DESIGN AND FABRICATION OF A SOLAR WATER HEATING SYSTEM

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CERTIFICATION

This is to certify that the project requested here was carried out by **SODJE EFETOBORE STEPHEN** with the matriculation number **ENG2010794** of the Department of Agricultural Engineering, University of Benin, Benin City, Nigeria, in accordance with the rules and regulations of the University of Benin.

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DEDICATION

This project is dedicated firstly to the All Mighty God, whose immeasurable wisdom, strength and grace has illuminated this my academic journey.

To my devoted and dedicated parents, whose constant encouragement, love, and selfless and selflessness have helped me become the person I am today. I have found solace in your affection throughout these turbulent times, and this accomplishment is proof of your lasting impact.

This report serves as a symbol of my appreciation and thanksgiving for the heavenly direction and parental supervision that have served as the pillars of my journey.

ACKNOWLEDGEMENT

I want to sincerely thank everyone who helped to see this initiative through to its successful conclusion. Their encouragement, support, and advice have been priceless, and I sincerely appreciate their assistance.

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In addition, I express my heartfelt gratitude to **Engr. Dr. O. I. Ihenyen,** for his helpful and encouraging support and assistance to me and my project colleagues during the duration of the project.

Special thanks to my project colleagues for their cooperation, team spirit, and mutual commitment to the project. Without a doubt, our combined efforts have improved the result.

My appreciation goes out also to the Department of Production Engineering for offering the tools and a setting that are ideal for study and research. The resources provided (both facilities and help) have been crucial to the project's successful completion.

ABSTRACT

This project involves the design and fabrication of a solar water heating system utilizing the thermosiphon principle. The system consists of a 30-liter and 15-liter tank, an absorber plate constructed from copper rods and aluminum sheets, and an integrated pump and battery for enhanced performance.

The project commences with a comprehensive review of previous researches on various solar water heating systems, majoring on the types of Solar water heating systems, its components, materials and method of fabrication of the system, its design considerations, as well as the importance and significance of the project. The system's efficiency and effectiveness in heating water using solar energy are evaluated, demonstrating its potential as a sustainable and cost-effective solution for water heating applications.

The performance of the system was evaluated under various operating conditions, and the results showed a significant increase in water temperature, demonstrating the system's potential for efficient solar water heating. The average temperatures of the hot water for the 1st, 2nd and 3rd days of testing are 45.4^{o}C, 46.5^{o}C and 45.9^{o}C respectively. The use of locally sourced materials and simple design make this system an attractive option for rural and urban areas where access to hot water is limited.

This project contributes to the development of sustainable and renewable energy solutions, aligning with global efforts to reduce carbon emissions and promote energy efficiency.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

A solar water heating system (SWH) is a device that converts solar energy into thermal energy to generate hot water for residential, commercial, and industrial applications. The origin of this heating system is based on the idea of solar radiation, defined as the energy emitted by the sun in the form of electromagnetic waves. Solar energy is a significant source of renewable energy utilized both directly and indirectly. “Solar power” encompasses both solar thermal and photovoltaic systems. Photovoltaic systems generate electricity by converting sunlight into electrons within a semiconductor, so producing an electric current. Solar thermal systems utilize sunlight to heat air or water.

Today, fossil fuels are mostly utilized to heat and power homes, as well as to fuel cars or automobiles. It is convenient to utilize oil, coal, and natural gas to meet human energy needs, but the scarcity of these fuels has become the principal constraint on people’s capacity to use them as continuous sources of energy over the world. Because energy is so vital in people’s daily lives, there are many alternative energy sources that can be utilized instead of fossil fuels, one of which is renewable energy, which includes solar energy. For the simple reason that solar energy systems can provide substantial environmental protection, such as lowering carbon emissions, which lowers air pollution, they are examples of clean energy sources. Because it is renewable, it can also be used as a steady source of energy.

Due to its fundamental method of utilizing the sun’s abundant energy, solar water heating systems have a history spanning more than a century. Utilizing solar energy dates back to 1861, when Mouchout developed a solar-powered steam engine. The first solar cells made of selenium wafers were built in 1883 by American inventor Charles Fritts. The first solar water heater was invented and patented in the United States in 1891 by Clarence Kemp of Baltimore. His system, called the “Climax,” consisted of a basic black-painted metal tank filled with water and placed in a glass-enclosed box to maximize heat collection. In the 1950s, Israeli engineer Levi Yissar proposed using solar energy to heat residential water, which sparked the widespread use of solar water heaters until today, with ninety percent of homes in Israel owning one.

In the nineteenth century, people used stoves to heat water by burning coal, wood fragments, or coal-derived gas. For a long time, Nigeria has used heat energy generated from chemical energy, such as burning wood and fossil fuels like petroleum and kerosene, to deliver hot water. Electrical water heaters, water storage tanks, and other electrical devices can also be used to generate hot water using electrical energy. These two main sources are unreliable and unpredictable as a long-term option for water heating because of the challenges they encounter in Nigeria.

Statement of the Problem

In Nigeria, the primary methods of producing hot water are burning fossil fuels and using electrical energy to power water heaters. Nigeria today produces the majority of its energy from fossil fuels due to the country's current economic predicament. This has resulted in a number of concerns, including an increase in oil demand, which is a crucial role in energy production, particularly in machines, general power supply, and automobiles. As a result, the national oil price has risen dramatically. Additionally, burning fossil fuels has a significant negative influence on the environment and can be extremely harmful to people's health. Furthermore, the unreliable power source limits the usage of electrical water heaters, making them unreliable. This is the point at which solar water heaters become a good option.

Despite the relatively high cost of solar water heaters and the delayed financial returns, efforts are being made to develop an economical solar water heating system that is sufficiently efficient to provide a swift financial return, thereby addressing the aforementioned issues.

1.2 Aim and Objectives of the Study

1.2.1 Aim

The Aim of this project is to develop a low cost solar water heating system using locally sourced materials.

1.2.2 Objectives

In order to achieve the following aim of the project, the following objectives will be followed;

1. To conduct a literature review on the solar water heating system.
2. To Design the component parts of the solar water heating system.
3. To Fabricate an appropriate model of the solar water heating system that will increase its efficiency under the climatic and weather conditions of Nigeria.

4. To carry out the performance evaluation of the solar water heating system fabricated.

1.3 Significance of the Study

The notion that global warming poses a significant threat necessitates the reduction of carbon emissions to protect the environment, prompting a global interest in alternative solutions. This has heightened the focus on renewable energy production, which could diminish reliance on coal and natural gas power plants in the future. Photovoltaics, geothermal, hydropower, and biomass systems are among the most popular renewable energy technologies. Solar thermal water heating systems are an extra and less expensive option.

The use of solar water heaters to reduce traditional electricity water heating costs and preserve finite fossil fuel supplies is a major source of inspiration in many developed countries. Because most of these countries lack natural sources of traditional fuel and because most of their populations reside in rural regions without conventional electricity grids, solar water heating is crucial in developing countries like Nigeria. In such cases, solar water heating could easily meet the hot water needs of rural health clinics and cottage enterprises (for processing agricultural produce).

The main energy sources used to generate electricity In Nigeria are mostly fossil fuels, and given the country's large population, the ongoing rise in electricity tariffs, and the need for hot water for household, institutional, and industrial uses (particularly during the harmattan period), it is imperative to promote solar water heating systems in both rural and urban areas of the country. Furthermore, the demand for electricity is increasing rapidly. As a result, during cold weather, particularly in the mornings and nights when hot water demand is highest, electrical energy facilities are regularly overloaded, resulting in power outages. Solar water heaters can help address these issues by reducing the amount of energy required for hot water production from electricity.

The solar water heating system Is also designed to address the challenges and hazards associated with using fossil fuels, such as rising oil costs and demand, a shortage of petroleum reserves, and limited fossil fuel availability (fuel scarcity). Furthermore, studies demonstrate that, during its lifetime, solar power has a considerably lower environmental impact than fossil fuels and produces no emissions during the electricity generation process. This is a good advantage of the solar water heating system over the use of fossil fuels, considering the drawbacks of charring them, such as the depletion of the ozone layer and other issues with air pollution.

Because solar energy, which is a renewable energy source from the sun, powers a solar water heating system, it is very advantageous because it never runs out of supply and can be used continuously, especially in a region like Nigeria that has abundant solar energy.

1.4 Scope of the Study

The scope of this project includes a primary research on design and fabrication of a flat plate solar water heater under the climatic conditions of Benin City using locally sourced materials, and the fabrication and testing of the solar water heater at Latitude 8°E.

The cylindrical storage tank of the solar water heating system has a capacity of 30 litres of water for residential use and it is to be constructed and operated with no expense for fuel, supplying heated water of about 50 to 60 degrees Celsius.

CHAPTER TWO

LITERATURE REVIEW

2.1 Solar Water Heating System

A solar water heating system is a device that uses solar collectors and concentrators to harness the energy of the sun's radiation to raise the temperature of water or air for use in homes, businesses, or industries. A solar water heating system is a free, highly promising renewable energy technology that is accessible worldwide. Because they offer an environmentally friendly heat for a variety of applications, including swimming pools, homes, and other places where hot water is required, solar water heating systems are mostly utilized on a larger scale. The initial cost of a solar water heater is largely dependent on the size of the collector, which is also largely dependent on the amount of solar radiation present in the area and the efficiency of the collector. This system uses the energy from the sun to heat water or air (Nshimyumuremyi et al., 2018).

Solar water heaters, also known as domestic-hot water systems, are good investments because they are cost-effective, despite their somewhat high initial cost. They have the advantage of using free sunshine (free solar radiations), which is crucial regardless of the current climate when compared to other conventional water heaters that use electricity or another type of fuel. High solar radiation and less collector area are taken into consideration assuming that other parameters stay the same (Nshimyumuremyi et al., 2018).

2.2 Types of Solar water heating system

Depending on how the heat transfer fluid (water or antifreeze fluid) passes through the collector or how the household water is heated, solar water heating systems are categorized. SWH is generally divided into two categories: Solar water heating system, both active and passive (Tadvi et al., 2014).

2.2.1 Active solar water heating system

Active solar water heaters utilize electric pumps and controllers to move water or other heat-transfer fluids via the collectors (Layton, 2020). They are also referred to as forced circulation systems. This requires an electronic controller, a tiny pump, and valves. In this configuration, the collector and storage tank can be fitted independently. Furthermore, no height gap between tank and collector is required. Two temperature sensors monitor the temperature of the collector and the tank (Anand et al., 2021). In general, active systems are more costly than passive ones, but they are also more effective. Two categories further subdivide the active system:

• Open-loop (Direct) Active System

• Closed-loop (Indirect) Active System (Shelke et al., 2015).

In contrast to thermosiphon systems, which necessitate a storage tank always above the collector, active systems, whether direct or indirect, can be readily retrofitted to already-existing water heaters because the storage tank can be positioned anywhere (Tadvi et al., 2014).

(a) Open-loop (Direct) Active System

Pumps circulate water via open-loop active systems' collectors. This design is efficient and low in operating expenses, however it is not suitable for hard or acidic water since scale and corrosion quickly disable the system. These open-loop systems are popular in nonfreezing areas (Shelke et al., 2015). Straight (Open Loop) As direct systems that use a solar collector apart from the storage tank, active systems are comparable to thermosiphon systems. Direct active systems vary in that they circulate water from the storage tank to the collector and back again using an electric pump. A check valve is usually necessary for these systems to avoid reverse thermosiphoning at night (Tadvi et al., 2014).The easiest to design and build are open loop systems. Due to their few moving parts, they typically require the least amount of construction and may last longer without requiring significant maintenance; nonetheless, they are not the best choice for locations where temperatures might fall below freezing. The pipes may burst if they freeze because the liquid water will expand into ice. A pump that forces traditionally heated water through the system in cold weather or manual or thermostat-controlled system drains are examples of preventative methods (Garrett, 2007).

(b) Closed-loop (Indirect) Active System

In a closed-loop active system, a non-freezing heat transfer fluid is circulated by the pumps via the heat exchange and collectors. As a result, the water gets heated and enters the house through pipes. Mostly, these are utilized in regions where freezing temperatures are common (Anand et al., 2021).

A heat exchanger is a component of active, indirect glycol antifreeze systems. While domestic water is pumped from the storage tank through the heat exchanger, freeze-resistant propylene glycol is circulated through the solar collector(s) and heat exchanger. The heat exchanger heats the household water, which is subsequently kept in the tank until it is needed. DC pumps driven by a solar energy PV module or AC pumps powered by the utility grid are used to circulate the water and antifreeze (if an external heat exchanger is being used) (Tadvi et al., 2014). Heat exchangers are required to move heat from the collector to the water because of the nature of closed-loop systems. Closed loop systems can also be utilized instead of water to heat an area using wall radiators or radiant flooring. Closed Loop systems can be utilized in areas with temperatures below freezing, in contrast to the majority of Open Loop systems. Water has certain characteristics that might cause pipes to rupture when it freezes. Using a fluid with a significantly lower freezing point than water avoids this (Garrett, 2007). Certain indirect systems are equipped with "overheat protection," which prevents the collector and glycol fluid from overheating in situations where the load is light and the amount of incoming solar radiation is large. The two most widely used indirect systems are drain-back and antifreeze systems (Layton, 2020).

