DESIGN AND FABRICATION OF A SOLAR WATER HEATER FOR DOMESTIC USE

BY

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AN UNDERGRADUATE PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING (B.Eng) DEGREE IN PRODUCTION ENGINEERING.

SEPTEMBER, 2023.

CERTIFICATION

This is to certify that this project work was carried out by **OPARA OLUCHI CYNTHIA** with Matriculation Number **ENG1704504** of the Department of Production Engineering, Faculty of Engineering, University of Benin, Benin City in partial fulfillment of the requirement for the award of bachelor of engineering (B.Eng) degree in Production Engineering.

ENGR. DR. F. INEGBEDION **(Project supervisor)**	**DATE**
ENGR. DR. E. M. ETUK **(Project Coordinator)**	**DATE**
PROF. R. O. EDOKPIA **(Head of Department)**	**DATE**

DECLARATION

I "**OPARA OLUCHI CYNTHIA**" hereby declare that "**design and fabrication of a solar water heater for domestic use**" is my own work and that all sources that I have used or quoted have been acknowledged by means of complete references and that this work has not been submitted before for any other degree at any other university.

OPARA OLUCHI CYNTHIA

DEDICATION

This project work is dedicated to God Almighty for His goodness, grace and mercies which has brought me this far in my academic journey.

ACKNOWLEDGEMENT

I wish to express my utmost gratitude to God Almighty for his unending grace and mercies towards me. I will always remain grateful for his goodness, without His divine help, I would never have been able to complete it.

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ABSTRACT

This project reports the design, fabrication and experimental test of a solar water heater for domestic use. It consists of a flat plate collector of aluminum sheet of 1.016mm thickness. A water source tank which is also made from aluminum which can be installed at any location and circulation of water is with the aid of gravity through plumbing network.

Experiments were performed on the solar water heater operating under force circulation with the aim of evaluating the collector’s performance. This involves hourly reading of temperature at various locations of the unit from 9am to 4pm for a period of three days. Results show that a temperature of 55ºC was obtained when 20 litres of water was heated during one of the tests carried out.

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CHAPTER ONE

INTRODUCTION

1.1 Background of Study

The increasing demand for clean and sustainable energy sources has led to a growing interest in solar heating technologies. Solar heating harnesses the power of the sun to generate heat for a wide range of applications, offering an environmentally friendly alternative to traditional heating systems.

Solar heating encompasses a range of technologies designed to capture and utilize solar energy for heat generation. These technologies can be categorized into passive solar heating systems which rely on the design and orientation of buildings to optimize the capture and storage of solar heat, and active solar heating systems which utilize mechanical and electrical components to capture and distribute solar energy. These systems which typically include solar collectors such as flat-plate collectors, evacuated tube collectors, or concentrating collectors, capture solar radiation and convert it into heat which is then transferred to a fluid, such as air or water and is circulated through the system, storage units such as insulated tanks or thermal storage materials, store the heat for later use, ensuring a continuous supply of hot water, and distribution mechanisms.

Solar water heating systems are a common application of solar heating technology. These systems utilize solar energy to heat water for various commercial and domestic purposes, such as bathing, washing etc. Solar heating for domestic use can be harnessed through the use of flat plate collectors. These collectors are devices that capture the sun's energy and convert it into heat, which can then be used to provide hot water in residential buildings.

A flat plate collector typically consists of a flat, rectangular box with a glass or transparent cover on the top. Inside the box, there is a black or dark-colored absorber plate made of a material that absorbs solar radiation effectively. The absorber plate is usually covered with a special coating to enhance its heat absorption capabilities. When sunlight passes through the transparent cover, it strikes the absorber plate, which absorbs the solar energy and converts it into heat. The heat is then transferred to the water, circulating through a series of tubes or channels within the collector. This heated fluid is then transported to a storage tank or directly to the heating system, where it can be used for hot water purposes. To maximize the efficiency of flat plate collectors, they are typically installed in a location with good sun exposure, facing south or within a specific range of angles to optimize solar radiation capture. Insulation is also added to minimize heat loss from the collector.

1.2 Statement of Problem

The global demand for energy continues to rise, accompanied by the pressing need to address sustainability challenges. As a result, the poor harnessing and under-utilization of solar energy in as much as solar energy is in abundance, coupled with a heavy dependence on fossil fuels, has become a critical challenge.

Hence this project aims at addressing these challenges by giving solutions to enhance solar energy harnessing while reducing reliance on fossil fuels, thereby contributing to the development of sustainable energy systems.

1.3 Aim of Study

The aim of the project is to design and fabricate a solar water heater for domestic use.

1.4 Objectives of Study

The objectives of this project include:

i. To design a solar water heater system for domestic use.
ii. To select appropriate materials.
iii. To fabricate the design.
iv. To test the performance of the solar water heater.

1.5 Scope of Study

The solar water heater is fabricated for heating water for various domestic use. The solar water heater is designed to serve an average family of five (5), consisting of the parents (father and mother) with three (3) children whose age are four, six and nine respectively.

1.6 Significance of Study

Solar water heating systems are a sustainable way to provide hot water for domestic use. They are particularly well-suited for areas that rely heavily on fuel gas and electricity or do not have access to it. This project will develop and fabricate a solar water system that is affordable and easy to maintain to utilize solar energy to heat water, reducing dependence on conventional energy sources such as electricity or gas and can be used by small households in Nigeria.

