DESIGN, MODIFICATION, AND PERFORMANCE STUDY OF A SERPENTINE TUBE SOLAR WATER COLLECTOR

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CANDIDATE'S DECLARATION

The is to certify that the work presented in this thesis, "***Design, modification and performance study of a serpentine tube solar water collector***", is the outcome of the investigation and research carried out as requirement for the award of degree B.Sc. in Technical Education (Mechanical Engineering) at the Islamic University of Technology (IUT), Gazipur, Dhaka, under the supervision of Dr. Md. Rezwanul Karim, Professor, MPE Department, IUT.

It is also declared that neither this thesis nor any part of it has been submitted elsewhere for the award of any Degree or Diploma.

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RECOMMENDATION OF THE BOARD OF EXAMINERS

The thesis tittle "***Design, modification, and performance study of a serpentine tube solar water collector***" submitted by Sheikh Sabally, Saidou Sallah, and FatoumattaJatta has been accepted as satisfactory in fulfillment of the requirement for the degree of B.Sc. in Technical Education (Mechanical Engineering) at the Islamic University of Technology (IUT).

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ABSTRACT

Interest in various renewable energy technologies has increased due to factors such as rising costs for conventional fuels, rising energy demand, concerns about climate change, and pollutants produced by burning fossil fuels. For various industries, air-conditioning has a substantial energy cost. Both residential and commercial water and air heating have been accomplished with the help of renewable energy. In this project, the design modification and performance study of a solar water collector, which uses thermal energy from solar radiation to heat water are presented. Design modification has been done with the collector. A double-glazing cover is placed at the top to reduce the heat loss. A two flank reflectors on both side occupying an area of 8.4 m² have been integrated to capture more radiation reflected to collector with the aim to improve system performance.

The amount of solar energy absorbed by the absorber, the amount of heat transferred to the heat transfer fluid (HTF), and the length of fluid residence time in the collectorall affect a flat plate solar water collector's (FPSWC) thermal performance. This real- time experimental study compares the modified serpentine channeled FPSWC's thermal efficiency to that of a traditional collector without reflectors. The project is a modification of the previously fabricated serpentine tube solar water collector.

After the design and modification, the serpentine tube solar water collector was tested to determine its performance. The setup exhibits a notable improvement in its thermal performance after more components were added. It shows the temperature rise of 23˚C, which reach a new maximum water temperature of 80 ˚C from 57 ˚C, which was the previous setup's temperature. Additionally, the thermal efficiency has been increased to 41% for the new setup. It is evident the design modification has improved the performance of a traditional serpentine tube solar water collector.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 Background study

The pressing need to address significant environmental issues and mitigate the negative effects of global warming resulting from the continued use of conventional fossil fuels is what is responsible for the scientific community's increased interest inrenewable energy. Domestic energy consumption is further increased by cooking and water heating, which leads to pollution. Only when diverse energy outputs have beenused by the abundant renewable energy source can the environmental quality degradation and energy demand be satisfied. Among all the renewable energy sources, solar energy is the best choice because it can be used to fully meet the world's rapidly expanding energy demand. The energy needed for applications such as cooking, refrigeration, drying agricultural products, industrial process heating, hot water and space heating, building thermal comfort, and solar desalination is greatlyincreased by solar thermal collectors **[2]**.

In a solar thermal collector, solar energy is converted to thermal energy. In both homes and factories, various kinds of solar collectors are used to capture solar radiation. Nowadays, a large number of solar thermal collectors are conventional. However, their thermal efficiency is low. Regular research is done to maximize the performance of solar thermal collectors. A solar collector with transparent glazing and the collector's frame enclosing the working fluid inside. An estimated two billion people worldwide lack access to clean water on a daily basis. Drinking water that is unsafe to drink because of bacteria and salinity is a serious global health risk.

Furthermore, the need to feed the world's growing population and the ensuing food scarcity necessitates the extension of agriculture into arid regions, or the greening ofdeserts. The need for coordinated national and international efforts to address this issue is amply demonstrated by the hunger in the sahara desert and other less well- known parts of the world. Approximately 40% of the earth's land area is made up ofarid and semi-arid zones, which are typified by high solar radiation levels and a dearthof freshwater. Brackish or saline water reservoirs are common in these areas and canbe treated appropriately to be used for irrigation as well as drinking **[3]**.