(c) Antifreeze Closed-loop systems

A glycol-water mixture is typically used as the heat transfer fluid in antifreeze systems, with the concentration of glycol varying according to the anticipated minimum temperature. Due to its non-toxicity, the glycol is typically food-grade propylene glycol (Layton, 2020). A closed loop, antifreeze system's main components include heat exchangers, circulating pumps, solar collectors, a sensor-equipped differential control, and a storage tank. A check valve, expansion tank, drain/fill assembly, pressure and temperature gauges, and a pressure relief valve are smaller but equally important components (Olson, 2001). Nevertheless, the antifreeze fluid has a propensity to deteriorate with time. The fluid degrades rapidly at high temperatures, leading to inefficiency and deposit accumulation on the collector and pipe inner walls. The antifreeze fluid should only need to be changed every ten years for a well-maintained system (DeGunther, 2016).

(d) Drain-back Closed-loop systems

Water is circulated through the collectors by pumps in a drain-back system, which is an indirect system type. When the pumps stop, the water in the collector loop drains into a reservoir tank. Because of this, drain-back systems are a wise option in colder climates (Layton, 2020). Under drain-back systems, the collector loop's heat-transfer fluid is water, which is pumped through the collectors and then gravitationally drained to the heat exchanger and storage tank. Because there are no valves to malfunction and the collectors are empty while the pumps are off, these systems guarantee freeze protection and automatic shut-off in the event that the water in the storage tank gets too hot.

Nonetheless, they consume more energy than a closed-loop system due to the necessity of pumping water against gravity to attain the collector elevation (Shelton, 2003). Drain-back systems require meticulous installation to ensure that the piping consistently slopes downhill, facilitating complete drainage of water from the system (Layton, 2020).

(e) Pumps in Active Systems

Due to their low power requirements, some industries are now using direct current (DC) pumps that are driven by tiny solar-electric (also known as photovoltaic, or PV) panels. Photovoltaic panels generate direct current electricity. These systems don't require any maintenance and keep working even when there is no power (DeLaune et al., 1995).

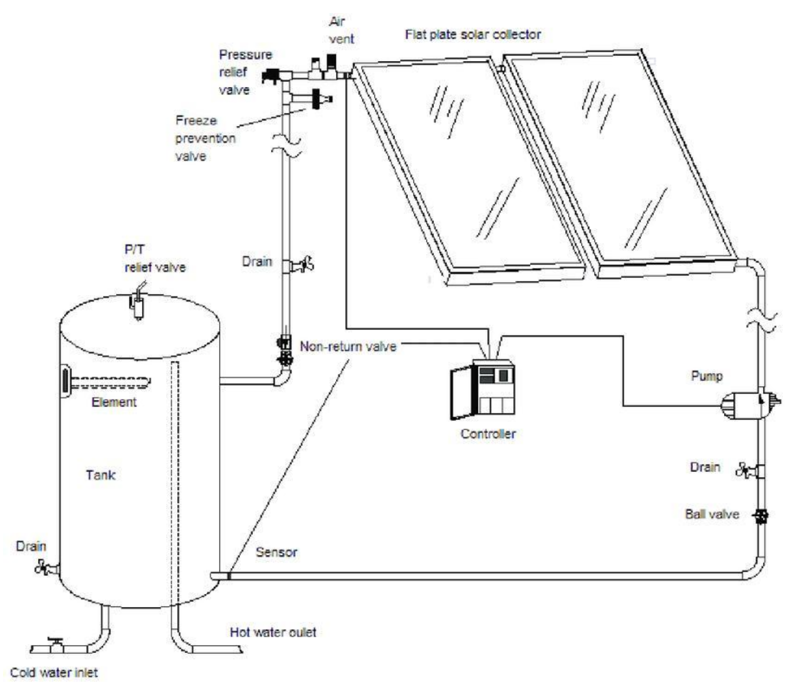

Fig 2.1 An Active Closed-loop System

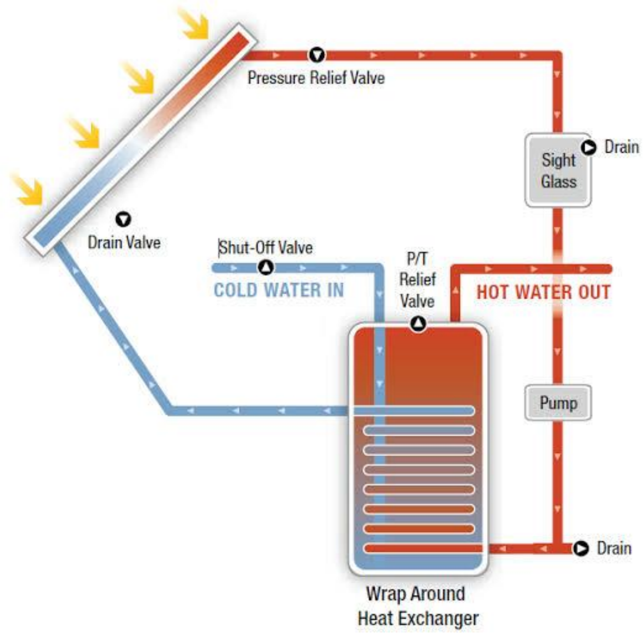

Fig 2.2: A Drain-back Closed-loop System

2.3 Passive solar water heating system

In order to heat water, passive solar water heaters use gravity and the water's natural tendency to circulate. Passive systems, which don't have any electrical components, are typically easier to maintain, more dependable, and may last longer than active ones. On cold days, the storage tank is exposed to external temperatures, which can result in significant heat loss, and the remaining water can freeze at night and harm the panels. With little upkeep, certain passive systems can operate for up to 25 years (Layton, 2020). Compared to active systems, passive systems are less expensive but less effective (Shelke et al., 2015).

The two most widely used passive system types are thermosiphon systems and Integral-collector storage systems (Layton, 2020).

(a) Integral-collector storage (ICS) systems

Often referred to as "batch" systems, integral collector-storage (ICS) systems consist of one or more empty tanks or tubes enclosed in a glazed, insulated box. After passing through the solar collector to preheat the water, cold water is sent to the traditional backup water heater. Because the collector or the exterior pipes may freeze in extremely cold temperatures, ICS systems—which are dependable solar water heaters—should only be placed in areas with mild freezing temperatures (Layton, 2020). Because of their structural simplicity, ICS systems are less costly. Additionally, because the glass surface is not adequately insulated, it loses a lot of energy at night. However, in warm climates, the ICS system is an affordable solar water heating solution for homes (Bin et al., 2019).

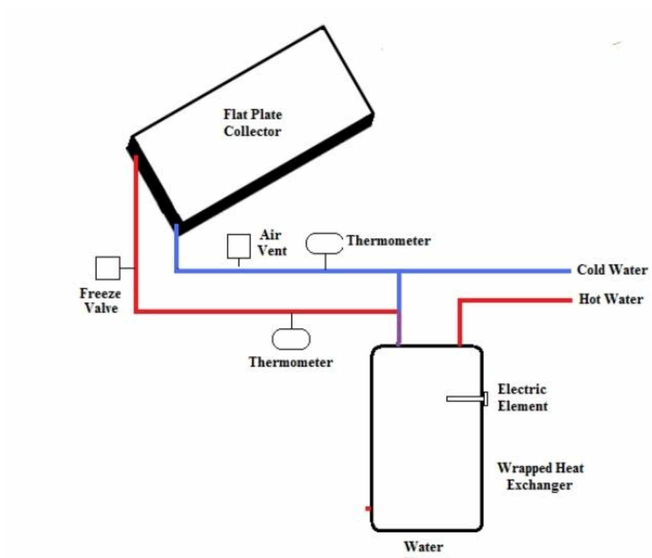

Fig 2.3: Integral-collector storage system (Passive)

(b) Thermosiphon systems

Thermosiphon systems are a dependable and affordable option, particularly for newly constructed homes. To move water through the collectors and to the tank (which is above the collector), these systems rely on the natural convection of heated water ascending. The water in the solar collector naturally rises into the tank above since it gets lighter as it heats up. In the meantime, the circulation is improved as the colder water travels down the pipes to the collector's bottom. Some manufacturers hide the storage tank from view by placing it in the attic of the house. If the plumbing in the unconditioned room is sufficiently protected, indirect thermosiphon systems—which use a glycol fluid in the collector loop—can be placed in climates that are prone to freezing (Layton, 2020). The efficiency of a collector is determined by the difference between the collector temperature and ambient temperature, and it is inversely proportional to the intensity of solar radiation. Thermosiphon systems are straightforward and require less maintenance because they lack controls and instrumentation (Shelke et al., 2015). The collector's top and the tank's bottom must be at least 30 cm apart in height for this system to function correctly (Anand et al., 2021). They are reasonably inexpensive but require careful design in new construction because the water tanks are heavy. By heating the household water in a closed loop using an antifreeze solution, they can be made freeze-proof (DeLaune et al., 1995).

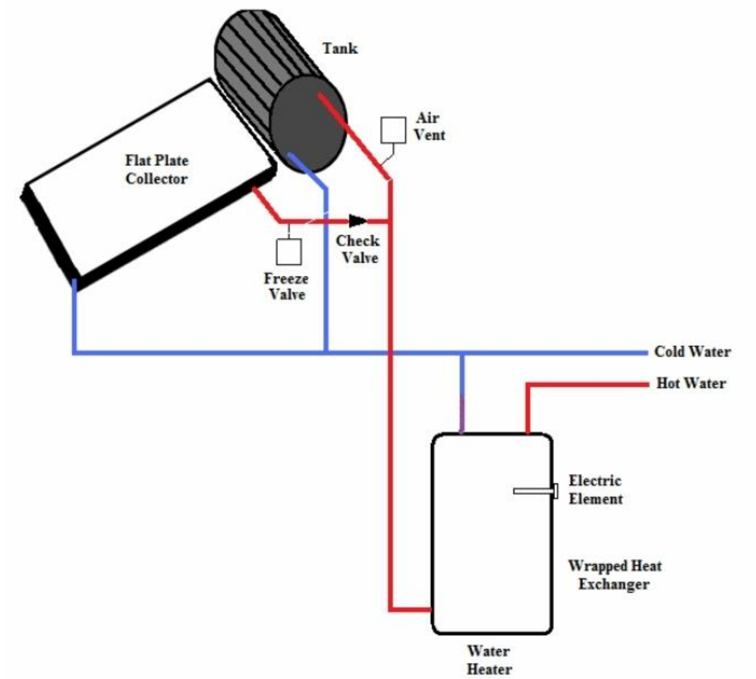

Fig 2.4: Thermosiphon storage system (Passive)

2.4 Components of a Solar water heating system

The collectors (solar collectors), heat transfer fluid, and storage tank are the fundamental components of the majority of solar water heaters; depending on the system's intended design, operation, and application, additional parts may be added, including a heat exchanger, backup water heater, expansion tank, pumps, pipe network, valves, auxiliary energy source, and control systems (Agbo et al., 2006).

2.4.1 Collectors

The most important part of solar-heating systems are solar collectors, which collect solar radiation, convert it into heat, and then transfer that heat to water, solar fluid, or air. The efficiency of the system is directly correlated with heat losses from the collector surface, which are primarily controlled by the thermal gradient between the temperature of the collector surface and the ambient temperature. Efficiency decreases as the temperature of the collector rises or falls, and this decrease can be lessened by giving the unit more insulation, such as by sealing it in glass, as is the case with flat collectors, or by using a vacuum seal, as in evacuated tube collectors. The operating temperature of solar thermal collectors (and the systems themselves) determines their characteristics. There are three types of systems: low-, mid-, and high-temperature systems. Low-temperature systems can function up to 18°F above room temperature and are often unglazed. Polypropylene or other polymers are extruded to create low-temperature collectors. The absorber plate has water flow tunnels built right into it. Applications for these systems in swimming pools are widespread. At low temperatures above ambient, this type is quite effective at gathering solar energy; but, at medium and high temperatures over ambient, it becomes very inefficient. Water produced by mid-temperature systems ranges from 18°F to 129°F above ambient. Flat plates with a glass cover and fiberglass or other insulation are typically used as mid-temperature collectors. At low temperature differentials, the efficiency is decreased by the cover glass's reflection and absorption of sunlight; but, at greater temperatures, the glass must retain heat. Copper tubes are welded to the fins of a copper absorber plate. The absorber plate is frequently coated with a black surface to lower radiative losses from the collector. Residential water heating systems are a good fit for flat-plate collectors, which are mid-temperature collectors.

High-temperature systems frequently use focusing curved mirrors to concentrate sunlight and use evacuated tubes surrounding the receiver tube to give high amounts of insulation. Because the focusing mirrors must be tracked to maintain their orientation toward the sun, high-temperature systems are often very big and placed on the ground next to a facility (Layton, 2020).

Three main categories of solar collectors exist: Parabolic concentrating collectors, evacuated tube collectors, and flat-plate collectors (Tadvi et al., 2014).

2.4.2 Flat-plate collectors

The most prevalent solar collectors for solar space heating and solar water heating systems in residences are flat-plate collectors. An insulated metal box with a dark-colored absorber plate and a glass or plastic cover (referred to as the glazing) is a common flat-plate collector. These collectors raise the temperature of liquid or air below 180°F.

The fluid in a flat-plate collector circulates through tubing to transfer heat from the absorber to an insulated water tank, where it may be used directly or indirectly in a heat exchanger or another device. A fully flooded absorber made of two metal sheets stamped to create a circulation zone is used by certain manufacturers. Flat-plate collectors have a lifespan of more than 25 years and may be slightly more efficient than conventional absorbers because of their larger heat exchange area (Layton, 2020). This collector might experience two sorts of losses: convection and radiation loss. The temperature differential between the absorber and surrounding air causes air movements, which results in convection loss. Heat transfer from the absorber to the surroundings is the cause of the radiation loss. A portion of the radiation is also reflected by the glass (Anand et al., 2021).