CHAPTER TWO

LITERATURE REVIEW

Despite living some 300 years BC, Archimedes made some incredible contributions to the fields of science, mathematics, and engineering. Some of the things he invented and discovered are still used today. The effectiveness of Archimedes' solar death ray is debated, but his use of solar power set a standard for many advances that continue to this day. During the siege of Syracuse by the Roman armies, Archimedes set up several weapons and defenses to protect the city and its inhabitants. These included a solar death ray. This invention used a collection of carefully-arranged mirrors to concentrate sunlight which could then be used to light wooden Roman ships on fire in 212 BC (Kreider and Keith 1975).

2.1 Why Solar Energy is Important

According to Prof Abubakar Sambo, one of the leading pioneers in green energy usage in Nigeria, who has also contributed massively to the development of solar energy, between 1980 and 1989, conducted research and development in Solar Radiation Studies, Flat Plate Solar Collectors and Thermosyphon Solar Water Heaters. He also served as the Sub Dean and later Deputy Dean of the Faculty of Technology as well as Head of the Mechanical Engineering Department at BUK explained that "renewable energy sources are those energy resources, which, when consumed, their rate of replenishment through natural processes ensures that what is consumed is replaced within a short time."

Renewable energy has an important role to play in meeting future energy needs and achieving sustainability. However, its diffusion and deployment are slow in the past decade due to low fossil fuel prices and barriers in the energy market. Rigorous methods are needed to accelerate the development and utilization of renewable energy and to increase its contribution to the current energy supply mixes (Nnaji et al., 2010). The need for developing countries to enhance their renewable energy applications will present economic opportunities for trading-based cities. The use of renewable energy in developing countries like Nigeria is at present very limited, although their potential is believed to be significant (Oyedepo, 2012a).

Due to the desired impact, the decrease in dependence on fossil fuel use and availability, it is widely believed that solar energy should be one of the most widely used sources of energy.

With technological advances and the trend toward sustainable energy through renewable sources, the development of technologies that use this type of energy has thus become a priority, whether for industrial purposes, domestic uses, or scientific research. The use of solar energy, in the form of thermal energy (object of the present study) or photovoltaic energy, is one of the most promising energy alternatives to face the challenges of the new millennium guaranteeing sustainability.

Thirugnanasambandam et al. claimed that solar energy is by far the most abundant of all available energy sources, including renewable and non-renewable, and can be explored directly and indirectly. However, 73.20% of the energy currently consumed in the world comes from non-renewable sources, mainly petroleum and natural gas.

According to Salamoni and Rüther, the least sunny region in Brazil has solar irradiation rates of around 1642 kwh/m^2 per year, which are above the values presented in the area with the highest solar incidence in Germany, which receives about 1300 kwh/m^2 per year. Despite having better weather conditions, in the market comparison, Brazil is behind this European country. Therefore, the use of solar energy to heat water in buildings in Brazil should be encouraged.

2.2 The Benefits of Solar Thermal Systems

Solar water heating is one of the prime application areas of solar energy. According to (Kishor et al., 2010) water heating by solar energy for domestic use is one of the most successful and feasible applications of solar energy. Other areas of application of solar energy include solar drying, electricity generation using photovoltaic cells, solar cooling, and refrigeration, solar still (or solar distillation), and solar cooking.

Indeed, the prospects of climate change and, eventually, fossil fuel depletion, trigger a growing interest in renewable energies in general, solar energy in particular. The benefits of renewable energy systems were clearly defined in a political declaration agreed to by government representatives of 154 nations at the international “Renewables 2004” conference held in Bonn, in June 2004 as a follow-up to the 2001 World Summit Sustainable Development, Johannesburg. Benefits outlined included energy supply security, equity, and development, improved health, overcoming peak oil price fluctuations, provision of clean water, close association with energy efficiency measures, climate change mitigation, and the common belief that “there will be no need for war over solar energy”

Using the sun's energy to heat water is not a long-known idea (Marshall, 2009). The Romans warmed their baths with large south-facing windows and modern-prototype solar water-heating systems of copper tubes in glass-enclosed boxes were already invented by the late 1800s.

These pioneering forays, however, seemed to be lost on Americans until the 1970s, when oil shortages prompted then-President Jimmy Carter to grant generous federal and state solar-energy tax credits for solar water heaters.

Solar water heating has been reported to enjoy much popularity in places like Australia, Israel, the United States of America, Germany, Sweden, India, Jordan, Cyprus, China, Greece, and Japan (Reeves, 2009; Garg, 2009). Nigeria, like many other tropical countries, is blessed with abundant solar energy which is beamed over the geographical entity and received freely daily.

Tapping solar energy for heating water is based on a simple natural phenomenon. Cold water in a container exposed to the sun undergoes a temperature rise. However, this natural temperature gain is usually very low, being only a few degrees Celsius. The reasons for this low-temperature gain are twofold. One reason is due to the low heat absorption of water. The second reason is that much of the heat that is absorbed goes into increased evaporation, a change of state from liquid to gas phenomenon, thus reducing temperature rise. A solar water heater employs a solar collector with good absorption capacity and with the ability to collect energy from over a wider area and harness the energy collected to raise the water temperature significantly. The issue of evaporation of the working liquid is significantly minimized since the fluid flow is within insulated pipes and storage tanks. Solar water heaters, also called solar domestic hot water systems, can therefore be a cost-effective way to generate hot water. They can be used in any climate, and the fuel they use the most, sunshine, is free (Revees, 2009).

