investigation of the night heat losses of hot water storage tanks in thermosyphon solar water heaters. Utilizing the method suggested by ISO 9459-2:95, they tested three typical thermosyphon solar water heating systems with different storage tank sizes. The results were analyzed to quantify the night heat losses and to investigate the effect that these may have on the system daily performance [1]. Analysis of the results showed that a linear behavior of the heat losses with the night mean ambient temperature exists. The research confirmed that the night loss is one of the most important sources of energy loss in thermosyphonic systems [8].

Photovoltaic thermal technology (PV/T) which refers to solar thermal collectors that use PV cells as an integral part of the absorber plate are examples of systems which generate both thermal and electrical energy simultaneously [9] . They can generate electricity and produce hot air or hot water at the same time. Spiral flow absorber collectors, which are designed in the form of a continuous coil or tube having at least one inlet and outlet so as to allow fluid to enter and to exit from coil, respectively, help to improve on the combined PV/T efficiency and the mass flow rate [10].

The study carried out by Ibrahim, et al. [11] showed that spiral flow absorber collector at temperature of 55 °C (panel temperature) achieved the best mass flow rate at 0.011 kg sec^{-1} and generated combined PV/T efficiency of 64%, with 11% of electrical efficiency and power maximum of 25.35 W; while a single-pass rectangular collector absorber obtained the best mass flow rate at 0.0754 kg sec^{-1}, when the surface temperature was 392°C, generated combined PV/T efficiency of 55%, with 10% of electrical efficiency and maximum power of 22.45 W [12].

Some countries like Nigeria have abundant available solar energy from which useful energy can be harnessed for several purposes (despite the draw-back of night heat losses); hence, the development of this low cost solar water heater (constructed using a high percentage of locally available materials) aimed at providing energy for heating water for domestic use with all the attendant advantages. Being low cost, some features that will increase its cost were not integrated in the system so that it will be affordable by a larger population of the people.

Solar Water Heating System

A solar thermal device captures and transfers the heat energy available in solar radiation which can be used for meeting the requirements of heat in different temperature ranges.
Three main temperature ranges used are [13]:

Table 1: Temperature Range.

Low Temperature	Hot Water - 60°C to 80°C
Medium Temperature	Drying-- 80°C to 140°C
High Temperature	Coking and Power generation->140°C

A solar water heating system (SWHS) is a device which supplies hot water at 60°C to 80°C using only solar thermal energy without any other fuel. It has three main components, namely [13]:

1. Solar Collector

2. Insulated hot water storage tank and

3. Cold water tank with required insulated hot water pipelines and accessories.

In the case of smaller systems (100 – 2000 liters per day), the hot water reaches the user end, by natural (thermosiphon) circulation for which the storage tank is located above the collectors. In higher capacity systems, a pump may be used for forced circulation of water.

Flat Plate Collectors (FPC) based Solar Water Heaters

The solar radiation is absorbed by Flat Plate Collectors which consist of an insulated outer metallic box covered on the top with glass sheet. Inside there are blackened metallic absorber (selectively coated) sheets with built in channels or riser tubes to carry water. The absorber absorbs the solar radiation and transfers the heat to the flowing water [13]

Table 2: Collector Area with Capacity.

Capacity in (LPD) for 60°C SWHS	Recommended Collector Area (in Sq.m)
100	2
200	4
300	6
500	8
1000	16

Evacuated Tube Collectors (ETC) Based Solar Water Heaters

Evacuated Tube Collector is made of double layer borosilicate glass tubes evacuated for providing insulation. The outer wall of the inner tube is coated with selective absorbing material. This helps absorption of solar radiation and transfers the heat to the water which flows through the inner tube [13].

Table 3: Collect Area, Capacity and Diameter.

Capacity (LPD)	Dia:47mm Length:1500mm	Dia:47mm Length:1800mm	Dia:48mm Length:1800mm	Collector Area (Sq.m)
100	14	12	10	1.5
125	18	15	13	1.93
150	21	18	15	2.25
200	28	23	19	3.0
250	34	28	23	3.75
300	40	33	27	4.5
400	52	43	35	6
Above 500LPD	12 Tubes per 100LPD	10 Tubes per 100LPD	8 Tubes per 100LPD	1.3sq.m/100LPD

Selection of suitable Solar Water Heating Systems [13]

1. Flat plate collector (FPC) based systems are of metallic type and have longer life as compared to Evacuated tube collector (ETC) based system as ETCs are made of glass which are of fragile in nature.