As conventional energy supplies are almost depleted, energy consumption is rising and the need for new technologies in the renewable energysector is growing. The ability of the sun to produce thermal energy, which can beused for a variety of purposes, including the production of electricity, is known assolar thermal energy. Utilizing the Sun's radiation, solar thermal energy generatesthermal energy. In a solar thermal collector, solar energy is converted to thermalenergy. In both homes and factories, various kinds of solar collectors are used to capture solar radiation. Nowadays, a large number of solar thermal collectors areconventional. However, their thermal efficiency is low. Regular research is done to maximize the performance of solar thermal collectors.

1.2 Solar Energy and Its Availability

The entire amount of energy required for human needs could be supplied directly by solar energy. The sun could provide all of the energy needed for the human population if it could only be extracted from 1% of the planet's surface. The amount of solar radiation that reaches the earth's surface is likewise far lower than that whichreaches the outer layers of the atmosphere.

When solar radiation enters the earth's outer atmosphere, between 25 and 50 percentof it is lost. A large portion of the energy emitted toward the earth is reflected and absorbed by greenhouse gases and water vapor **[5]**. The entire amount of energy required for human needs could be supplied directly by solar energy. The sun couldprovide all of the energy needed for the human population if it could only be extracted from 1% of the planet's surface. The amount of solar radiation that reachesthe earth's surface is likewise far lower than that which reaches the outer layers of the atmosphere. When solar radiation enters the earth's outer atmosphere, between 25 and 50 percent of it is lost. A large portion of the energy emitted toward the earthis reflected and absorbed by greenhouse gases and water vapor.

The time of year, geographic location, and weather all affect solar energy availability. The best places to produce solar energy are those that are closer to the equator because they typically receive more constant and intense sunlight. Yet, because of improvements in efficiency and energy storage options, solar technologies can also be advantageous in areas with less direct sunshine. Among themany advantages of solar energy are its ability to lower greenhouse gas emissions, lessen reliance on fossil fuels, and provide a decentralized power source that can improve energy security. Solar energy is becoming a more attractive and popular option for both residential and commercial energy needs as costs come down and technology advances.

1.3 Solar Energy Utilization

Since 1970, there has been a growing interest in using solar energy, mostly as a resultof the rising cost of energy from conventional sources. The world's most plentiful and sustainable energy source is solar radiation. Solar energy is evidently used in a wide range of applications, including:

- ❖ Heating industrial processes.
- ❖ Producing electricity through photovoltaic systems and solar thermal power plants.
- ❖ Heating greenhouses.
- ❖ Heating swimming pools
- ❖ Heating domestic hot water through evacuated-tube solar collectors, integral collector-storage systems, and flat-plate collectors. Heating and cooling of spaces.

1.4 Objectives of the study

- To design and modify a serpentine flat plate solar collector.
- To study the performance of the modified serpentine flat plate solar collector.
- To use a double-glazing cover to minimize heat loss from the serpentine flat plate solar collector and optimize the efficiency using reflector.

CHAPTER 2: LITERATURE REVIEW

2.1 Flat plate collector (FPC)

The primary component of all living things is water. It makes up almost 75 percent of the planet's surface and is home to millions of marine animals, including fish and other aquatic plants. The sun provides enormous amounts of solar energy to the earth's surface. Solar energy can be used directly or indirectly by transforming it into another form of energy, such as chemical, mechanical, electrical, or thermal energy [1]. Due to population growth, the amount of energy required for cooking in both rural and urban areas worldwide is rising daily. The use of fuels like firewood, fossil fuels, and other biomass products for cooking has contributed to global warming, necessitating the development of novel techniques that will raise people's standard of living [2]. It is imperative that the modified serpentine flat plate solar collector be designed, analyzed, and installed as soon as possible because its application in the current system will lessen the usage of finite conventional energy sources.

However, as long as there is life on Earth, renewable energy sources will persist and be infinite in quantity. The primary goal of a solar thermal collector is to absorb solar radiation in order to raise the fluid's temperature as it passes through the collector tube. This heat can then be used for a variety of purposes, such as heating water or a room during the winter. The goal of this article is to give a general overview of the different methods and advancements that the serpentine flat plate collector used to maximize solar radiation absorption and minimize losses to the surrounding [2].