There are two basic types of solar water heating systems on the market, one known as passive (no pumps, also called thermosiphon system) and the most popular known as active, which has pumps that circulate heated water through the system.

Solar collectors are of three main types — evacuated tube, copper glazed, and polymer. Traditional glazed collectors are large heavy glass-covered boxes that need roof-loading engineering equipment or cranes to install. On the other hand, polymer collectors are lightweight and are easy to install by one person, and require no roof loading or special equipment to install (Revees, 2009).

According to (Kishor et al., 2010), flat-plate collectors are the most economical and popular among domestic solar water heating systems since they are permanently fixed in position, have simple construction, and require less maintenance. The main components of a solar water heater are a flat plate collector and a large insulated storage tank with pipes fitted between them to convey cold water from the bottom of the storage tank to the inlet of the collector at the base and hot water from the outlet of the collector at the top, to the top of the storage tank. The collector, which is the most critical part of the solar heating system, is where solar radiation is absorbed and energy is transferred to the fluid.

2.3 Problems Facing the Full Implementation of Solar Heating Systems in Nigeria

The drawbacks are well-known: the solar radiation reaching the earth is very dilute (only about 1 kWh per square meter), intermittent (available only during day-time), and unequally distributed over the surface of the earth (mostly between 30° north and 30° south latitude).

Due to various financial and technical constraints, renewable energy remains untapped in Nigeria. Nigeria continues to be heavily dependent on fossil fuels. The detrimental impacts on the environment and, the financial burden placed on the economy, through the current inefficient use of these fossil fuels, need to be addressed through the application of appropriate technologies, national energy policies, and management measures. Nonetheless, social and economic development and poverty alleviation are the overriding priorities of Nigeria.

The energy requirements for the urgently needed socio-economic development in this country could be provided by renewable energy (RE) sources. Thus, to promote renewable energy technologies (RETs) in Nigeria, more effective and responsive policies are required that would cater to the immediate needs of people. A country experiencing energy poverty can be said to be a situation where its citizens lack electric power to meet even their basic needs such as lighting and cooking. In this situation, a large number of people in developing countries like Nigeria are negatively affected by their very low consumption of energy use, while some use dirty polluting fuels and others spend excessive time obtaining fuel to meet their basic needs (Emodi and Boo, 2015). According to the Energy Poverty Action Initiative of the World Economic Forum (IEA, 2007), “Access to energy is fundamental to improve the quality of life and is a key imperative for economic development.” Poor access to energy in Nigeria translates into increased poverty, poor economic performance, limited employment opportunity, and complicated prospects for institutional development. The high growth rate of the population is an indication that the country’s energy demand will continue to rise, similar to how the increase in global population and industrial transformation of the 20th century tremendously increased energy demand (Mohammeda, 2013). The energy crisis in Nigeria has considerably affected the public users of electricity. This phenomenon has undeniably compelled the majority of households in both rural and urban segments of the country to significantly depend on combustible RE sources, especially for domestic heating and cooking. Fuel wood and charcoal are widespread energy sources commonly used in Nigeria. Universally accessible energy services in the form of renewable energy resources that are adequate, affordable, reliable, of good quality, safe, and environmentally benign are therefore a necessary condition for sustainable development and poverty reduction in the country. (Sunday Oyedepo et al 2108)

Renewable energy projects have high initial costs. This affects the overall cost of energy produced per kWh. Investors will not be favorably disposed to wind, small hydro, or power from co-generation plants if they will not make a profit by selling the electricity. The average electricity tariff in Nigeria is put at about N6.75 per KWh (approximately 5 cents per kWh). The average cost of typical sources of renewable power for mini hydro is 5-10 cents; solar PV: are 20 -40 cents; biomass power: 5-12cents; wind power: is 6 -10 cents. Without adequate financial incentives market entry will be difficult. Renewable electricity projects are not common practice; therefore, bankers perceive a higher degree of risk and are reluctant to lend – instead, they give preference to large-scale conventional electricity investments. Interest rates are generally high and the appetite for long-term credits is low among financial institutions, especially for non-business-as-usual projects such as small-scale renewable power projects. Nigeria has no significant manufacturing capacity for components of renewable energy technologies. The existing capacity in solar PV and small hydro plants is limited. Significant supply chain constraints include long project implementation periods, high import tariffs, bottlenecks in the customs clearing of goods, and the issue of corruption. (Sunday Oyedepo et al 2108).

In a review of solar water heating systems for domestic and industrial applications carried out by Ogueke et al. [13], 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% to 80% higher than those of the passive systems. They are more complex and expensive. Accordingly, they are most suited for industrial applications where the load demand is quite high or applications where the collector and service water storage tank need not be close to each other, or for 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.

2.4 Material Selection for Flat Plate Collector

Currently, the most widely used Hot Water Supply Systems, are those with flat plate SCs, although recently, the application of vacuum SCs increased considerably due to their significantly decreasing cost (Chen et al., 2010, Hamed et al., 2014, Hayek et al., 2011).

Nevertheless, the construction of an HWSS is expensive and this is the main reason for restraint in the application of such systems. Thus, the direction of the development of solar systems is toward the design of more economical SCs with high efficiency.