2. ETC based systems are 10 to 20% cheaper than FPC based system. They perform better in colder regions and avoid freezing problem during sub-zero temperature. FPC based systems also perform good with anti-freeze solution at sub-zero temperature but their cost increases.

3. At places where water is hard and has larger chlorine content, FPC based system with heat exchanger must be installed as it will avoid scale deposition in copper tubes of solar collectors which can block the flow of water as well reduce its thermal performance. ETC based systems do not face such problem.

4. For a house with one bathroom and 3 to 4 members, 100 liters per day capacity system should be sufficient. For more numbers of bathrooms, the capacity will increase accordingly due to pipe losses and more number of family members. Generally the capacity is decided based on hot water required in mornings for bathing. If the usage is in evening & at other times also, the capacity is decided accordingly.

5. A 100 lpd capacity may cost Rs. 20,000 to Rs. 25,000 depending on type and location. The cost, however, does not increase linearly with increase in capacity, rather it comes down proportionately as we go for higher capacity system. The system cost does not include the cost of cold water tank, & its stand which is required if overhead tank is not installed in a house/ building. Cost of hot water insulated pipe line also, may be extra if numbers of bathrooms are more than one. Additional cost towards all these components may increase by 5 to 10%.

6. Avoid putting in an electricity back up in the storage tank of solar system. If you have electric geyser of say less than 10 lpd capacity or an instant geyser it would be better if you connect the outlet line of solar system with inlet of geyser and set thermostat at 40^{o}C. Your geyser will start only when you get water below 40^{o}C from solar system and will switch off when temperature goes above say 42^{o}C or so. This will save a lot of electricity and will heat water according to your requirements. However, if you have storage geyser of higher capacity, it is better to have a separate tap for the solar system and use your electric geyser when you don’t get hot water from solar water heater.

A Brief History of Solar Water Heating

Solar water heating has been around for many years because it is the easiest way to use the Sun to save energy and money. One of the earliest documented cases of solar energy use involved pioneers moving west after the Civil War. They would place a cooking pot filled with cold water in the Sun all day to have heated water in the evening. The first solar water heater that resembles the concept still in use today was a metal tank that was painted black and placed on the roof where it was tilted toward the Sun. The concept worked, but it usually took all day for the water to heat, then, as soon as the Sun went down, it cooled off quickly because the tank was not insulated [14].

A Brief History of the American Solar Water Heating Industry

1890 to 1930's - the California Era: The first commercial solar water heater was introduced by Clarence Kemp in the 1890's in California. For a $25 investment, people could save about $9 a year in coal costs. It was a simple batch type solar water heater that combined storage and the collector in one box [14].

The first thermosyphon systems with the tank on the roof and the collector below were invented, patented, and marketed in California in the 1920's by William Bailey. One of the largest commercial systems in California was installed for a resort in Death Valley.

Natural gas was discovered in southern California and cheap natural gas, aggressively marketed by utility companies, ended the solar water heating market. Patents were sold to a Florida company, owned by HM Carruthers in 1923 and the solar hot water industry began in the coastal cities of central Florida and southern Florida [14].

1930's to 1973 - the South Florida Era: Floridians purchased or shipped to the Caribbean more than 100,000 thermosyphon water heaters between 1930 and 1954 when the industry collapsed. During the second World War (1942 to 1945) copper was reserved for the military and the solar industry was not able to make solar collectors [14].

After the war, the Florida industry boomed again for about six years. Half of Miami homes had solar water heaters with over 80% of new homes having them installed. In the early 1950's electricity became cheap in Florida and utility companies gave away electric water heaters in an effort to eliminate the solar water heating industry [14].

By 1973, there were only two full-time solar water heating companies left in the United States both operating out of Miami, Florida.

1973 to 1986 - Oil Embargo and Tax Credits: The oil embargo of 1973 resulted in a rise in fuel prices. A few companies started experimenting with solar water heaters and designing systems but there were really no national solar collector manufacturers with widespread distribution until the late seventies[14].

The federal government sponsored a few Housing and Urban Development (HUD) Grants for domestic solar water heaters in the period just before the start of the 40% Federal tax rebate in 1979. The tax credit era, 1979 to 1986, started a nationwide boom in solar hot water systems that resulted in hundreds of manufacturers and thousands of contractors and distributors starting new businesses [14].