There are primarily two categories of flat-plate collectors: glazed and unglazed.

Flat-plate, glazed collectors for residential water heating are made up of corrugated copper pipes covered in glass, with insulation underneath and black, sunlight-absorbing material above. These layers are held together by a metal frame, which also gives the collector more rigidity.

Unglazed, flat-plate collectors, commonly utilized for pool heating, comprise serpentine polyvinyl chloride (PVC) pipes encased in rubber or plastic that has been treated for ultraviolet radiation protection (Mott, 2022).

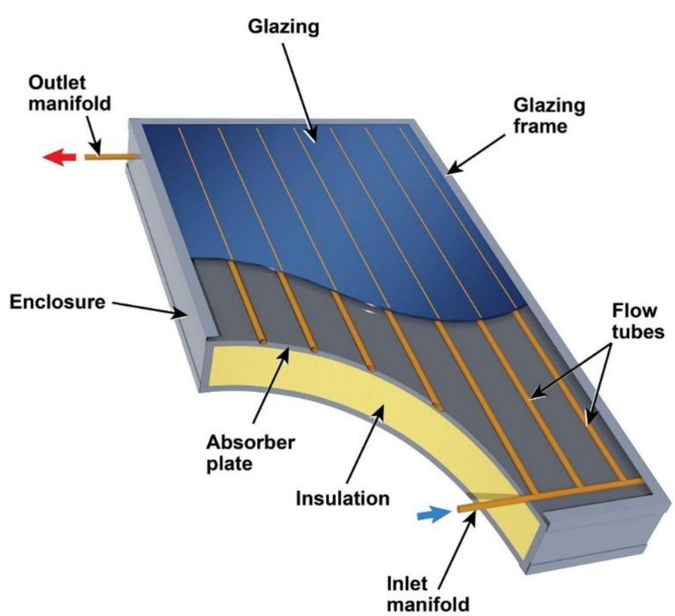

Fig 2.5: Flat-plate, glazed solar hot water collector

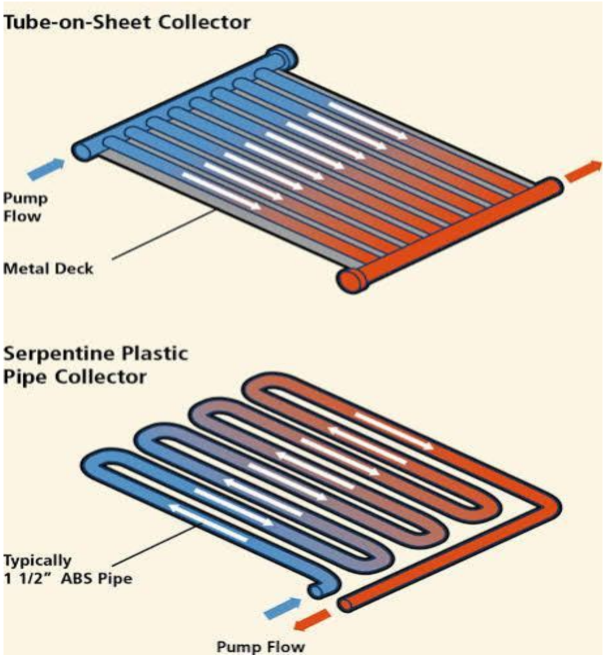

Fig 2.6: Unglazed, Flat-plate solar hot water collector

2.4.3 Evacuated-tube collectors

Evacuated-tube collectors, which are typically composed of parallel rows of transparent glass tubes, are effective at high temperatures. Each tube has a metal absorber tube that is fastened to a fin and an exterior glass tube. A covering that effectively absorbs solar radiation while preventing heat loss covers the fin. In order to create a vacuum and stop convective and conductive heat loss, air is evacuated from the area between the two glass tubes. Because evacuated-tube collectors can reach exceptionally high temperatures (170°F to 350°F), they are better suited for commercial and industrial applications as well as cooling purposes. However, evacuated-tube collectors cost around twice as much per unit area as flat-plate collectors, making them more costly (Layton, 2020).

Two main types of evacuated tube collectors are currently available on the market: direct flow and heat pipe. The former is called a direct flow evacuated tube and is depicted in Fig. 4 below, where the heat transfer liquid is pumped in the tubes, while the latter is depicted in Fig. 5 and uses heat pipes inside vacuum-sealed glass tubes with a reflector to further enhance radiation absorption capabilities. A collector's suitability to a system is determined by the rated efficiency of the panel as well as its suitability for the application. The heat exchanger transfers heat to the system's primary circuit, and the condensed fluid flows back down the heat pipe. The temperature of hot water required in the system, as well as the climate where the system is installed, can all influence the selection of the appropriate collector (Tadvi et al., 2014).

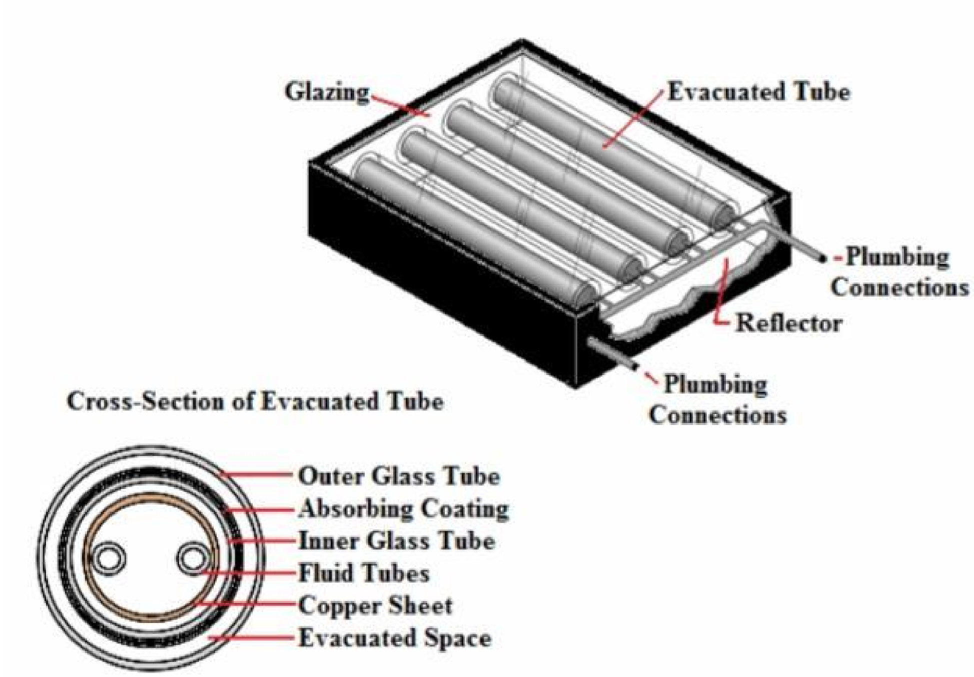

Fig 2.7: Direct Flow Evacuation-tube collector

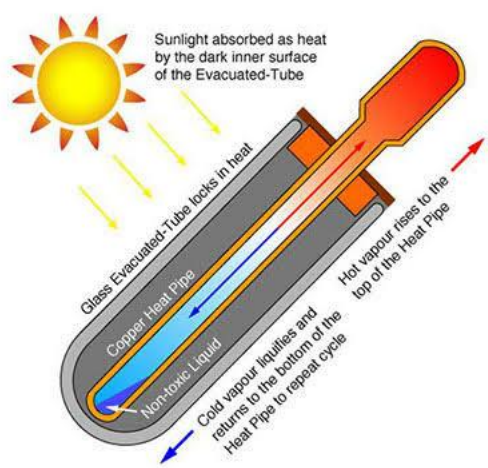

Fig 2.8: Heat pipe solar collector

Better temperatures are reached using evacuated tube collectors, and certain versions offer significantly better solar yields per square foot than flat panels. They are more costly and brittle than flat panels, though. Because evacuated heat tubes only depend on the light they receive and not the ambient temperature, they outperform flat plate collectors in cold climates.Evacuated tubes can remain effective over a broad range of ambient temperatures and heating needs for a specific absorber area. Flat-plate collectors are typically a more affordable option than evacuated tubes in excessively hot areas. They function efficiently in conditions of continuously low light levels and are well adapted to extremely cold ambient temperatures. The life expectancy of properly built evacuated tubes is over 25 years, which significantly increases their worth (Layton, 2020).

2.4.4 Parabolic concentrating collectors

Another name for these collectors is parabolic troughs. These gather and focus the heat energy from solar rays using highly reflecting materials. Reflective parts of these collectors are parabolically curved and join to form a long trough. To heat the contents, a water pipe is positioned in the middle of the trough so that sunlight gathered by the reflecting material may be focused onto the pipe. These collectors have a lot of power. As a result, they are typically not utilized in residential settings (Anand et al., 2021).

Parabolic-trough collectors are best suited for regions with strong solar radiation because they only use direct sunlight and need tracking systems to stay oriented toward the sun (Mott, 2022).

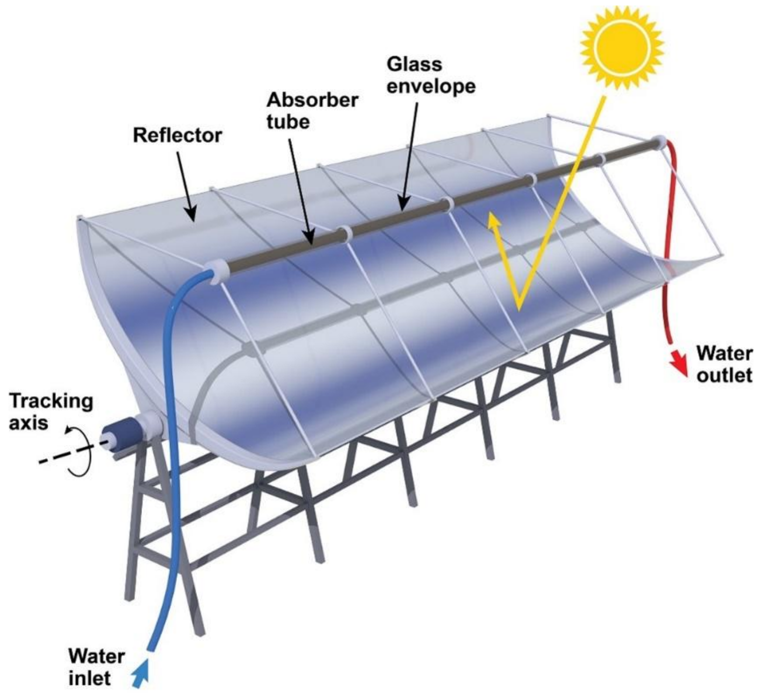

Fig 2.9: A Parabolic concentrating collector

2.4.5 Heat Transfer fluid

In direct systems, the heat transfer fluid is potable water; in indirect systems, it is an antifreeze solution. Indirect systems are especially frequent in areas that encounter freezing temperatures since they must either use antifreeze or shut down and evacuate the system during the winter. Ethylene glycol or propylene glycol can be used in antifreeze solutions. Toxic is ethylene glycol. The Food and Drug Administration has categorized propylene glycol as a food additive that is generally accepted to be safe for use. As a result, the most popular antifreeze solution in solar hot water systems is made of propylene glycol and water (Mott, 2022).

2.4.6 Storage tank

The water heated by the SWH collectors is kept in a storage tank. A backup water heating system and/or a heat exchanger may be installed in the storage tank. In relation to SWH production capacities, the tank's size is determined by the quantity and timing of peak hot water use. Systems with a single tank must rely on stratification within that tank to prevent transferring already-heated water to the solar array; it is better to have a separate solar storage tank to preheat water before the conventional heater (Mott, 2022).

2.4.7 Heat Exchangers

Heat exchangers are used in indirect SWH systems to move heat from the antifreeze solution, which absorbs heat inside collectors, to potable water without combining the two liquids. External heat exchangers can have inputs and outputs for both water and antifreeze solution, or they can be integrated into the storage tank so that the potable water flows freely around it and the antifreeze solution passes via the heat exchanger pipes inside the tank (Mott, 2022).

2.4.9 Backup water heater

The backup water heater can be a new water heater that is sized to supplement the SWH system during periods of low insolation or peak demand, instead of supplying the entire hot water load, or it can be an existing water heater in a retrofit application. As previously indicated, backup water heaters can be built into the storage tank, have a tank, or operate on demand using any fuel that a site normally uses for water heating (Mott, 2022).

2.4.10 Expansion tank

In order to relieve the high pressures caused by heated fluids, an expansion tank is required for the majority of household SWH systems, which are pressurized. In order to prevent overheating and antifreeze stagnation, the most resilient systems also include expansion tanks for the “pressure stagnation method.” In situations where water heating is not required, excessive heat from the sun might cause the antifreeze to become acidic and harm the collectors. This is avoided by forcing all of the fluid out of the collectors and into an expansion tank when the water in the antifreeze flashes to steam at a specific temperature. The expansion tank releases the fluid to continue operation when the temperature decreases and the steam condenses to liquid (Mott, 2022).

2.4.11 Pumps and valves

The heat transfer fluid is moved through the pipes, collectors, and storage tank by a pump in active SWH systems. The majority of active systems make use of a pump station that is incorporated into or connected to the storage tank. Usually, the pump station also has gauges that show the pressure and temperature of the system. SWH systems can be bypassed or turned on and off using automated or manual valves. For safety, they also feature a pressure relief valve (Mott, 2022).