The concept of using polymeric materials (PM) to make cheaper, lower-weight SCs is not new (Martinopoulos et al., 2010, Nielsen and Bezzel, 1997). The current PM producers manufacture modern plastics that are stable against ultraviolet radiation (UVR). This property makes them suitable for solar energy applications. Undertaken LCA studies show that PM has several environmental advantages over metals. The PM is also less costly than non-ferrous metals and has a lower weight, which decreases the material capacity of SCs and their supporting constructions.

The solar flat plate collector is a device that uses solar energy from the sun and converts this solar energy into thermal heat that is passed into water flowing across the absorber plate. There are different flat plate collectors available, such as single flat collectors and multi flat collectors, which are connected in series or parallel according to the consumer water quality and quantity needs. The flat plate collector is made up of a flat surface with greater absorptivity for solar radiation on the absorbing surface. There is a metal plate generally made with copper, steel, or aluminum, which absorbs the heat energy, and fluid contacting the absorber plate is then heated up. Generally, the absorber plate is constructed of a copper sheet of 1–1.5 mm thickness, with tubes of diameter 1–1.3 cm. The thermal insulation of the flat plate collector is 5–12 cm in thickness and is sometimes placed below the absorber plate to eradicate the conduction and convection losses from the rear surface. The insulation material is made up of mostly rock wool or heat-resistant fiberglass. To attain maximum optical absorptivity, the surface of the absorber plate is painted with a selective coating.

The surface generally is coated with black paint, black chrome paint, or rarely nano paints are used to increase the thermal coefficient of the flat plate collector system. A selective coating will increase the absorption and reduce the emissivity property of the surface. Generally, the selected coating of the absorber plate attains an absorption rate of 92%.

In an analysis carried out to compare the relationship between the material and the temperature difference of water, the results obtained show that Aluminum had a heat gain of 1100.69W. Copper had a heat gain of 1025.36W. The water heating efficiency calculated for aluminum is 0.97 while copper is 0.93. The paper finally justified that aluminum is better as the absorber plate in this flat plate solar collector compared to copper plate.

Aluminum has some special properties that make it a useful mirror in various applications of solar cells, lasers, and astronomers' instruments. For example, aluminum can be deformed easily to have the best shape of reflectors and achieve the highest concentrating efficiency. Unlike glass mirrors, aluminum reflectors cannot be broken easily, which is a favorite property for outdoor applications. Aluminum mirrors not only have better surface reflectivity than glass mirrors, but they are also much lighter. Compared to glass mirrors which have an average weight of 11kg/m^2, aluminum reflectors have only a weight of 7kg/m^2. Due to the mechanical properties of aluminum and its low cost compared with silvered glass mirrors, aluminized reflectors found applicability to high-temperature solar concentrating technologies. Rolled aluminum also can be suitable for certain solar energy applications since it is cheaper than other reflector materials and can be cost-effective material for this application. Thermal evaporation is one of the most practical methods to prepare aluminum reflectors to use in concentrated solar power systems. Ling et al. studied the performances of aluminum reflectors produced by the thermal evaporation method on different substrates including galvanized iron, acrylonitrile butadiene styrene (ABS), and aluminum alloy. Experimental results clarified that the reflection of thermally evaporated aluminum on ABS is comparable with that of a silver mirror of ultra-white glass. It was also found that the smoothness and roughness of the substrate have important effects on the optical properties of the aluminum reflectors.

Copper, on the other hand, Copper offers high thermal conductivity, allowing for efficient heat absorption and transfer within the collector. This results in higher overall efficiency and better performance in converting sunlight into usable heat energy.

Copper is highly resistant to corrosion, making it a durable choice for outdoor applications. It can withstand exposure to moisture, humidity, and other environmental elements, ensuring long-term reliability and performance.

Copper has a long lifespan and can withstand extreme temperature variations without significant degradation. It is a robust material that can withstand the rigors of outdoor use, making it suitable for long-lasting solar collector systems.

Copper is compatible with a wide range of selective coatings, which are used to enhance the efficiency of absorber plates in solar collectors. This compatibility allows for optimal performance and improved energy conversion, can be easily formed and shaped into various configurations, allowing for flexible design options and customization. It can be welded or brazed using specialized techniques, facilitating the manufacturing process of solar collectors, it is a highly recyclable material, contributing to sustainability efforts. At the end of its useful life, copper can be recycled and reused, reducing environmental impact and promoting resource conservation.

CHAPTER THREE

METHODOLOGY

3.1 Design Consideration

The solar water heater consists of two major units namely the flat plate solar collector unit and the circulatory unit.

3.1.1 Flat Plate Solar Collector Unit

The flat plat solar collector consists of an absorbing surface, transparent glass cover, thermal insulation and housing/casing. The function of the absorbing surface is to convert solar energy to thermal energy. The absorbing surface is made of aluminum sheet, which has a high thermal conductivity of 237 W/(m·K), and it has a good resistance to corrosion. The sheet is painted black in the front surface to maximize solar absorption.

The absorbing surface is covered with transparent glass of thickness 3mm kept at a distance of 25mm to 50mm from the absorber surface. The glass cover produces a greenhouse effect. It transmits the sun's short-wave, high-temperature radiation while effectively blocking the absorbing surface's long-wave, low-temperature radiation. Glass's iron content affects its transmittance. The best transmission is achieved by water white glass with little iron, but it is expensive and hard to get. It has about 0.95 transmittance. The second-best transmittance of 0.88

is achieved by greenish glass that contains iron; it is commonly available, light in weight, damage-resistant, manageable, and reasonably priced (Iddo et al, 1986). Collector insulation is provided to reduce heat losses by conduction, convection and radiation. The most important property considered in the choice of thermal insulators for the solar collector is their low thermal conductivity. Saw dust with a low thermal conductivity of 0.12 W/(m.K) is used in this project. The flat plate collector is enclosed in a box made of wood and insulated on its bottom with sawdust of 20mm thick.