Equipment has improved since the 1980’s. Improvements were precipitated by both certification design review and experienced installers. Today, more than 1.2 million buildings have solar water heating systems in the United States. Japan has nearly 1.5 million buildings with solar water heating. In Israel, 30 percent of the buildings use solar- heated water. Greece and Australia are also leading users of solar energy.

There is still a lot of room for expansion in the solar energy industry. There are no geographical constraints. For colder climates, manufacturers have designed systems that protect components from freezing conditions. Wherever the Sun shines, solar water heating systems can work. The designs may be different from the early solar pioneers, but the concept is the same.

Environmental Benefits

- Solar water heaters do not pollute.
- Solar water heaters help to avoid carbon dioxide, nitrogen oxides, sulfur dioxide, and the other air pollution and wastes created when the local utility generates power or fuel is burned to heat domestic water.
- When a solar water heater replaces an electric water heater, the electricity displaced over 20 years represents more than 50 tons of avoided carbon dioxide emissions alone

Long-Term Benefits

- Solar water heaters offer long-term benefits that go beyond simple economics.

- In addition to having free hot water after the system has paid for itself in reduced utility bills, owners could be cushioned from future fuel shortages and price increases.

- Solar water heaters can assist in reducing this country's dependence on foreign oil.

- It is estimated that adding a solar water heater to an existing home raises the resale value of the home by the entire cost of the system. Homeowners may be able to recoup their entire investment they sell their home.

Economic Benefits

- Many home builders choose electric water heaters because they are easy to install and relatively inexpensive to purchase. However, research shows that an average household with an electric water heater spends about 25% of its home energy costs on heating water.

- It makes economic sense to think beyond the initial purchase price and consider lifetime energy costs, or how much you will spend on energy to use the appliance over its lifetime. The Florida Solar Energy Center studied the potential savings to Florida homeowners of common water-heating systems compared with electric water heaters. It found that solar water heaters offered the largest potential savings, with solar water-heater owners saving as much as 50% to 85% annually on their utility bills over the cost of electric water heating.

MATERIALS

The water used in this experiment was supplied from borehole located at 9^{th} mile corner Enugu, Enugu State. The water from this located remain the best quality water in the country.

The 9^{th} mile water was chosen because the water is good both for domestic and industrial purposes. The solar water heating tank was designed and fabricated, locally. Mild steel of 2mm thick was used for the tank building to reduced cost. The stand was also fabricated with mild steel of thickness 6 mm. The water tubes are made of copper for proper heat transfer.

METHODS

The Sun sends a huge amount of energy to Earth every day. As a rough estimate, approximately one kilowatt of energy is arriving per square meter of the Earth's surface that is receiving direct sunlight. A solar collector tries to collect as much of this energy as possible and convert it into a usable form, usually either heat energy or electrical energy.

A solar collector is basically a flat box and is composed of three main parts, a transparent cover, tubes which carry a coolant and an insulated back plate. The solar collector works on the greenhouse effect principle; solar radiation incident upon the transparent surface of the solar collector is transmitted through this surface. The inside of the solar collector is usually evacuated, the energy contained within the solar collect is basically trapped and thus heats the coolant contained within the tubes. The tubes are usually made from copper, and the back plate is painted black to help absorb solar radiation. The solar collector is usually insulated to avoid heat losses. Solar thermal heat can provide hot water for an entire family during the summer. The collector size needed per person is about 1.5 m^2. An average family of four people therefore needs a collector about 6 m^2.

RESULT AND DISCUSSION

The cold water tank was filled with water after proper filtration. The valve was opened to allow water flow to the circulating pipes, which are made of riser and header pipes, through the carriage pipe (i.e., the inlet pipe). The water was heated up from the heat supplied by the absorber plate to the tubes integrated underneath the absorber plate; hence, by virtue of density difference between the cold water and hot water (i.e., the cold water goes down, while the hot water comes up), a flow is initiated (thermosyphon or natural convection).

The hot water flows to the hot water storage tank, which has a gate valve to allow tapping when needed for use. The values in Table 4 shows the ambient temperature, inlet temperature to the tank and temperature after circulation of the heated water otherwise known as the outlet temperature. The ambient temperature varied from 25°C to 28°C on 27th November 2016. The temperature was recorded from 8am to 6pm on the same day. The temperature inlet to the tank has similar value with the ambient temperature except for two cases where there was a drop in the value of temperature by 1°C and another case where there is an increase in the value of temperature by 1°C. These cases are at 8 am where the inlet temperature was 24°C and by 10 am where the inlet temperature was 27°C.