2.4.12 Pipes / Pipe Network

The pipes carry water or antifreeze solution between the collectors, tank or tanks, and final applications. The pipes are commonly composed of PVC or cross-linked polyethylene (PEX) between the storage tank, backup water heater, if applicable, and end users, and copper between the collectors and storage tank (Mott, 2022).

2.4.13 Sensors and controls

Sensors are used by active SWH systems to measure the water temperature in the collectors and storage tank. A control system checks the temperature inside the collectors to see if the water temperature inside the storage tank is below the setpoint. The pump is turned on by the control system to transport fluid through the collectors and heat the water in the tank to the required setpoint if the temperature in the collector is higher than the temperature in the tank. The pump is then turned off. In order to move fluids between the storage tank and collectors, passive systems usually lack controls and rely on the physical characteristics of the fluids, which cause them to rise when heated and decrease when cooled (Mott, 2022).

2.5 Recent researches on Solar water heating system in Nigeria

Over the years, Nigerian researchers and academics have concentrated on the use of renewable energy in applications related to home heating. Energy efficiency and solar uses in buildings, especially for water heating, have been the subject of extensive experimental, numerical analytic, and review study (Ayodeji et al., 2023). The use of solar electricity for water heating has garnered a lot of attention because of its potential to reduce energy prices and negative ecological effects. As an environmentally beneficial alternative to conventional energy sources, which have drawbacks and cause problems for the environment, solar water heater systems have emerged. Growing concerns about the environment and energy sustainability have led to a shift in recent years toward renewable energy sources. Solar water heater systems have become a fascinating technology for heating water for residences and commercial buildings. Despite their potential benefits, solar water heater systems still face a number of challenges. Although they might operate differently depending on the weather, which could lead to uneven water temperatures, this system will appear beneficial in a country like Nigeria with significant levels of solar radiation, particularly in the northern parts (Patel, 2023).

CHAPTER THREE

METHODOLOGY

3.1 Facility development

Numerous ideas for solar thermal water heating systems are taken into consideration. Two proposals, however, pass the first test for possible consideration and further production following careful evaluation of operational and design factors. Using a choice matrix, a preferred notion will be chosen among the two. Two ideas are examined with a decision matrix:

3.1.1 Concept one: the siphon water flow

The concept depicted in Figure 3.1 uses the difference in density between the heated and cold water to start the water's flow from the cold water storage through the pipes and back to the storage tank. Natural forced convention serves as the foundation for the solar heating system's operation. Using steel pipes, the reservoir is connected to a tank that is kept at a slightly higher level above the insulated heat exchanger box. The cold water enters the steel pipes through the top of the storage tank. This process, known as the thermos-syphon effect, occurs when the sun's infrared radiation is trapped in the box, causing the water inside the pipe to heat up and become lighter. The heavier, colder water, which is at a relatively lower temperature, flows down into the pipes, while the lighter, hotter water flows against gravity into the gas tank.

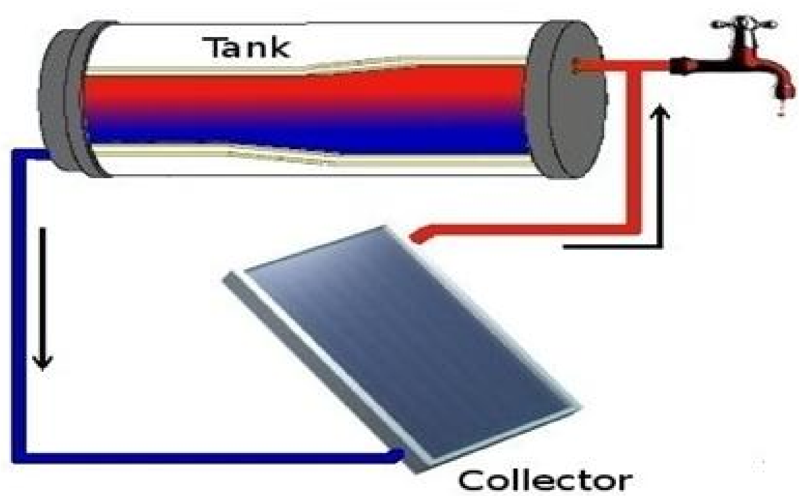

Figure 3.1 Solar thermal water heater concept one

Advantages of concept one

1. It uses a natural convection effect.
2. It is cheap to produce and install
3. No moving parts are present therefore little or no vibration occurrence.

Disadvantages of concept one

1. It is a very slow process because it depends on natural convection.
2. The cold water heated may not attain high temperature quickly due to temperate weather conditions.

3.1.2 Concept two: Pump assisted water flow

Figure 3.2 illustrates this. A significant addition to the setup that sets it apart from concept one is a pump, which is used to force the fluid (water) to flow in order to start the syphon effect. A battery or solar panel system installed vertically above a cylindrical tank filled with cold water from a reservoir powers the pump. With the help of a pump, cold water is forced through a heat exchanger that has black steel pipes that absorb heat, as well as reflective aluminum foil and glaze to improve the water's ability to absorb heat. In order to make room for more water to enter the heat exchanger for heating, the pump assists in moving the heated water from the pipes in the collection box to the storage tank or direct use.

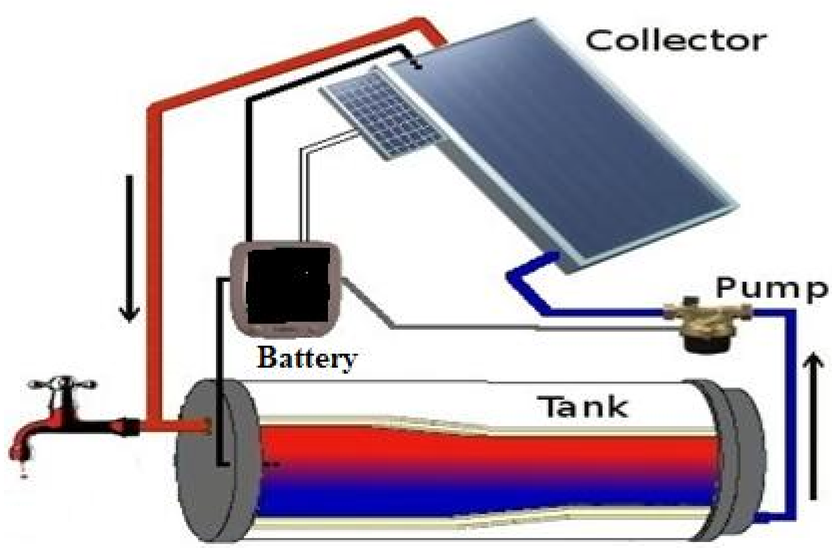

Figure 3.2 solar thermal water heater concept two

Advantages of concept two

1. Fluid flow is fast because it depends on forced convection with the aid of a pump

2. The cold water could attain high temperature quickly due to the rate of flow.

Disadvantages of concept two

1. The pump depends on additional energy.
2. Where cost reduction is a priority, it is more expensive to set up.

3.2 Evaluation and selection of concept using decision matrix

The two emphasized concepts are evaluated according to particular design criteria, and the most feasible concept will be chosen via a decision matrix, as illustrated in Table 3.1.

Table 3.1 Decision matrix for solar thermal water heating concept selection

S/N	Design Specification	Concept 1	Concept 2
1	Improved heating process	1	2
2	Improved fluid flow	1	2
3	Energy use and conservation	2	1
4	Reliability for scaled up use	1	2
5	Cost of production	2	1
	TOTAL	**7**	**8**

Concept 2 was chosen for development as, according to Table 3.1, it has the greatest weighted score among the parameters taken into consideration.

3.3 Design considerations

The design considerations for the solar water heater were conducted with the following precise input parameters:

a) The required temperature of hot water for domestic purposes, such as preparing tea, handwashing, or similar activities, is approximately 50-60°C.

b) The daily hot water need for a human population of 10, with each individual's water necessity approximated at 4 liters.

c) The temperature requirement depends on daily sun radiation.

d) The active heating duration of the water is approximately 8 hours, during which sunlight is available from 9:00 AM to 4:00 PM..

e) The water supply is anticipated to be accessible at all times, within the storage volume capacity, requiring a pumping system.

f) Transmittance of the transparent cover body is estimated to be 0.9 (Dziedzic et al., 2017).

g) The absorptivity of the absorber steel pipe, which is covered with black paint, is 0.95 (Kumar et al., 2021). This is dependent on surface roughness, steel material condition, and light wavelength. However, it is enhanced with a layer of black film.

h) The solar collector's inclination angle with respect to the horizontal can be changed to accommodate the angle of sun incident.

3.4 Material selection criteria

The materials are selected based on the following criteria;

a) Highest Temperature Limit (maximum temperature)

b) Resistance to Corrosion

c) Availability

d) Thermal Conductivity

Table 3.2 lists the parts and supplies required for the solar water heater along with the selection criteria.

Table 3.2: Materials and selection criteria

	COMPONENTS	MATERIAL	USE	BASIS FOR SELECTION
1	Transparent cover	Glass	It reduces significantly the	• High transmittances of

			radiative and convective heat losses of the absorber plate.	incident solar radiation. • Low cost • Low convective and relative losses
2	Absorber plate	Aluminium	Designed to efficiently reflect the sun rays on the pipe for improved heating.	• Ease of application on the insulated heat exchanger. • Good thermal reflectivity •
3	Collector casing	Wood	It houses the components of the collector box	• Resistance to corrosion • Good insulator with minimal heat loss
4	Heat transfer tube	Steel (stainless) painted black	Water to be heated passes through this tube for heat transfer.	• High flexural strength • High thermal absorptivity. • Less costly to acquire, • Good availability
5	Storage tank	Polymer	Acts as a reservoir for water.	• It is readily available. • It offers better insulation. • Cheap to acquire
6	Hose	Polymer	It serves as a channel for the flow of water outside the collector	• They are readily available.

3.5 Machine Component Description

The various components of the solar heating machine system and their function are as follows**;**

(1) **Water Storage tanks:** It is used for retaining a set amount of water for sun thermal heating.

(2) **Valves:** It is used for fluid flow regulation.

(3) **Cold Water hoses:** For transferring fluid from point to point.

(4) **Heat absorbing steel pipes:** To convey fluid and transmit heat into the fluid.

(5) **Heat exchanger box with glaze:** This includes the reflective coating and glass for solar thermal heating of the fluid and conduction pipes inside.

(6) **Water Pump:** For the purpose of forcing the fluid to expand and compress in order to improve flow.

(7) Weather measuring devices: Examples of devices that measure temperature and humidity include thermostats, thermometers, and humidity meters.

3.6 Design Details of collector area

Design of collector area

Collector area (A_C) Is the ratio of the quantity of heat required (Q_w) to raise the temperature of water from T_{in} to T_{out} to the energy absorbed by the collector over a specified period of time.

The sizing of the collector area is according to the hot water demand.

The heat requirement is given by:

$$Q = mc_{pw}(T_{hot} - T_{cold}) \quad (3.1)$$

Since $Density = \frac{Mass}{Volume}$

$Mass(m) = Density \times Volume = \rho V$

Substitute for mass in the above equation

$$Q = \rho V_T c_{pw}(T_{hot} - T_{cold}) \quad (3.2)$$

Where:

ρ = density of water = 1000kg/m^3

V_T = volume of water = 30 litres = 0.03m^3

C = heat capacity of water

T = temperature of media

T_{hot} = 60^{0}C

T_{cold} = 20^{0}C

The collector area is given by

$$\boldsymbol{A_c = \frac{Q}{ntI}} \tag{3.3}$$

Where:

I = solar radiation = 1,470W/m^2

n = Collector efficiency= 40%

t_h= Heating time (sec)

To obtain a temperature of 60^{0}C i.e $T_{hot} = 60\ ^0$C

$$A_c = \frac{1000\ X\ 0.03\ X\ 4200\ X\ (60 - 30)}{0.4\ X(6\ X\ 3600)X\ 1470}$$

A_C = 0.3m^2 approx.

The collector is designed using glass.

According to equation 3.3, the area and thickness of the glass should be increased in order to maximize heat collection.

Mass flow rate

Mass flow rate of water within the collector plate area is given by

Mass flow rate (M_f) = Volume flow rate (V_f) x Density (ρ) (3.4)

Where t is the time to drain the fluid within the collector

Velocity of water on the collector plate is given by:

$$\mathbf{V} = \frac{\mu \times \mathbf{Re}}{\rho \times \mathbf{D}} ,$$

At 60 °C, ρ = 971.82kg/m^3, μ = 351 x 10^{-6}kg/ms, D = 0.005m

Velocity of fluid flow, V = 0.15m/s

$$\mathrm{Re} = \frac{\rho \mathrm{VD}}{\mu} = \frac{351\ x\ 10^{-6}\ x\ 0.15\ x\ 0.005}{971.82} = 2072 \text{ (Laminar Flow)}$$

Area of heat transfer tubes, A = $\frac{\pi D^2}{4}$

Volume flow rate(V_f) = Area of heat transfer tubes x Velocity

Mass flow rate (M_f) = Volume flow rate (V_f) x Density (ρ)

Heat loss coefficient

A process of iteration is used to estimate the main losses from conduction, convection, and radiation, assuming one-dimensional heat flow that takes into account thermal capacity and temperature drop across the system.