3.1.2 Circulatory unit

In this design work, a source tank was made cuboid in shape and made of aluminum sheet of 1.016mm thickness, and insulated round with sawdust of 30mm thickness and housed by a wooden box frame made of seasoned plywood. The circulation of water between the collector unit and source tank takes place through pipes connecting these two components of the solar water heater. This circulation is achieved through gravitational force. For this reason, the source tank is place higher than the flat plate collector. The solar energy absorbed in the flat plate collector is transferred to the water contained in it and becomes hot. The hot water can be drained out directly using a tap channel for immediate use.

3.2 Design Calculations

This is concerned with the evaluation of the various data necessary for the design of a solar water heater for the conversion of solar energy into thermal energy.

In different places of the world, the time of the day, the collector tilted angle and the amount of solar energy incident on the collector varies. Therefore, knowledge of the effects of the orientation of receiving surfaces and the period the solar energy is available is required.

3.2.1 Design Specification

The initial design data based on assumption are stated below:

The ambient temperature, T_a= 27°C= 300K

Fluid inlet temperature, T_{fI}= 28°C= 301K

Expected fluid outlet temperature, T_{f0}=65°C=338K

3.2.2 Determination of the total radiation, H on the surface of the collector

Flat plate collector utilizers both direct and diffuse radiation. This is one of the advantages it has over other collectors and it is given by:

$H= H_B R_B + H_D$.

(a) Average Solar Intensity in Benin, Hs

According to Owonnubi and Olurunju (1986), this can be calculated

by the formula;

$26.7d + 132.7$........…………… (3.1)

Where d=14.5 (i.e., radiation Gunn Bellani ML)

Therefore, Hs = (26.7 x 14.5) + 132.7 = 519.85 Cal/cm^2 day

= 519. 85 x 4200

= 2183370 J/m^2 day

considering the hour 1100 and 1200 hours, i.e., mean of h from solar noon. The ratio of hourly total to daily total radiation is 0.144, according to Dume and Beckham (1980).

Thus; 0.144 x 2183370

= 314405.28 J/m^2 hours = 314405.28 / 3600

= 87.3348 w/m^2

(b) Declination:

According to Duffe and Beckham (1980), using approximate equation of cooper, the declination, Ψ i.e., angular position of the sun at solar noon with respect to the plane of the equator is;

Ψ=23.45sin [(360) (284+N)]/365……………………..... (3.2)

Where N = 75 days

Therefore, Ψ = 23.45sin [(360) (284+75)]/365

= 2.4177

(C) Solar Day

The day has twenty-four hours, and sun shine is only for about half of a day and it varies at different day of the month and year and at various places and it’s given by;

$\tau d = 2/15 \cos^{-1} (\tan\phi \times \tan\Psi)$ ……………….... (3.3)

$\tau d = 2/15 \cos^{-1} (\tan 7 \times \tan 2.41770°)$

= 11.96 hours

(d) Diffuse Component of Solar Radiation

THE amount of diffuse component of solar radiation, H_D received by solar collector is given by McDaniel (1978) as;

$H_D/H_S = 1/2 (1 + \text{COS } S)$ ....(3.4)

$H_D = 1/2(1 + \text{COS } 17)\ 87.3348$

$= 85.42674\ W/M^2$

(e) Direct Component of Solar Radiation, H.

According to McDaniel (1978), H_D is given by:

$H_S = H_B + H_D$ .... (3.5)

$H_B = H_S - H_D$

$= 87.3348 - 85.42674$

$= 1.90806\ W/M^2$

(f) Factor for Converting Horizontal Direct Radiation to That of a Tilted Surface.

According to Shitzer et al (1979), Hottel and Woertz suggested a convenient method for calculating the ratio of the direct radiation on the titled surface, H_T to that on a horizontal surface H_H is given by;

$$R_B = H_T/H_H = \frac{\text{Cos}\ (ø\text{-}S)\ \text{Cos}\ \Psi\ \text{Cos}\ W + \text{Sin}\ (ø\text{-}S)\ \text{Sin}\ \Psi}{\text{Cos}\ ø\ \text{Cos}\ \Psi\ \text{Cos}\ W + \text{Sin}\ \Psi} \ldots\ldots\ldots\ldots (3.6)$$

Where W=7.5° (i.e., the hour angle between 11.00 hours and 12.00 hours.)

$$= \frac{\text{Cos}\ (7-17)\ \text{Cos}\ 2.4177°\ \text{Cos}7.5° + \text{Sin}\ (7-17)\ \text{Sin}\ 2.4177}{\text{Cos}\ 7°\ \text{Cos}\ 2.4177°\ \text{Cos}\ 7.5° + \text{Sin}\ 7°\ \text{Sin}\ 2.4177°}$$

= 0.9796

(g) Total radiation on the collector surface:

Thus, total radiation on the collector surface is given as;

$H=H_BR_B+H_D$……………... (3.7)

(19.0806 x 0.9796) + 85.42674

=104.1181 w/m^2

3.3 Manufacturing Process

3.3.1 Source Tank Capacity

For a family of five residents, if it is assumed that the family exhaust the daily demand of hot water (20 litres) per time, then the tank capacity is;

Dimension of the Storage Tank:

Volume =Length × breadth × height

Taking the length, breadth and height as;

Length = 400mm

Breadth = 125mm

Height = 500mm

= 400 × 125 × 500

Therefore, volume of the tank = 25,000,000mm^3 = 25 litres

Dimension of Flat Plate Collector:

Dimension of flat plate collector that will collect 20 litres of water per time;

Given height of the collector as 1inch.