The heated temperature coming out from the storage tank otherwise called outlet temperature increased significantly from 23°C to 51°C. There is a great improvement from the outlet temperature from the tank .The maximum temperature of 51°C temperature was recorded at 3 pm and the minimum temperature of 23°C was recorded at 8 am and 9 am, respectively. The result showed that in a bright sunny day one will enjoy using warm water from 12 pm to 6 pm.

Figure 1 shows the variation of temperature from 8 am to 6 pm for ambient temperature, inlet temperature and outlet temperature. It was observed that as the Insolation increased from time period of 10 pm to 4 pm the outlet temperature increases. There were two cases where the outlet temperature decreased slightly from 5 pm to 6 pm as the Insolation decreased gradually at these two time interval, respectively.

Table 4: Record of Ambient Temp (°C), Temp in (°C) and Temp Out (°C) from 8 am to 6 pm.

Time (h)	Ambient Temp (°C)	Temp. In(°C)	Temp. Out (°C)
8am	25	24	23
9am	25	25	23
10am	26	27	24
11am	26	26	28
12pm	26	26	33
1pm	27	27	39
2pm	27	27	44
3pm	28	28	51
4pm	28	28	50
5pm	27	27	48
6pm	25	25	42

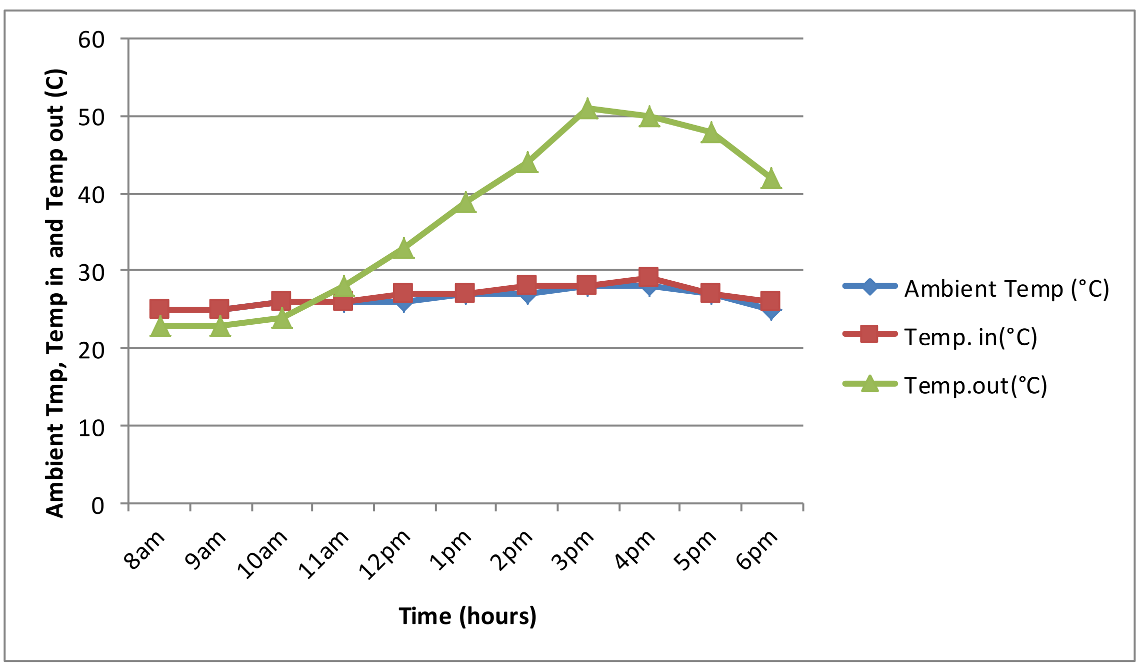

Figure 1: Temperature (°C) Variation versus Time (hr).

Table 5: Record of Collector Temperature (°C) 8 am to 6 pm.