Under steady state condition, the heat loss Q_l from the absorber plate to the glass cover is given by;

$$Q_l = UA_C \Delta T \quad (3.5)$$

ΔT = 100ºC

Temperature of Glass (T_{glass}) = 100ºC - 50ºC = 373.15k – 323.15k = 50ºC

Convective heat transfer for Air at Laminar flow (h_{air}) = 0.8476W/m^{2}k

Thermal conductivity for Glass (k_{glass}) = 0.96 W/mk

The convective heat transfer coefficient between the steel pipe and glass cover is calculated from the Nusselt number obtained using equation given by (Hollands et al 2007).

$$Nu = 1 + 1.44\left[1 - \frac{1708}{\cos\beta\,.Ra}\right]\left[1 - \frac{\sin(1.8\beta)^{1.6}.1708}{\cos\beta\,.Ra}\right] + \left[\left(\frac{\cos\beta\,.Ra}{5830}\right)^{1/3} - 1\right] \quad (3.7)$$

Where $Ra = \frac{g\beta(\Delta T)l^3}{v^2} \times Pr$

For Air at 60ºC and 1 atm, g = 9.81m/s^2

Computation for the heat exchange between glass and steel pipes is as follows;

Prandtl No, Pr = 0.692

Characteristic Length, L = Lc = 0.79m

Dynamic Viscosity of Air, µair = 2.181 x 10^{-5} kg/ms

Density of Air, ρ = 0.9413kg/m3

Thermal Conductivity, K = 3.186 x 10^{-5}kW/mK

Coefficient of Cubic Expansion, β = 0.00309 k^{-1}

Kinematic Viscosity of Air, V= µ/ρ = 2.317 x 10^{-5} m^2/s

$$Ra = \frac{9.81\ x\ 0.003095\ \text{x}\ (50)\ x\ 0.79^3}{(2.317\ \text{x}\ 10^{-5})^2} \times 0.692 = 2235096024$$

$$Nu = 1 + 1.44\left[1 - \frac{1708}{\cos\ 0.003095\ x\ 2.235\ x\ 10^6}\right]\left[1 - \frac{\sin{(1.8\ x\ 0.003095)^{1.6}}\ x\ 1708}{\cos 0.003095\ x\ 2.235\ x\ 10^6}\right] + \left[\left(\frac{\cos 0.003095\ x\ 2.235\ x\ 10^6}{5830}\right)^{1/3} - 1\right] = 21.018$$

$$\text{Nu} = \frac{h_{airx}L}{k}$$

$h_{air} = \frac{NuxK}{L} = \frac{21.018 \text{ x } 3.186 \text{ x } 10^{-5}}{0.79} = 0.8476\text{W/m}^2\text{k}$ for Natural Convection

$$U = \frac{L_{steel}h_{air}k_{glass} + k_{steel}k_{glass} + L_{glass}k_{steel}h_{air}}{k_{steel}h_{air}k_{glass}}$$

From the Nusselt number the overall top loss coefficient U is calculated at different tilt angles β and Ra. The radiative heat transfer coefficient varies with the wind loss coefficient and the temperature difference between the glass cover and the ambient.

3.7 Heat Exchanger

The heat exchanger comprising of the steel pipe and the flowing water. The governing equation of the heat exchanger is expressed as:

$$Q = UA\Delta T_m = Q = m.C_p.\ (T_2 - T_1) = U(N\pi dL)T_m \qquad 3.8$$

The log mean temperature difference ΔT_m is:

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \qquad 3.9$$

Where:

T_{hi} = hot fluid inlet temperature

T_{ci} = cold fluid inlet temperature

T_{ho} = hot fluid outlet temperature and

T_{co} = cold fluid outlet temperature.

m = mass flow rate

C_p = Specific heat

N = number of tubes

d = diameter of tube (m)

L = length of tube

From equation 8, it follows that,

$$Q = UA\frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \qquad 3.10$$

For the overall heat transfer coefficient U of the steel tube with thin wall, the thermal resistances due to tube wall thickness and scale formed due to hardening of water will be neglected hence;

The overall heat transfer coefficient (U_o) based on the outer surface is given as

$$U_o\ A_o = \frac{1}{\frac{1}{h_i}+\frac{1}{h_o}}\ A_O \ = \qquad 3.11$$

The overall heat transfer coefficient (U_o) based on the inner surface is given as

$$U_i\ A_o = \frac{1}{\frac{1}{h_i}+\frac{r_i}{k}\ln\left(\frac{r_o}{r_i}\right)+\left(\frac{r_i}{r_o}\right)x\frac{1}{h_o}}\ A_o \qquad 3.12$$

Where; h = average heat transfer coefficient given for flow inside tubes

$$h = \frac{k}{d}\,Nu \qquad 3.13$$

where;

Nu = Nusselt number = hd/k 3.14

k = thermal conductivity

d = diameter of pipe or tube

Re = Reynolds number

P_r = Prandtl number $= \frac{\mu c_p}{k}$ 3.15

where;

μ = dynamic viscosity of air = 2.3 x 10^{-5}kg/ms

c_p = specific heat capacity of air = 1.006Kj/kg K

Heat supplied by generator exhaust = Heat gained by the exchanger

Let Q = heat supplied by the sun = Q = heat gained q by the water in pipe

Therefore; Q. = qL

That is; L = total length of pipe.

For range of values of L the corresponding values of Q can be obtained as shown in Table 3.6

From equations 3.8 and 3.9 it is observed that there is a direct proportionality of the quantity of energy transferred with the overall heat coefficient U and the logarithmic temperature $T_{m..}$ U is expressed as;

$$U = \frac{1}{\frac{1}{h_i}+\frac{r_i}{k}\ln\left(\frac{r_o}{r_i}\right)+\left(\frac{r_i}{r_o}\right)x\frac{1}{h_o}} \qquad 3.16$$

and it is dependent on the following variables:

i. Average heat coefficient for flow inside tube $h = \frac{k}{d} Nu$

ii. Nusselt number, $Nu = 0.023(R_e)^{0.8}(P_r)^{0.33}$

iii. thermal conductivity, k

iv. diameter of tube, d

v. Reynolds number

vi. Prandtl number, $Pr = \frac{\mu c_p}{k}$

vii. dynamic viscosity of air, $u = 2.3 \times 10^{-5}$kg/ms

viii. c_p = specific heat capacity of air = 1.006Kj/kg K

ix. Logarithmic temperature difference T_m

Table 3.3 Values of quantity of heat and length of steel pipe

Length of pipe L(m)	Quantity of heat Q (J) = qL
0.0001	0.005
0.0005	0.025
0.001	0.051
0.003	0.154
0.01	0.516
0.05	2.570
0.1	5.150
0.5	25.86
1	51.62
1.2	61.92
1.4	72.24
1.6	82.56
1.8	92.88
2	103.2

3.8 Design of the water storage tanks

The data for the water storage tank is shown in Table 3.7. it is a single thin-walled cylinder of $V_T m^3$ capacity with a diameter$D_T m$and length$L_T m$.

Table 3.4 Table of data for water storage tank

Diameter of storage tank, D_T (m)	0.24
Volume of storage tank, V_T (m^3)	0.03
Height of tank from then ground, H_T (m)	1.58
Temperature rise of water in tank, $\Delta T_w = T_{hot} - T_{cold}$(°C)	60 – 30 = 30

Therefore,

$$Volume(V_T) = Area(A_T)\ x\ Length(L_T) \qquad 3.17$$

$$\text{Where } A_T = \frac{\pi {D_T}^2}{4} = \frac{\pi x 0.24^2}{4} = 0.0452\text{m}^2$$

$$\text{Therefore,} V_T = \frac{\pi {D_T}^2}{4} L_T$$

$$L_T = \frac{4V_T}{\pi {D_T}^2} =$$

Pressure in the hot water storage tank at full capacity is expressed as;

$$P_T = \rho_{w2} g H_T$$

$$\rho_{w2} = \rho_{w1}[1 + \beta \Delta T_w]^{-1}$$

where;

p = density of water, w = weight, g = acceleration due to gravity, H = height of column

Stress analysis on the tank.

The polymer-based cylindrical water tank reservoir experiences internal pressure because of the water within. It is assumed that the internal surface of the tanks experiences a uniform distribution of pressure. The vessel is considered thin-walled if the wall thickness is 1/20 of the internal diameter or less; if not, it is considered thick-walled. Taking the following tan specifications into consideration:

Material: mild steel

Yield Strength of the tank material = σ_T

Height of hot water tank H_T = 0.158m

Wall thickness of the tank, t = 0.002m

From the above, for a thin-walled cylinder, wall thickness t is related to the diameter of the following inequality: $t \leq 1/20 D_T$, for the water tank. A bursting stress known as hoop stress will be set up on the wall of the cylindrical tank caused by water pressure.

$$2\sigma_T H_T t - P_T D_T H_T = 0$$

$$2\sigma_T H_T t = P_T D_T H_T \qquad 3.18$$

Therefore, tangential stress for water tank

$$\sigma_T = \frac{P_T D_T}{2t} =$$

Where P_T is internal pressure on water tank.

Recall $P_T = \rho_{w1} g H_T$

$$\sigma_T = \frac{\rho_{w2} g H_T D_T}{2t}$$

Since the tank is closed, the longitudinal stress σ_l exist because of the pressure at the ends of the tank. Assuming stress to be distributed uniformly over the wall thickness, then,

$$\sigma_L = \frac{P_T D_T}{4t} = \frac{1}{2}\sigma_T \qquad 3.19$$

Pipe sizing

The pipe sizing is carried out to obtain required heat transfer

Number of pipes used is given as n.

For total heat intensity of 1,018.92W/m^2, if the heat conducted per length of pipe is qW/m; hence for the n number pipes, assuming there is no heat lost, the total heat conducted will be

$n \times qW/m^2$. 3.20

Thermal Storage

Heat is stored as sensible heat in the water contained in the storage tank. The sensible heat storage utilizes the heat capacity and the change in the temperature of the water during the process of charging or discharging of the system. These parameters are related to give the sensible heat gained or lost in changing temperature from an initial value T_{in} to final value, T_{out} as;

$$dQ = mc_{pw}(T_{hot} - T_{cold}) = \rho V_T c_{pw}(T_{hot} - T_{cold}) \qquad 3.21$$

The high specific heat capacity and density of water makes it a good heat storage fluid as reflected in equation above. Assuming the specific heat capacity of water and its density are 4200J/kg K and 1000kg/m^3 respectively,

The collector-storage tank energy balance is expressed as;

$$mc_{psteel} dT = Q_{steel} - Q_{glass}$$

$$mc_{psteel}\mathrm{dT} = Q_{\mathrm{steel}} - Q_{\mathrm{glass}} = \mathrm{UA}\left(T_{ssteel} - T_{sglass}\right) \quad 3.22$$

Where Q_L is the rate of heat removal by the load and T_s is the water temperature in storage tank. The useful heat gain may also be given as;

$$\mathrm{Qu} = \frac{\rho \mathrm{VcpdT}}{\mathrm{dt}}$$

In the above equation, V is the volume of water in the storage tank; is the average tank temperature and dT/dt is the mean rate of change of average water temperature.

3.9 Pump selection

The hydraulic pump power rating ($P_{h(kw)}$) is the pump capacity rating and selection is dependent on the total head calculated plus a factor of safety required to deliver the required pressure. The ideal hydraulic power to drive a pump depends on; the mass flow rate, the liquid density and the differential height. The pump power is expressed as:

$$P_{h(kW)} = \frac{q\,\rho\,g\,h}{3.6 \times 10^6} \quad 3.23$$

where

$P_{h(kW)}$ = hydraulic power (kW)

q = flow capacity (m^3/s) = $\frac{V}{h}$

ρ = 1000kg/m^3

g = 9.81 m/s^2

h = differential head (m)

The rating of the pump is in watt-hour.

The hydraulic horse power can be calculated as:

$P_{h(hp)}$ = P(kw) / *0.746* = 5.02x 10^{-6}hp

3.10 Production methods of component parts of the solar water heater

The different solar thermal water heater components were examined. Some were made in the workshop, while others were photographed for direct market sourcing. The different parts and the manufacturing technique used to make them are displayed in Table 3.5.

Table 3.5 Solar water heater components and their production processes

S/N	Part Name	Sourcing mode	Production technique
1	Heat transfer tube	Fabricated	It is a stainless steel material having a total length of 504cm and internal diameter of 0.5cm. it was divided into 6 equal passes each having a length of 42cm. The heat transfer tube was the clamped to the base absorber plate. The heat transfer tube was painted black.
2	Storage tank	Sourced from Market	A polymer was used according to specification needed for the amount of water storage.
3	Heat exchanger and Collector casing	Fabricated	The necessary marking out was carried out to design specifications with the necessary allowances. The wood was then cut to size using a machine saw and joined using nails and hinges. The glass was clamped to it at the top.

4	Pump	A car wiper pump was bought from motor spare parts market	It was attached to the stand with clips fabricated using mild steel with the attached suction and discharge piped out using flexible tubes.
5	Battery	Sourced from market	It was connected to the control switch electrically.
7	Structural stand	Fabricated	It was fabricated using mild steel cut to the required size and welding together using arc welding machine.
8	Control Switch and wiring.	Sourced from market	The control switch and wiring were connected together to the battery.
9	Flexible hoses	Sourced from market	It was cut to size and attached to the collector inlet and outlet, pump suction and discharge using clips.
10	Fittings (Brass tap, PVC Tee, brass valves, PVC reducer galvanized elbow and cap)	Sourced from market	The fittings were connected at the required positions using yarns to ensure that there is no leakage and to prevent galvanic corrosion of the metal to the metal connections.
11	Absorber film	Fabricated	Aluminium film was unwrapped and cut to the required size.