Volume=Area × Height

Converting 20 litres to mm^3; 20 litres = 20,000,000mm^3

Converting 1 inch to mm; 1 inch = 25.4mm

20,000,000mm^3 = (Area× 25.4mm)

Area = 787401.6mm^2

Area=L^2 (equal sides)

L=$\sqrt{(787401.6)}$

L= 887.35mm

Approximately 887.4mm

Therefore; Volume of the collector =887.4mm × 887.4mm × 25.4mm.

Solar water heater stand:

This is made from wood and the stand is 1066.8 mm (42 inches) high with the bed of the stand being 965.2mm (38 inches). It is designed to be tilted at an angle of 45° to maximize the absorption of solar energy.

Glazing surface Cover:

It is comprised of two glasses with dimension of 914mm × 914mm.

3.4 Material Selection

The glazing transparent cover of the flat plate collector was made from glass so as to allow the flow of solar energy to the absorber surface and also to block heat from escaping through to the surroundings, thereby creating a greenhouse effect for the solar water heater system.

The absorber surface was made from aluminum because it's readily available and much cheaper. Though copper is a much better thermal conductor it wasn't incorporated in the design since it's more expensive and not easily accessible like aluminum, nevertheless aluminum is a very good conductor of heat and thermal energy.

The flat plate collector was made from aluminum in order to maximize the heat energy transfer from the absorber surface.

The material for insulation employed was sawdust as it has very little thermal conductivity compared to other insulators like foam.

The entire solar water heater system is enclosed in a wooden frame to prevent heat losses from the entire setup as a whole.

3.5 Fabrication of Various Components of The Solar Water Heater.

Stage 1-Production of absorber plate:

The absorber plate was fabricated from aluminum sheet of 1.016mm thickness. It was marked and cut to required size and then followed by folding of the sheet to the required shape as drawn in the design/development and then joined using graphite aluminum foil tape. Two pipes of diameter 16mm were attached to the plate

Stage 2-Production of collector box Housing:

The collector box frame was made of 1/4-inch (19.05mm) wood, it was cut to required size and joined together by nailing with 2 inches. Before being joined together, glass holders or frame made of 1½ inch (12.7mm) were nailed to the pieces of wood. Two holes of 20mm diameter was were bored in one of the pieces to allow the 16mm diameter aluminum pipe in the absorber plate to pass through.

Saw dust of about 0.05mm thickness was placed at the bottom of the collector box.

Stage 3-Flat plate collector assembly and glazing surface cover:

Two glasses with dimension 914mm by 914mm were cut then attached to a wooden glass holder of 12.7mm to cover the flat plate collector. The space between the absorber plate and the base of the collector box was filled with saw dust before putting the absorber plate into the box.

Stage 4-Production of Source tank:

The source tank was fabricated from aluminum with 1.016mm thickness and dimension of 500mm x 400 x 125 were cut and joined using aluminum foil tape to form a cuboid. A point was drilled on the side of the tank to accommodate the inlet pipe to the collector.

CHAPTER FOUR

PERFORMANCE TESTING, RESULTS AND DISCUSSION

4.1 Performance Testing

The solar water heater was stationed outside for effective collection of solar energy. Mercury-in-glass thermometers were mounted in the following points of the heater.

1. The water inlet pipe of the collector. The thermometer measures the inlet water temperature.
2. The water outlet pipe of the collector. The thermometer measures the outlet water temperature of the collector.
3. The top of the collector plate. This measures the absorber plate temperature.

The test was carried out for three days, 15th, 16th and 17th September 2023. The temperature readings, the collector daily efficiency and daily useful heat gained by the collector determined by using equations derived respectively and the collector performance co-efficient;

$\frac{T - T3}{H}$ as shown in table 4.1 to 4.3.

4.2 Data Analysis

Table 4.1

15th September Test Readings

Time of day	Ambient temperature T_a (ºC)	Fluid inlet temperature T_{f1} (ºC)	Fluid outlet temperature T_{f0} (ºC)	Plate temperature T_p (ºC)
9am – 10am	33.5	28	33	42
10am – 11am	33.5	30	34	45
11am – 12pm	34	32	40	47
12pm – 1pm	34.5	35	42	50
1pm – 2pm	34	42	48	53
2pm – 3pm	35	42	51	55.5
3pm – 4pm	36	45	50	51

Useful heat gained by the collector;