Time (h)	Collector Temperature Tc (°C)
8am	22
9am	22
10am	23
11am	25
12pm	29
1pm	36
2pm	42
3pm	48
4pm	47
5pm	44
6pm	37

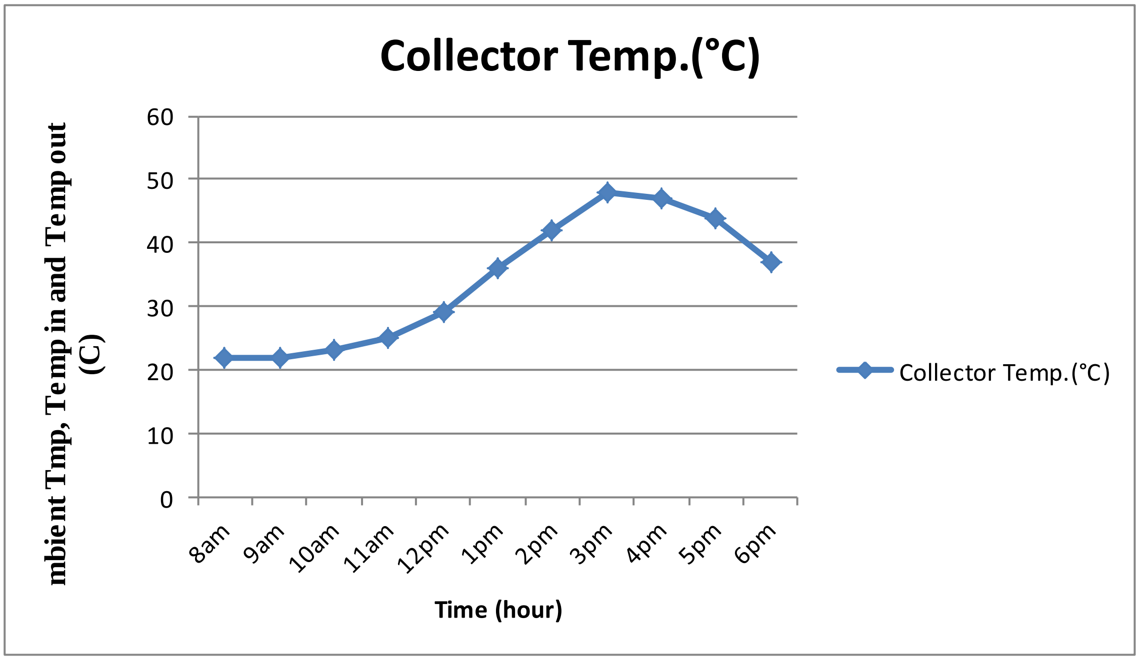

Figure 2: Variation of Collector Temperature Tc (°C) versus Time (hr).

CONCLUSION

A solar water heater consists of a collector to collect solar energy and an insulated storage tank to store hot water. The solar energy incident on the absorber panel coated with selected coating transfers the hat to the riser pipes underneath the absorber panel. The water passing through the risers get heated up and are delivered the storage tank. The re-circulation of the same water through absorber panel in the collector raises the temperature to 80°C (Maximum) in a good sunny day. The total system with solar collector, storage tank and pipelines is called solar hot water system.

This work aimed at using solar water heater to raise the temperature of cold water from its normal temperature to a certain temperature which depends on the intensity of the solar radiation. As the intensity of solar radiation increases, the solar collector's temperature increases, thereby increasing the outlet temperature of the solar water heater. The atmospheric temperature recorded at 8 am and 6 pm during the experiment were 25°C and 28°C respectively. The maximum outlet temperature of

51°C was recorded by 3 pm while the minimum outlet temperature of 23°C was recorded by 8 am.

REFERENCES

1. Ogie, N.A., I. Oghogho, and J. Jesumirewhe. 2013. "Design and Construction of a Solar Water Heater Based on the Thermosyphon Principle". *Journal of Fundamentals of Renewable Energy and Applications*. 3 (2013), Article ID 235592, 8 pages doi:10.4303/jfrea/235592.

2. Bradke, H., C. Doetsch, H. Huhn, D. Radloff, T. Schlegl, U. Schließmann, et al. 2011. "Researching: Energy". Brochure, Alliance of Scientific Organizations: Berlin, Germany.

3. Ogie, N.A., I. Oghogho, and J. Jesumirewhe. 2013. "Design and Construction of a Solar Water Heater Based on the Thermosyphon Principle". *Journal of Fundamentals of Renewable Energy and Applications*. 3 (2013), Article ID 235592, 8 pages doi:10.4303/jfrea/235592.

4. Flor, H., J. Frantzen, J. von Heyl, M. Hoi, R.G. Holtforth, A. Jacobsen, et al. 2011. *Green Production Technologies*. Dr. Florian Langenscheidt: Berlin, Germany.