3.11 Bill of Quantity of materials

The bill of engineering materials and evaluation for the solar thermal water heating system is presented in Table 3.6

Table 3.6 Bill of Engineering Materials and Evaluation

S/No	Component	Material	Dimension/ Capacity	Quantity	Unit Cost	Total Cost (N)
1	Transparent Collector Cover	Glass	79cm x 40cm	1	7,600	7,600
2	Absorber Plate	Aluminium	79cm x 40cm	1	4,800	4,800
3	Heat Exchanger	Steel (stainless)	42cm x 0.5cm	1	4,100	4,100
4	Collector Casing	Wood	82cm x 45cm x 13cm	1	5,700	5,700
5	Frame/Stand for structural work	Mild Steel	30mm x 30mm Angle Iron	3 Full length	13,000	39,000
6	Cylinder Storage tank	Polymer	30 Litres	1	5,000	5,000
7	Water Bucket	Polymer	10 Litres	1	3,000	3,000

8	Fittings	HDPE	(i) Tee - valve	(i) 10	500	5,000
			(ii) Elbow valve	(iii) 4	300	1,200
9	Battery		12V/18AH	1	21,000	21,000
10	Pump		0.25hp	1	5,000	5,000
11	Spray painting	Aerosol titanium dioxide		1	4,500	4,500
12	Welding electrode	Steel		10	600	6,000
13	Water Tap	PVC	½ inch tap	1	1,000	1,000
14	Flexible hose & sockets	Polyethene	0.5cm	3	3,000	9,000
15	Miscellaneous/Transportation				8,000	8,000
	TOTAL					129,900

The pictorial view of the fabricated concept of the facility is as shown in Figures 3.3.

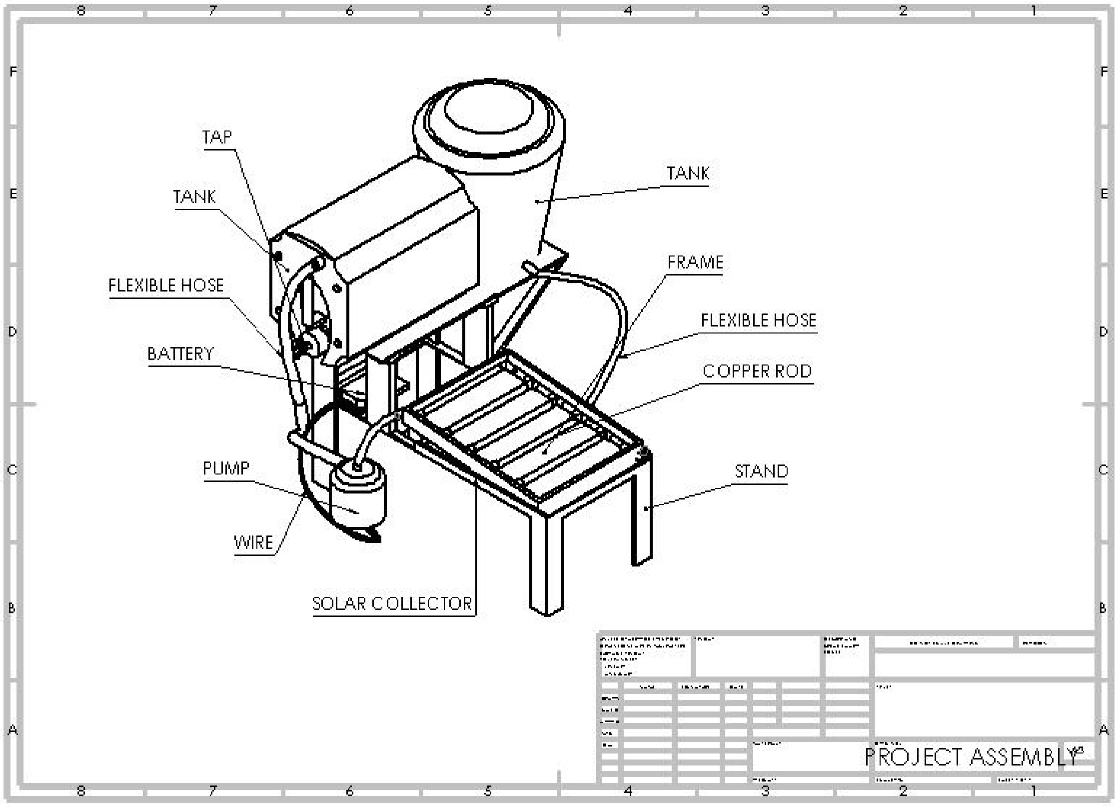

Figure 3.3 The solar thermal water heater.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RESULTS.

After the fabrication was completed, the solar thermal water heater was tested in an open field at the University of Benin where the solar radiation available at any time will not be inhibited. Temperature of hot water for 3 days in February, 2025 for 7 hours was recorded from Monday to Wednesday. The result of the tests is shown in Tables 4.1 to 4.7 as follows;

Table 4.1: Temperature of hot water for Monday, 3rd February, 2025.

Time of the day	Temperature of cold water, T_{in} (^{0}C)	Temperature of hot water, T_{out} (^{0}C)	Difference in Temperature (^{0}C)
9.00am	30	39	9
10.00am	31	43	12
11.00am	30.5	46	15.5
12.00pm	31	48.2	17.2
1.00pm	32	50	18
2.00pm	32	49.6	17.6
3.00pm	30	47.4	17.4
4.00pm	30	40	10

The average daily temperature of hot water in the tank = 45.4^{o}C

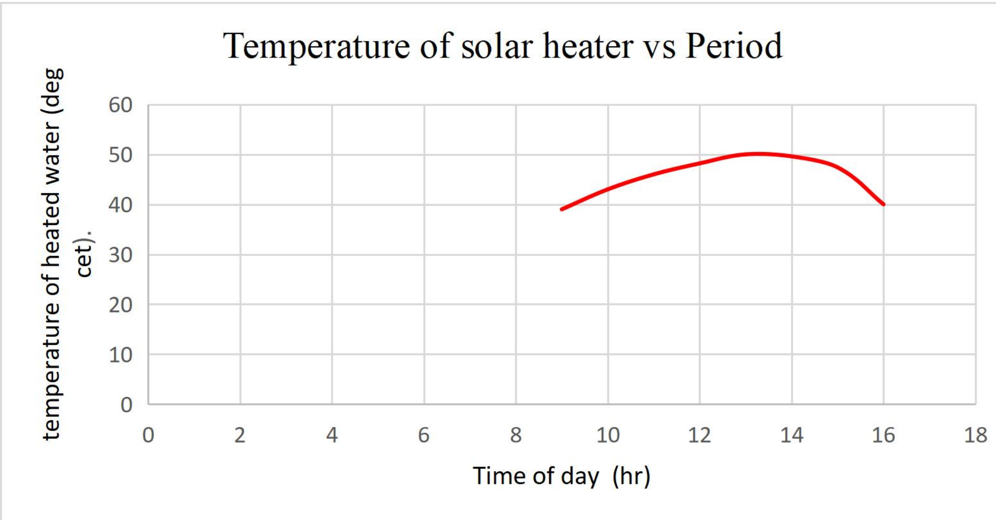

Figure 4.1 graph of temperature against daily period (Day one)

Table 4.2: Temperature of hot water for Tuesday, 4th February, 2025.

Time of the day	Temperature of cold water, T_{in} (^{0}C)	Temperature of hot water, T_{out} (^{0}C)	Difference in Temperature (^{0}C)
9.00am	30	37	7
10.00am	30	41	11
11.00am	30	45.8	15.8
12.00pm	30	50	20
1.00pm	30	55	25
2.00pm	30	49	19
3.00pm	30	49.3	19.3
4.00pm	30	45	15

The average daily temperature of hot water in the tank = 46.5^{o}C

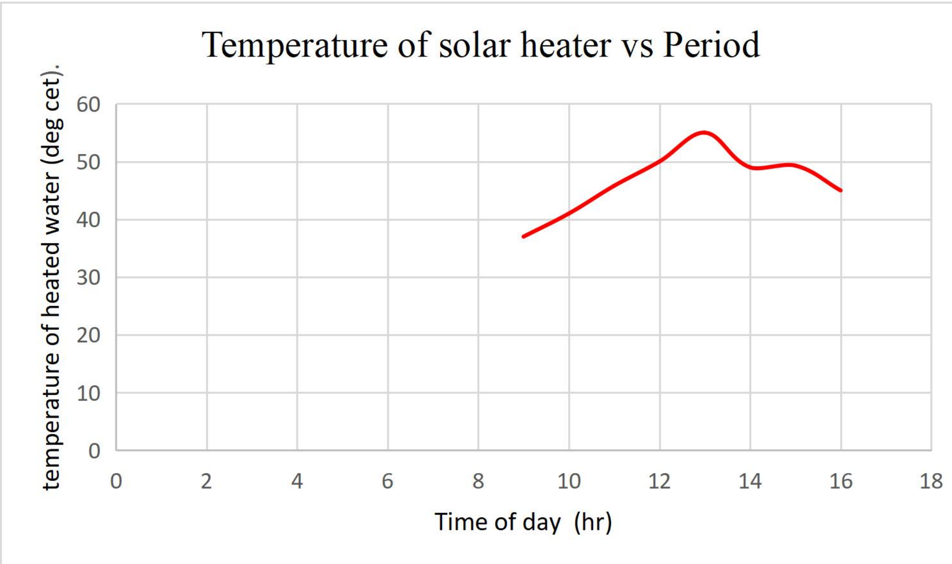

Figure 4.2 graph of temperature against daily period (Day two)

Table 4.3: Temperature of hot water for Wednesday, 5th February, 2025.

Time of the day	Temperature of cold water, T_{in} (^0C)	Temperature of hot water, T_{out} (^0C)	Difference in Temperature (^0C)
9.00am	31	38.5	7.5
10.00am	31	39.8	8.8
11.00am	31	44.5	13.5
12.00pm	31	49.2	18.2
1.00pm	31	49.3	18.3
2.00pm	31	53.1	22.1
3.00pm	31	49	18
4.00pm	31	43.8	12.8

The average daily temperature of hot water in the tank = 45.9^oC

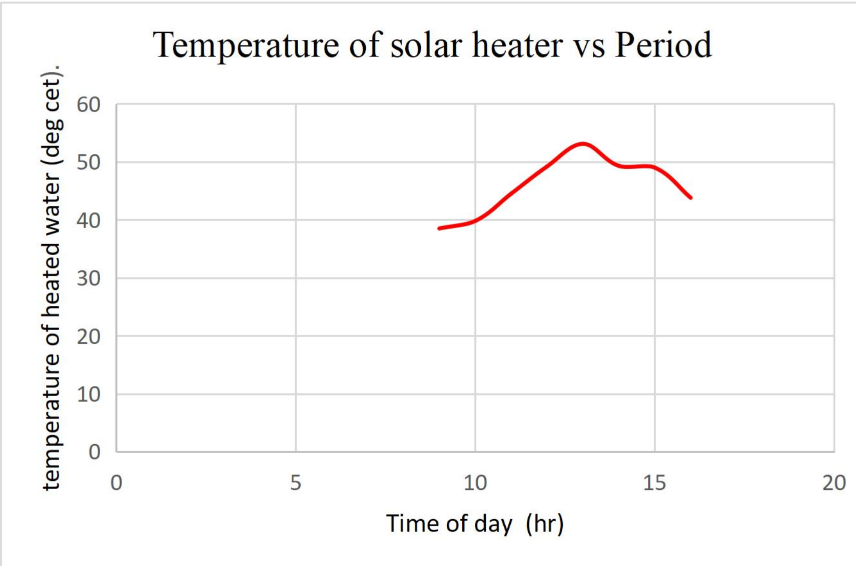

Figure 4.3 graph of temperature against daily period (Day three)

The various plots of temperature of hot water against time of the day shows an increase in temperature of hot water obtained up till a peak period accompanied by a drop in temperature of the hot water. The temperature of hot water and heat absorbed increased from 39^0C at 9:00a.m on the 1st day of testing and it peaked at 50^0C at 1:00p.m and dropped to 40^0C 315KJ at 3:00p.m to 4:00pm. This trend was seen to be recurrent for the other two days in which the test was carried out. It is important to note that the test was carried out during temperate and sunny periods hence fluctuations were observed at specific times especially between 3.30 pm and 5pm when the sun was in the process of setting. On a general note the solar heating process from a.m. to pm was characterized by a curve which started at a low point, increased to a peak point and start to decrees in accordance to the entire period of sunrise to sunset.

4.2 Discussion

4.2.1 Effect of tube length

It can be seen from Table 3.6 and the accompanying graph of the heat transfer rate Q plotted against the tube length in Figure 4.1 that as the tube length increased, so did the amount of heat that could pass through it and the heat exchanger's efficiency.