$Q_u=A_c(S-UL(T_{plate}-T_{ambient}))$

$S=A_c \times I \times \pi.$

$\pi=1$

$(887.4\times887.4) \times16.5\times1 \times10^{-6}$

$=12.718MJ$

UL= Total losses = Conductive losses + convective losses + Radiation losses

Conductive losses=U×A×ΔT

$=23.1\times10^{-6}\times0.787\times(51-36)$

$=2.72\times10^{-4}$J

Convective losses=h× A×ΔT

$=5\times0.787\times(51-36)$

=59.025J

Radiation losses$=5.67\times3\times10^{-3}\times(51-36)$

=0.289J

Total loss$=2.72\times10^{-4}+59.025+0.289$

=59.314J

$Q_u=0.787(12.718\times10^{6}-59.314\times(51-36)$

=150.1352898J

Thermal efficiency, n= $\frac{(Q/A \div G/A)}{Tf-Ta} \times 100$

$=\frac{150.135\div16.15}{14} \times 100$

=0.664 ×100

=66.4

Collector performance coefficient, $C_p=\frac{Tc-Ta}{Ts-Ta}$

$=\frac{51-36}{56-36}$

$=\frac{15}{20} = 0.75$

Table 4.2

16th September, 2023 Test Reading

Time of day	Ambient temperature T_a (ºC)	Fluid inlet temperature T_{f1} (ºC)	Fluid outlet temperature T_{f0} (ºC)	Plate temperature T_p (ºC)
9am – 10am	34	28	32	43
10am – 11am	34	31	34	45
11am – 12pm	36	34	49	51
12pm – 1pm	37	35	51	54.5
1pm – 2pm	39	39	53	57
2pm – 3pm	39	41	55	58.5
3pm – 4pm	38	43	53	55

Useful heat gained by collector;

Q_u= 0.787× ((12.71×10^6) - (59.314) × (58.5-39))

Q_u=195053104.7

Thermal efficiency; n =195.053/16.15(55-39) ×100

=0.755 ×100

=75.5%

Collector performance coefficient; $C_p = \frac{58.5-39}{55-39}$

$= \frac{19.5}{16}$

=1.22

Table 4.3

17th September, 2023 Test Reading

Time of day	Ambient temperature T_a (ºC)	Fluid inlet temperature T_{f1} (ºC)	Fluid outlet temperature T_{f0} (ºC)	Plate temperature T_p (ºC)
9am – 10am	30	29	33	36
10am – 11am	32	30	34	43
11am – 12pm	33	35	40	47
12pm – 1pm	34	37	43	51
1pm – 2pm	36	39	49	53
2pm – 3pm	35	42	55	56
3pm – 4pm	33	45	55	56

Q_u=0.787((12.71×10^6) - (59.314) × (56-33))

Q_u=230062636.4J

Thermal efficiency; n=230.06/16.15(55-33)

n =0.648×100

=64.8%

Collector performance coefficient; $C_p = \frac{56-33}{55-33}$

$= \frac{23}{22}$

=1.045

4.3 Discussion of Results

Analysis of the test results are discussed here. 15th of September was a slightly sunny day with little amount of rainfall and the sky was clear. A close evaluation of table 4.1 shows that the ambient temperature rose from 33.5ºC at 10am to 36ºC at 2pm and dropped gradually to 34ºC at 2pm. The maximum water outlet temperature of the collector was 51ºC at 3pm.

Table 4.2 shows the result obtained on 16th September. The day was also sunny with a little amount of rainfall just like the first day. The ambient temperature rose from 34ºC at 10am to 38ºC at 4pm. The maximum water outlet temperature of the collector was 55ºC at 3pm.

Table 4.3 shows the result obtained on 17th September. The morning was a bit cloudy, and it could be seen from the table that the ambient temperature rose from 30ºC at 10am to 36ºC at 2pm and fell to 33ºC at 4pm. The maximum water outlet temperature of the collector was 55ºC.

A comparison of the collector efficiency and the co-efficient of performance show that the collector efficiency increases with decrease in co-efficient of performance. It was also noted than the largest fraction of useful heat gain by the collector was delivered during periods of high radiation corresponding to when highest temperatures were recorded.

The solar water heater was able to heat a given volume of water (20 litres) to a maximum temperature of 55ºC (328K). From the results of the test, it did not deviate much from the initial assumption made in the design.

4.4 Bills of Engineering Quantity

LABOUR COST

The following labour cost analysis were involved;

Fixing of the glass holder	- ₦9,000
Work on the collector frame and source tank (carpentry)	- ₦10,000
Miscellaneous	- ₦22,200
Total cost	**- ₦41,200**

MATERIAL COST

S/N	DESCRIPTION	DIMENSION	QUANTITY	UNIT PRICE (₦)	TOTAL COST (₦)

1	Aluminum sheet	1.22 × 0.8 × 0.003	1	17,300	17,300
2	Graphite aluminum tape	1 inch	12 yards	500	6,000
3	Wood	3.66 × 0.305 × 0.002	3	4,000	12,000
4	plywood	0.8 × 0.6 × 0.006	1	8,000	8,000
5	Plain glass	914 × 914 mm	2	8,000	16,000
6	Black paint		1 tin	1,500	1,500
7	Nails	0.0127 (1/2 inch)	1 kg	1000	1000
8	Pipes	8.5 inches	1	1,000	1,000
9	Tap head	½ inch	1	500	500
10	Gate valve (Tap joint)	½ inch	1	500	500
11	Saw dust		2 bags	1000	2,000
	TOTAL COST				**62, 800**

Bill of quantity = labour cost + material cost

= ₦41,200 + ₦62,800 = ₦104,000

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the results obtained in the test, the solar water heater was able to heat 20 litres of water to a maximum temperature of 55ºC. It performed satisfactorily and could serve as a means of hot water supply for domestic use for both rural and urban dwellers, and for industrial use if upgraded or designed for large scale purposes.