The literature review highlights the significant impact of coating on material absorptivity as well as a deficiency in research on the effects of selective coating absorber plates on the efficiency of flat plate solar collectors. For this reason, the effects of using different absorber plate types—such as the black painted ones—on the thermal efficiency of flat plate collectors (FPCs) were examined in the current study. It should be mentioned that the high absorptivity at short wavelengths and low emissivity at long wavelengths of these coatings led to an enhancement of thermal energy collection [1, 2, 3]. It is also chosen because of its excellent accessibility, good thermal conductivity, and good optical qualities.

As far as we are aware, there hasn't been much research done on how black paint affects the flat-plat collector's (FPC) absorber plate. The ASHRAE Standard was used to evaluate the flat plate collector's (FPC) performance. Furthermore, a comparison was made between the thermal efficiency of flat plat collectors (FPC) with various coated absorber plates at different flow rates. The impact of various coatings on the values of the absorbed and removed energy parameters was presented, along with an explanation of each parameter. Since this research has never been done before, it is essential to take into account how the black paint affects the flat plate collector's thermal efficiency [3].

A serpentine duct is manually arranged in series with a flat- plate solar collector to provide a total exposed face area of 0.0084 m^2. The panel was electro anodized with matt black after the borders were welded using an arc welding process with a non-consumable tungsten electrode. The metal inert gas (MIG) welding process was used to solder the panel at four points in the space between the ducts.

The collector was housed in an aluminum case with low-iron glass glazing, and its copper connectors were handcrafted. The directional features can be significantly impacted by the roughness due to diffraction impacts. As a result of capturing light and preventing it from reflecting, the carbon coating has high absorption. As a result of capturing light and preventing it from reflecting, the carbon coating has high absorption. More light is trapped due to the higher porosity. Due to its accessibility, minimal environmental impact, and lack of impact on global warming, solar energy has garnered significant attention. This is according to Duffie JA, Beckman WA, Solar engineering of thermal processes, New York: Wiley; 2013. Solar systems known as flat-plate collectors (FPCs) collect solar radiation and convert it to working fluid. They are extensively employed in low- temperature applications, such as space heating and water heating production.

Water heating and space heating can be improved with the limited resources available to attain a highly desired result thanks to the abundance of solar radiation [4].

Maximum solar energy collection by the solar thermal collector and an improvement in the heat removal factor through appropriate component sizing and configuration are necessary for a solar collector to operate satisfactorily and dependably. This study uses a parametric analysis to ascertain how the collector design parameters— such as copper tube spacing, internal copper tune diameter, absorber plate thickness, insulation material, glass cover thickness, color coding, and collector tilt angle— affect the heat removal factor and solar energy received by the solar collector.

Over the past ten years, numerous investigations have been carried out to enhance heat transfer and thermal efficiency of flat plate collectors (FPCs). The techniques for augmenting the thermal performance of FPCs can be divided into two primary categories: (i) passive methods and (ii) active methods. There have been no outside forces employed in passive methods. Thus, it gets greater attention. Tabulators like wire coils, disks, and twisted tapes have been used in passive methods [1].

Additionally, a solar collector's performance is determined by numerous operational and design factors. Knowing the collector's "three governing parameters" makes evaluating its useful energy gain simple. These three parameters are the cover system's effective transmittance-absorptance product (ra), the total loss coefficient (UL), and the heat removal factor (FR). It is necessary to have some way of predicting these parameters so that the design engineer can choose his materials, dimensions, geometry, and operational variables to yield the most economical and/or efficient design. For a given set of operational variables, the governing parameters of the collector, i.e. FR, UL, and (za), can be determined experimentally [5].

Solar collectors are a unique type of device that increases the thermal effects of a transport medium by converting solar irradiance into internal energy. They take in, capture, and transform the incoming solar radiation into heat, which is then transferred to a fluid that passes through the collector. Domestic hot water demand was previously met by sources of energy other than solar power. On the other hand, household water heating expenses can be lowered by as much as 70% just with solar water heating. The most popular type of solar collector for industrial and residential use is the flat-plate type, which is also used for space and water heating.

The majority of flat plate solar collectors on the market right now are conventional flat plate solar collectors, or parallel tube types. They are pertinent to high flow rates that call for expensive operating expenses [4].