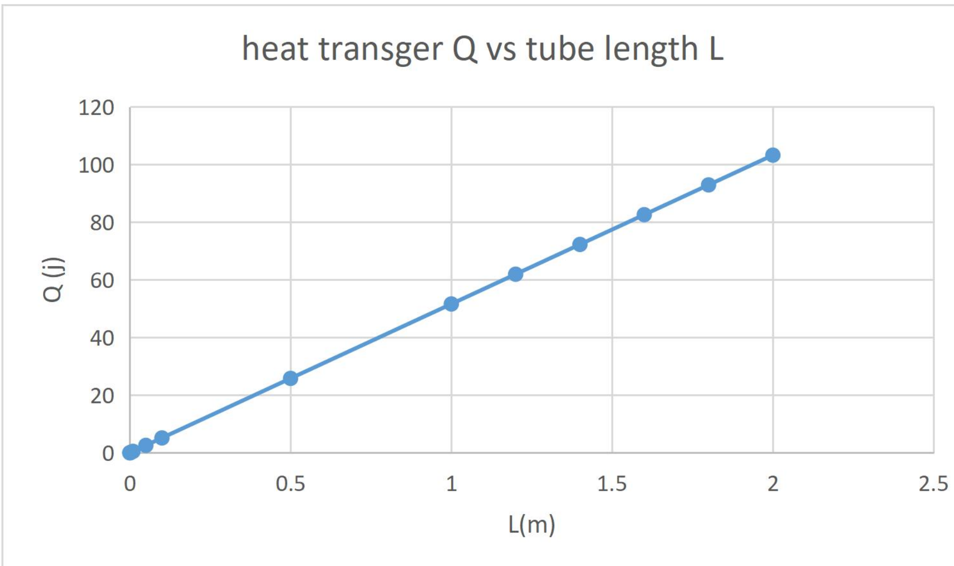

Figure 4.4 Effect of heat transfer with changes in tube length

According to Hossain (2013) and Ighodaro (2022), the longer the heat exchanger, the more residence time and surface area the hot and cold fluids received for heat transfer during the optimization of a domestic waste heat recovery from computational fluid dynamics (CFD). As a result, effectiveness rose with length; but, for some lengthy lengths, the effectiveness increase was negligible and may have even decreased slightly due to heat losses along the tube or pipe length that appear to negate the heat uptake by the cold fluid.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

From the test results and analysis, it was observed that the use of solar water heater incorporating a thermal storage is a cost effective way of heating water with locally sourced materials. The aims and objectives of the project were met during the course of the design, fabrication and experimentation.

The result of the 1st day of testing were recorded, analyzed and compared to obtain the average peak temperature of 50°C for heating water during the period of its testing on the 3rd February, 2025. The result conducted showed that within a period of 7 hours, between 9.00am to about 4.00pm the time of maximum or peak temperature of 50°C was obtained at 1.00pm, with an initial cold water temperature of 32°C.

The result for the 2nd day of testing on the 4th February, 2025 was conducted also and recorded having an initial cold water temperature of 30°C to obtain an average peak temperature of 55°C within the same period of 7 hours, 9.00am to 4.00pm, with the time of peak or maximum temperature at 1.00pm.

For the 3rd day of testing on the 5th February, the results obtained from the test having an initial cold water temperature of 31°C was an average peak temperature of 53.1°C from 9.00am to 4.00pm, in which the time of peak temperature was obtained at 2.00pm.

Deriving conclusions from the 3 days of testing, it was observed that the peak temperature of water heating is an average of 52.7°C (taking the average of the peak temperatures for the 3 days), and the time for the maximum sun heating is seen to be between 1.00pm and 2.00pm.

It was observed that the equipment was noiseless in its operations and equally pollution free unlike other fossil fuel based water heaters.

This solar thermal water heater can find its use in homes for domestic use and commercial applications. Objectively, the solar water heater cannot be the only sustainable heater in a house or industry because, its efficiency can vary depending on the amount of solar energy available on a given day.

5.2 RECOMMENDATIONS

1. Further research should be carried out to design and fabricate more efficient solar thermal water heater using organic fluids with more heat absorbing capacities.
2. Cheaper and better production processes for manufacturing solar water heaters should be researched.
3. Better thermal storage materials which help keep the water at desired temperature during the night should be researched.

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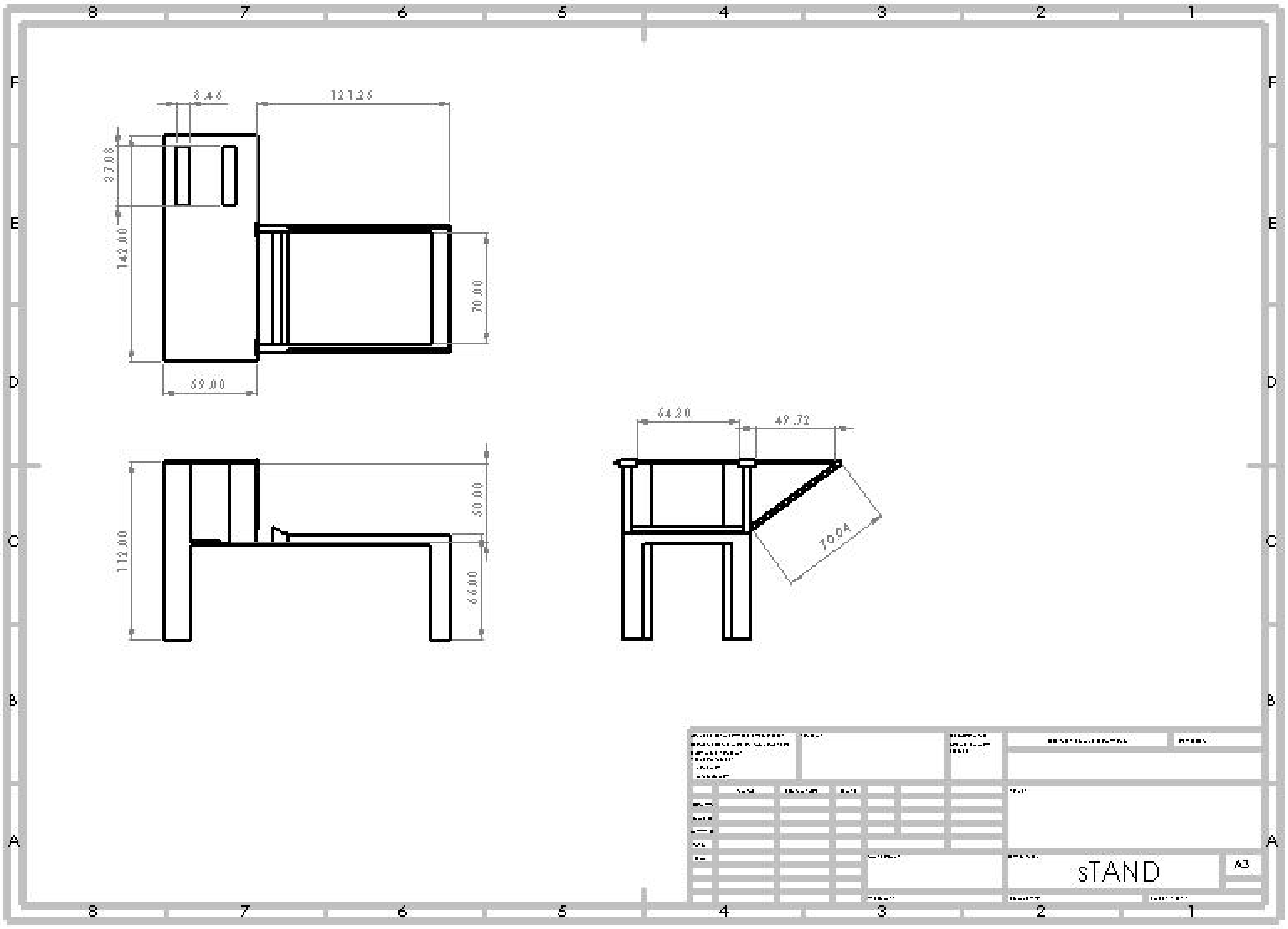
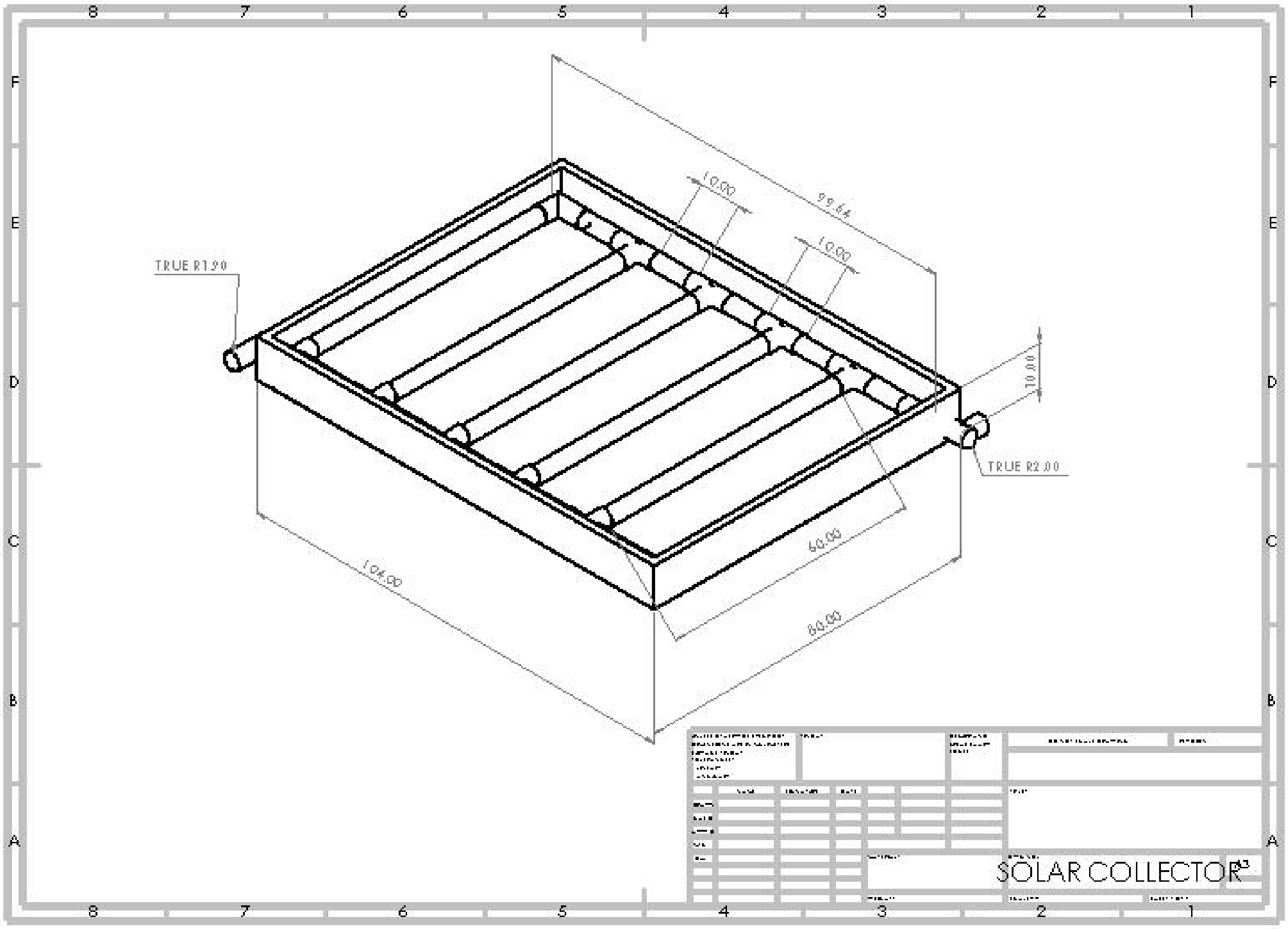
Appendix