5. Ogueke N.V., E.E. Anyanwu, and O.V. Ekechukwu. 2009. "A Review of Solar Water Heating Systems". *Journal of Renewable and Sustainable Energy*. 1 (2009), 043106.

6. Chuawittayawuth, K. and S. Kumar. 2002. "Experimental Investigation of Temperature and Flow Distribution in a Thermosyphon Solar Water Heating System". *Renewable Energy*. 26 (2002), 431–448.

7. Michaelides, I., P. Eleftheriou, G.A. Siamas, G. Roditis, and P. Kyriacou. 2011. "Experimental Investigation of the Night Heat Losses of Hot Water Storage Tanks in Thermosyphon Solar Water Heaters". *Journal of Renewable and Sustainable Energy*. 3 (2011), 033103.

8. Ogie, N.A., I. Oghogho, and J. Jesumirewhe. 2013. "Design and Construction of a Solar Water Heater Based on the Thermosyphon Principle". *Journal of Fundamentals of Renewable Energy and Applications*. 3 (2013), Article ID 235592, 8 pages doi:10.4303/jfrea/235592

9. Kim, J.-H. and J.-T. Kim. 2012. "The Experimental Performance of an Unglazed PVT Collector with two Different Absorber Types". *International Journal of Photoenergy*. Article ID 312168.

10. Ibrahim A., G.L. Jin, R. Daghigh, M.H.M. Salleh, M.Y. Othman, M.H. Ruslan, et al. 2009. "Hybrid Photovoltaic Thermal (PV/T) Air and Water Based Solar Collectors Suitable for Building Integrated Applications". *American Journal of Environmental Sciences*. 5 (2009):618–624.

11. Ibrahim, A., G.L. Jin, R. Daghigh, M.H.M. Salleh, M.Y. Othman, M.H. Ruslan, et al. 2009. "Hybrid Photovoltaic Thermal (PV/T) Air and Water Based Solar Collectors Suitable for Building Integrated Applications". *American Journal of Environmental Sciences*. 5 (2009): 618–624.

12. Ogie, N.A., I. Oghogho, and J. Jesumirewhe. 2013. "Design and Construction of a Solar Water Heater Based on the Thermosyphon Principle". *Journal of Fundamentals of Renewable Energy and Applications*. 3 (2013), Article ID 235592, 8 pages doi:10.4303/jfrea/235592.

13. MNRE. 2013. "Announcement Solar Water Heating Systems - Revised Benchmark Costs / Subsidy with effect from 1st June 2013". http://mnre.gov.in/filemanager/UserFiles/amendment_jnnsm_28052013.pdf

14. Homola, C.A. 2016. "Solar Domestic Hot Water Heating Systems Design, Installation and Maintenance". ASSE: Mokena, IL.

ABOUT THE AUTHORS

C.B. Ugwuodo, is a Lecturer at the Department of Chemical Engineering, Michael Okpara University of Agriculture, Umudike, Nigeria. He is currently pursuing his Ph.D. at the same institution. Chijioke_ugwuodo@yahoo.com, +2348037156199.

E.C. Ugwuoke, is a Master's Degree holder in Energy and Power Technology at the University of Nigeria, Nsukka, and he also works with Projects Development Institute (PRODA), Enugu, Nigeria. His research interest is in renewable energy. He has done a research on solar water distillation systems and biogas technology. emmychyugwuoke@yahoo.com, +2348039308009.

E.N. Anike, is a Lecturer at Department of Chemical Engineering, Michael Okpara University of Agriculture, Umudike, Nigeria. nnaemex2002@yahoo.com,+234803483363.

K.C. Onyeneho, is a Lecturer at the Department of Mechanical Engineering Technology, Akanu Ibiam Federal Polytechnic Unwana, Afikpo, Ebonyi State. His research interest is in production engineering.

kconyeneho@ymail.com,+2348187458600.

F.C. Umunna, works with National Productivity Center, Enugu, Enugu State Nigeria. +2348034868625**.**

SUGGESTED CITATION

Ugwuodo, C.B., E.C. Ugwuoke, E.N. Anike, K.C. Onyeneho, and F.C. Umunna. 2018. "A 100 Liter Capacity Solar Water Heater for a Household of Three Individuals". *Pacific Journal of Science and Technology.* 19(1):80-89.

Pacific Journal of Science and Technology