It is important to note that Solar thermal energy can be used to heat buildings using a variety of solar collector types, including evacuated tubes, parabolic troughs, and flat plate collectors. Flat plate collectors are the most widely used type for low temperature applications (323–343 K). Therefore, the focus of this review is primarily on serpentine flat plate collectors. Evacuated tube or parabolic trough collectors are also used when a higher working fluid outlet temperature is required, but their costs are higher and their payback periods are longer than those of flat plate collectors. Several creative studies have been conducted to improve the thermal performance of flat plate solar collectors by altering their fundamental design.

In order to achieve the promising results in thermal stability and performance, PCMs have been a committed motivator. PCM increases the operating hours and stabilizes the sporadic temperature fluctuations. There are three ways that a residential flat plate solar water heating system can be integrated with PCM: (a) beneath the absorber plate collector, (b) in line with the flow, or (c) in a different thermal energy storage device [6].

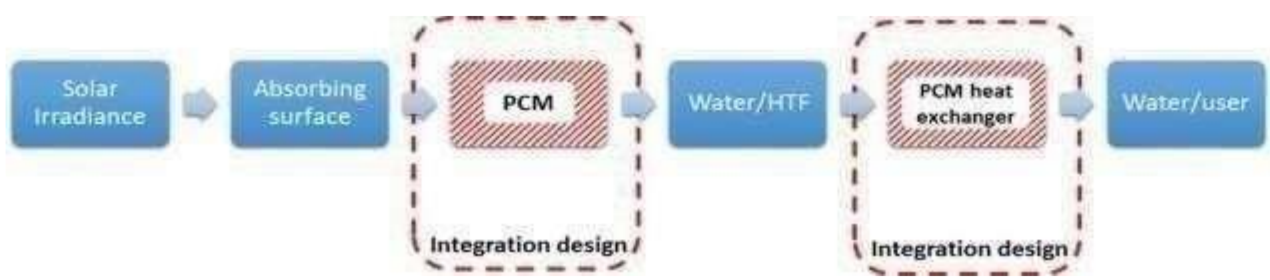

Figure 1. Energy flow direction in solar collectors.

2.2 Scopes of the study

There are basically two uses for solar energy. These are *solar thermal energy* used to heat buildings and water, and *photovoltaic energy* used to generate electricity. Our research focuses on solar thermal energy. Numerous studies have been conducted on this process, and the results have been overwhelmingly positive in terms of its ability to benefit the economy, the environment, and the potential to use the abundant and natural sunlight that is available worldwide. Among different types of solar thermal collectors available for water heating, serpentine tube collectors are cost efficient due to its less complex water heat exchanger part. However, there are limited studies on this type of water collectors compared to other types. Simple and low-cost heat transfer enhancement techniques may be applied to improve its performance for domestic uses. So, in the present work the design modification and performance study is undertaken.

2.3 Working principle of the solar thermal collector

Sunlight is used to heat water in a solar thermal water collector. This is an explanation of how it functions:

- ❖ **Solar Absorption:** When sunlight strikes the transparent cover of the collector,the majority of the radiation is able to pass through.
- ❖ **Capturing Heat:** The absorber plate traps solar energy as heat because it is coatedwith a particular material that maximizes absorption.
- ❖ **Serpentine Flow:** Within the absorber plate, water, the heat transfer fluid, moves through copper tubes arranged in a serpentine (or snake-like) pattern.
- ❖ **Heat Transfer:** The hot absorber plate's heat is absorbed by the water as it passes through the tubes.
- ❖ **Heat Delivery:** After leaving the collector, the heated water can be used for a

number of purposes, such as space heating or domestic hot water.

Essentially, in order to maximize heat transfer efficiency, the serpentine design makes sure that the water follows a lengthy path inside the hot absorber plate.

CHAPTER 3: DESCRIPTION OF THE SYSTEM

3.1 A serpentine tube flat plate solar collector's design

A trade-off analysis between efficiency, power requirement, desired operation temperature, array size, air ducting, and total air volume handled is necessary when designing flat plat solar collector systems for a given application. The following illustrations (Figure 2 and 3) shows the detailed design consideration for a flat plate solar collector: Foranalytical purposes, the design can be disassembled into its component parts. Finding potential materials and choosing components that best fit the specifications are crucial. Insulation, glazing, absorber coating, and absorber plate were the components that were removed for the evaluation.