Working Drawings of the solar thermal water heater

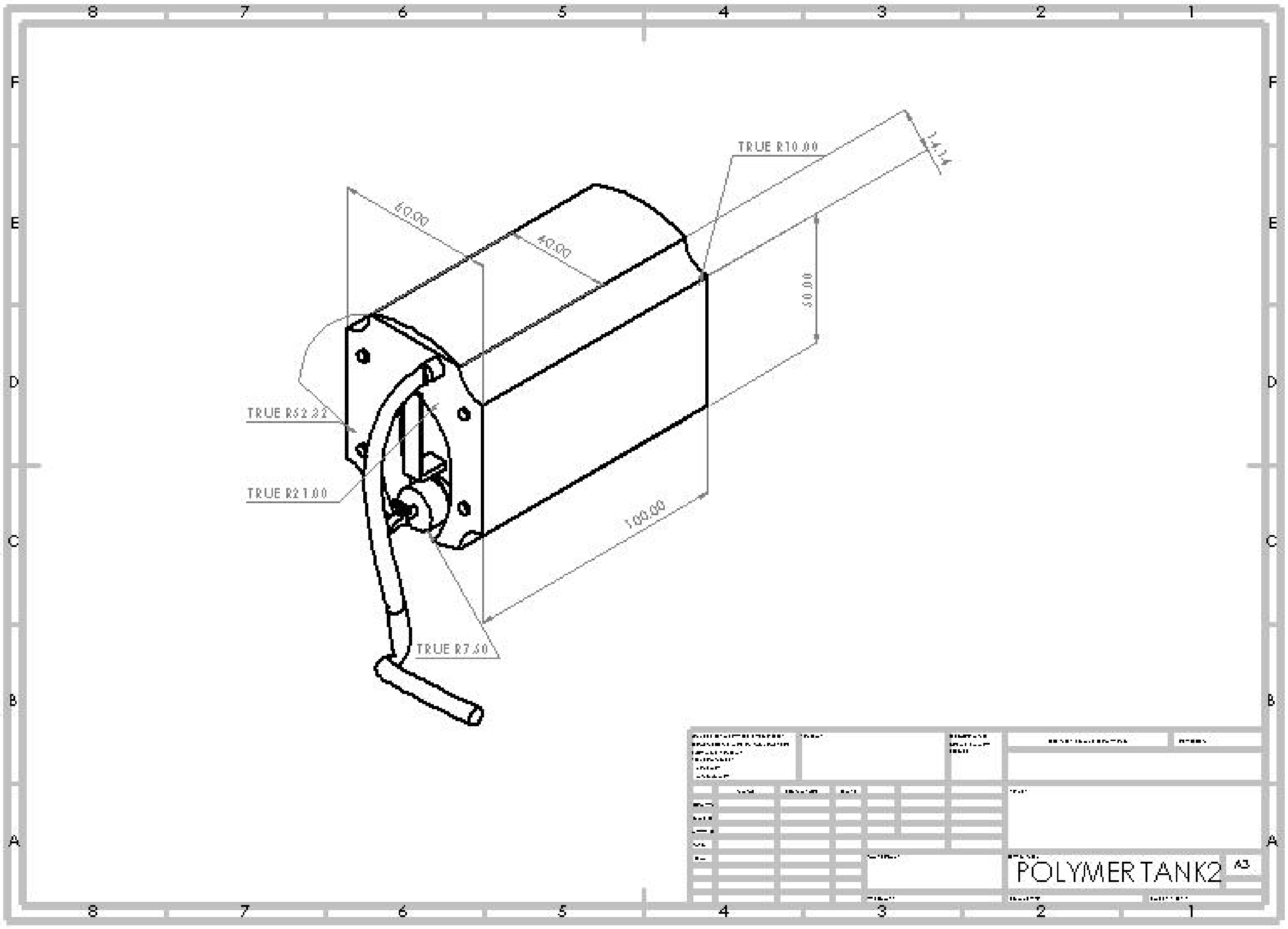
Appendix 1 Structural Frame Stand



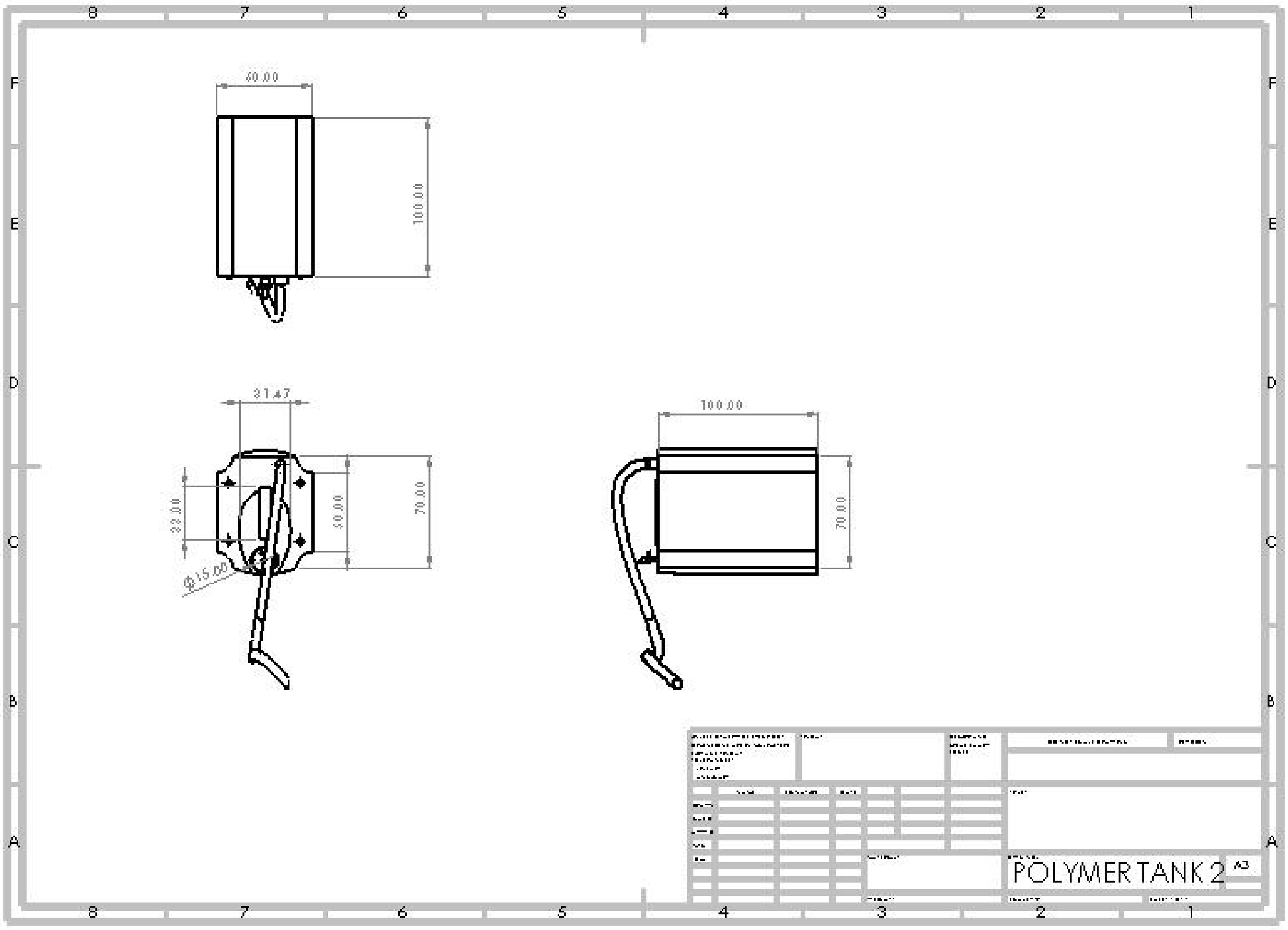
Appendix 2 Solar Collector Box



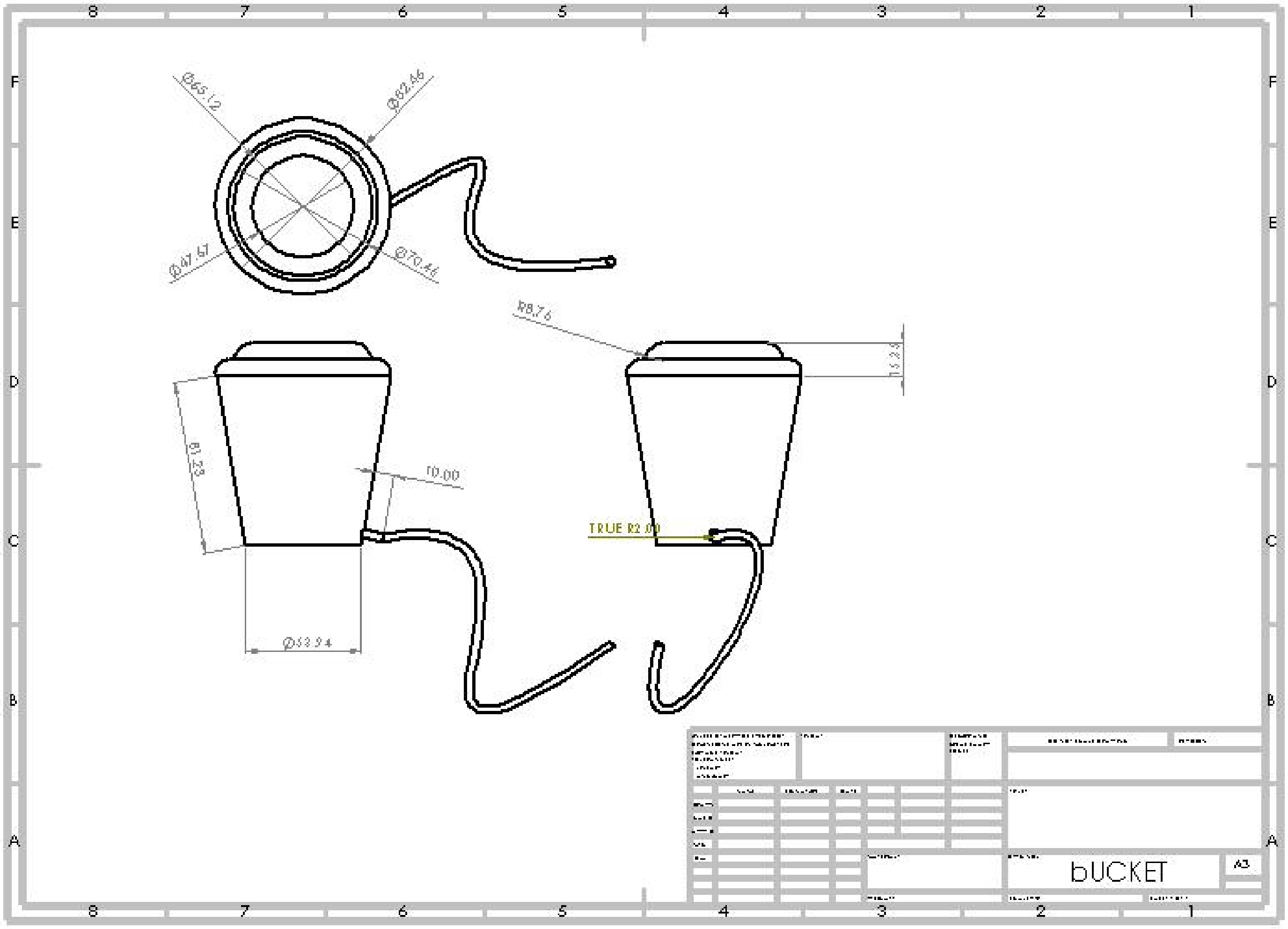
Appendix 3 Storage polymer tank


TRUE R10.00
14.14
60.00
40.00
50.00
TRUE R52.32
TRUE R21.00
100.00
TRUE R7.50
POLYMER TANK2
A3

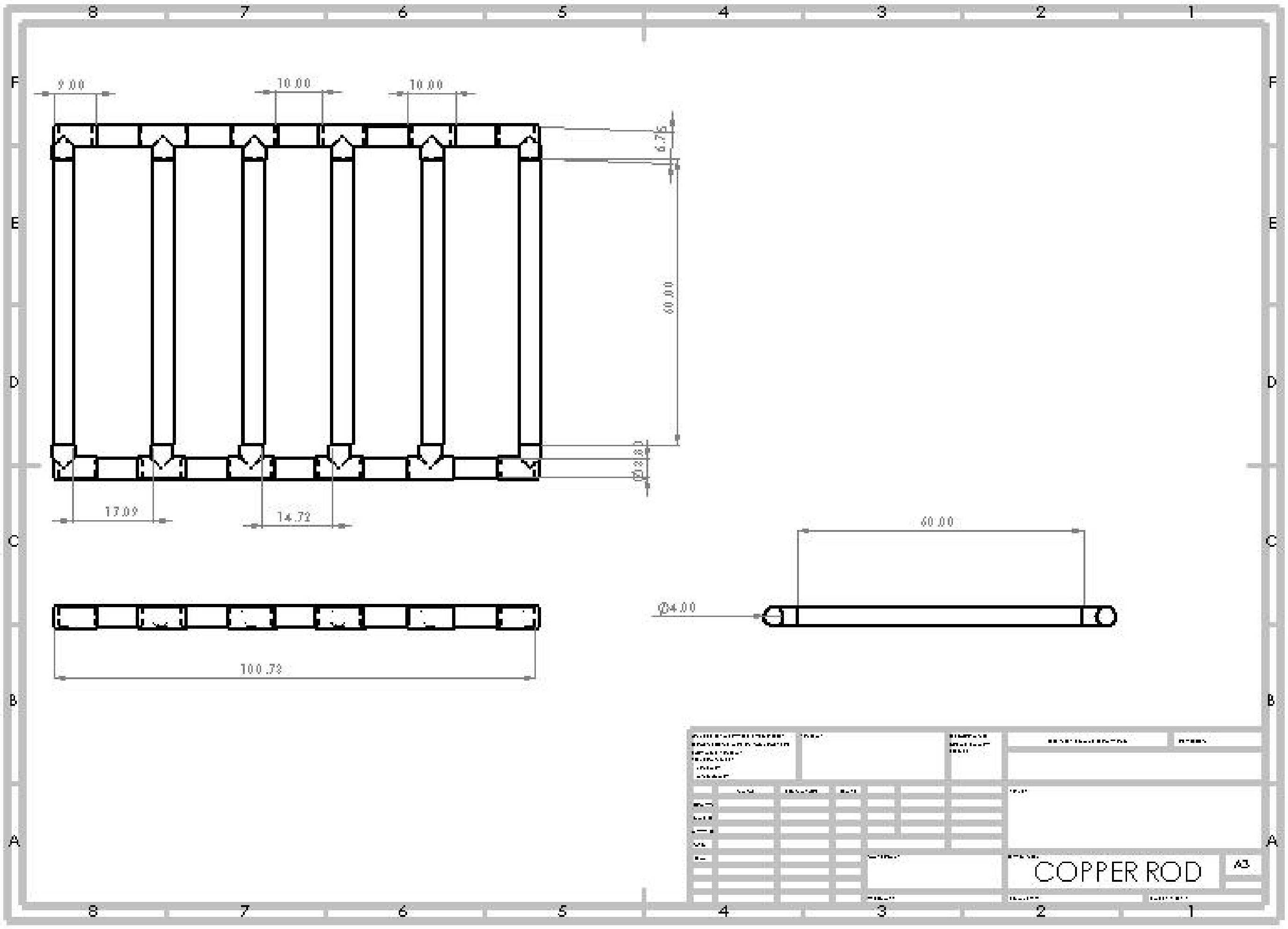
Appendix 4 Orthographic projection and isometric drawing of the storage polymer tank



Appendix 5 Orthographic projection and isometric drawing of Bucket



Appendix 6 Orthographic projection and isometric drawing of Copper Rods



Appendix 7 Orthographic projection and isometric drawing of Hydraulic Pump