The solar water heater uses the energy that is free, renewable and non-polluting. It can be produced using local materials and does not involve complex construction techniques. Fabricating can easily be done by semi-skilled workers under minimal supervision.

5.2 Recommendations

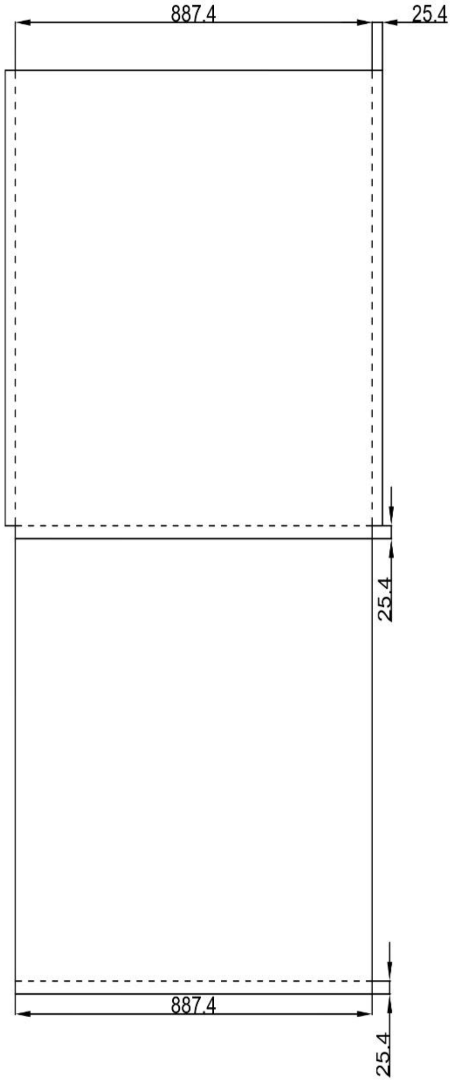
For further work on the water heater, the following recommendations will increase the cost of producing it, but enhance greater efficiency.

1. The area of the collector could be increased so that large volume of water can be heated.
2. More than one flat plate collector can be arranged in series with a view to getting a much higher temperature.
3. By employing a heliostat to track the sun rays.
4. By employing a pump to circulate the water back to the source tank.
5. By employing concentrators (mirrors, lens) the radiation from the sun can be focused onto a comparative small area. Thus, with the collector area reduced, the losses are also reduced and corresponding higher collection efficiencies or collection temperature can be achieved.
6. The solar energy flux is about 1.395 kw/m^2 at earth atmosphere and reduced to about 1kw/m^2 at the surface of the earth. Thus, if the height of the collector can be increased i.e.,

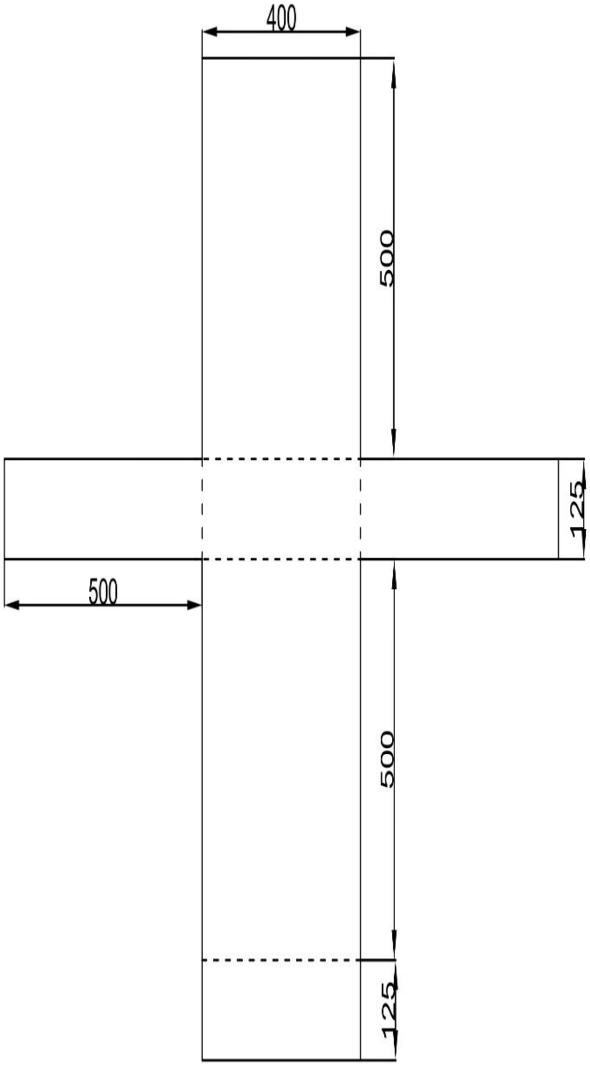
to the top of a building where solar energy flux is higher than the earth surface, the collection temperature can be increased.

7. The use of a combination of an outer glass carver with inner cheaper transparent plastic film can be advantageous as the plastic has a higher transmittance than glass.
8. The performance of the glass cover can be improved by depositing a transparent coating on its inner surface, which allow nearly all the incident solar radiation to be transmitted.

APPENDIX



DEVELOPMENT OF THE FLAT PLATE COLLECTOR 1



DEVELOPMENT OF THE STORAGE TANK

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