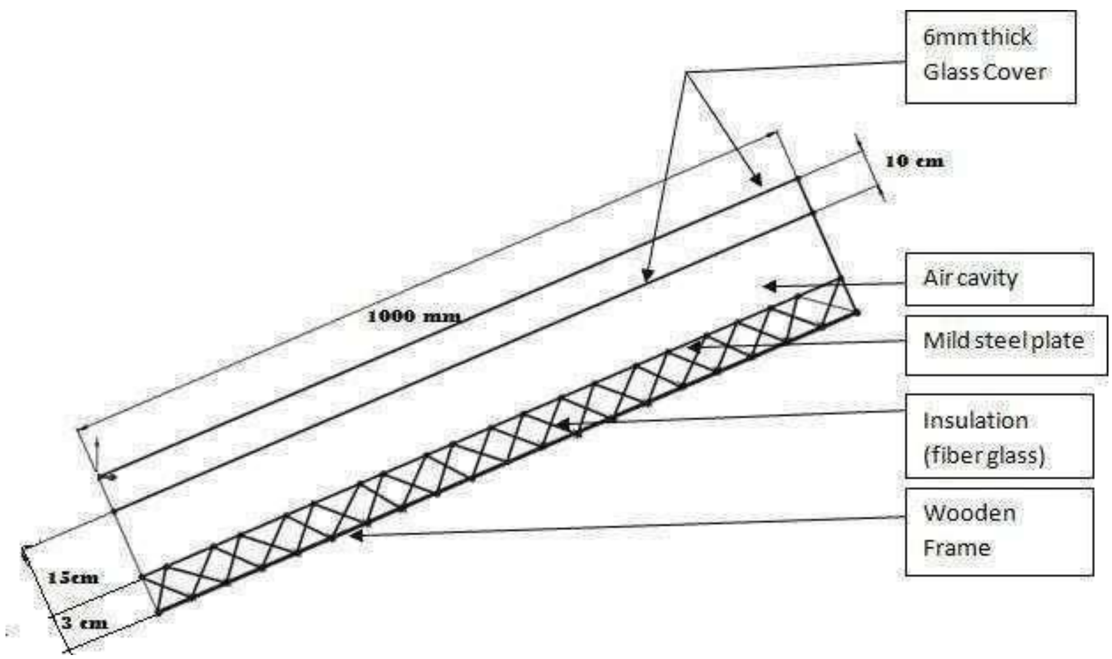

Figure 2. Design concept of flat plate solar collector

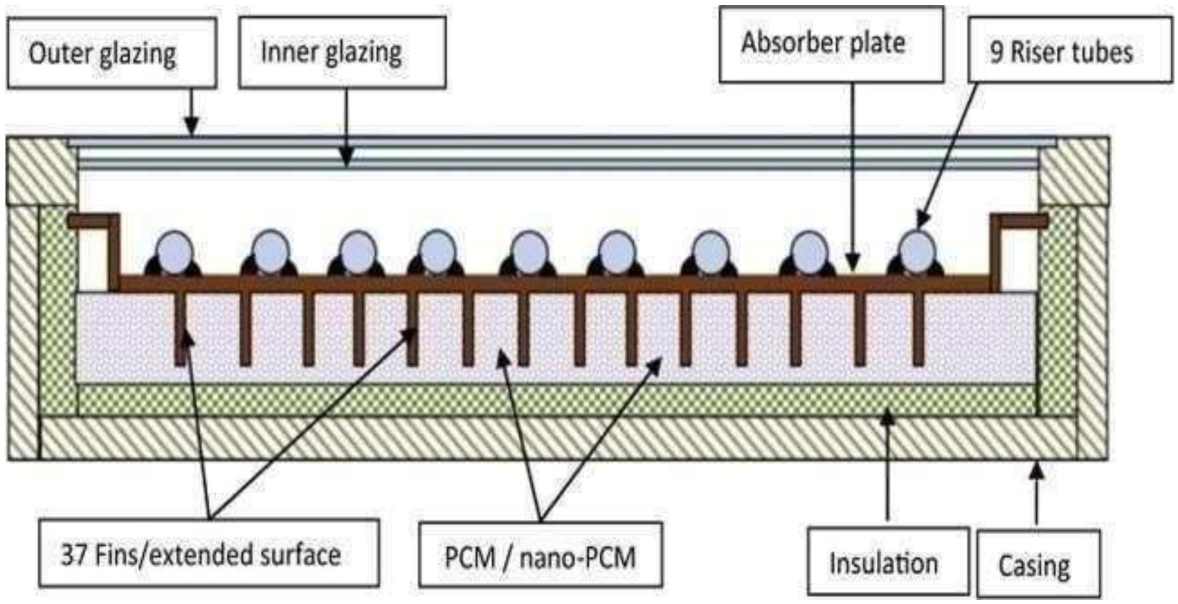

Figure 3. Schematic of solar collector coupled with PCM [6].

The top view of the serpentine flat plate collector is depicted in Figure 4. The system's housing is comprised of an outer frame made of plastic wood, measuring 25 cm in height, 70 cm in width, and 120 cm in length. An insulating fiber in the housing keeps heat from escaping the collector. The glass cover serves as a dust cover to keep foreign objects out of the casing, which could impede the heat transfer to the collector copper tubes. The mild steel plate acts as an absorber plate to absorb more heat from the sun radiation and this heat is transferred to the working fluid. The air cavity in the system is there to accumulate more heat in the system.

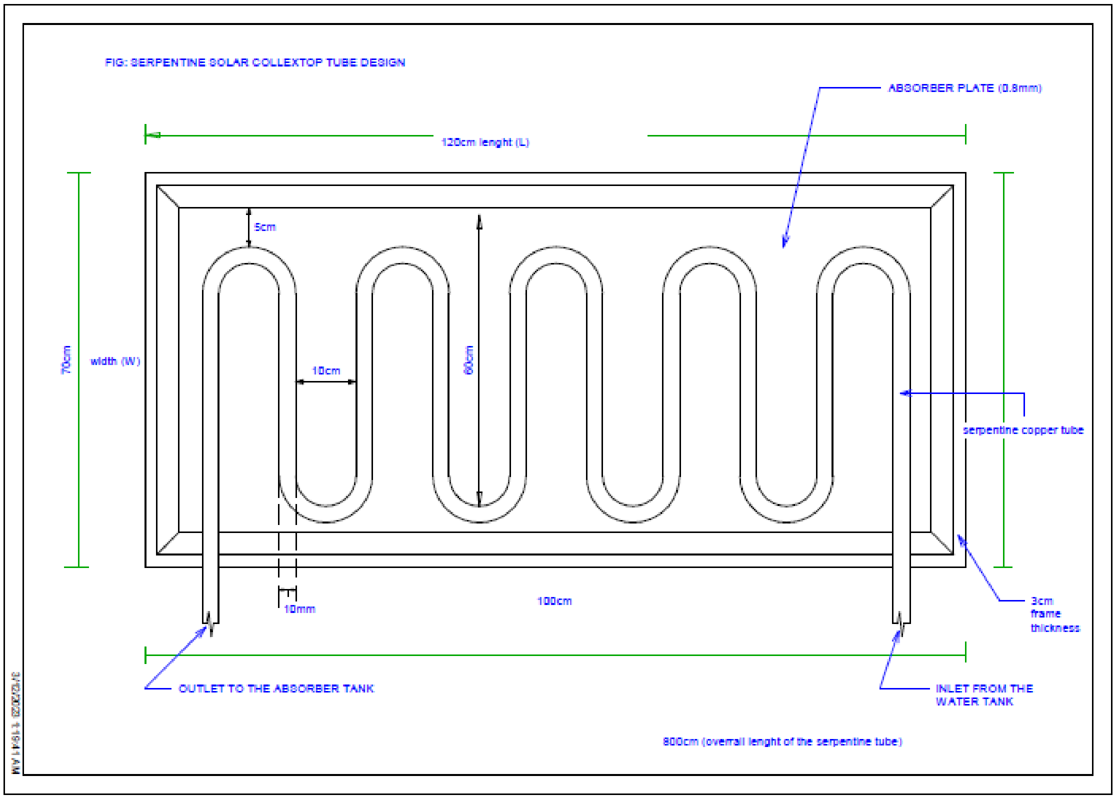

Figure 4. Design of the serpentine tube collector.

The solar collector depicted in Figure 4 is composed of a 10 mm serpentine copper tube with inlet and outlet ports. The plastic wood that acts as an insulator is encased in a 10 mm gap between the copper tubes. Heat loss into the atmosphere via conduction and convection is stopped by the plastic wood.

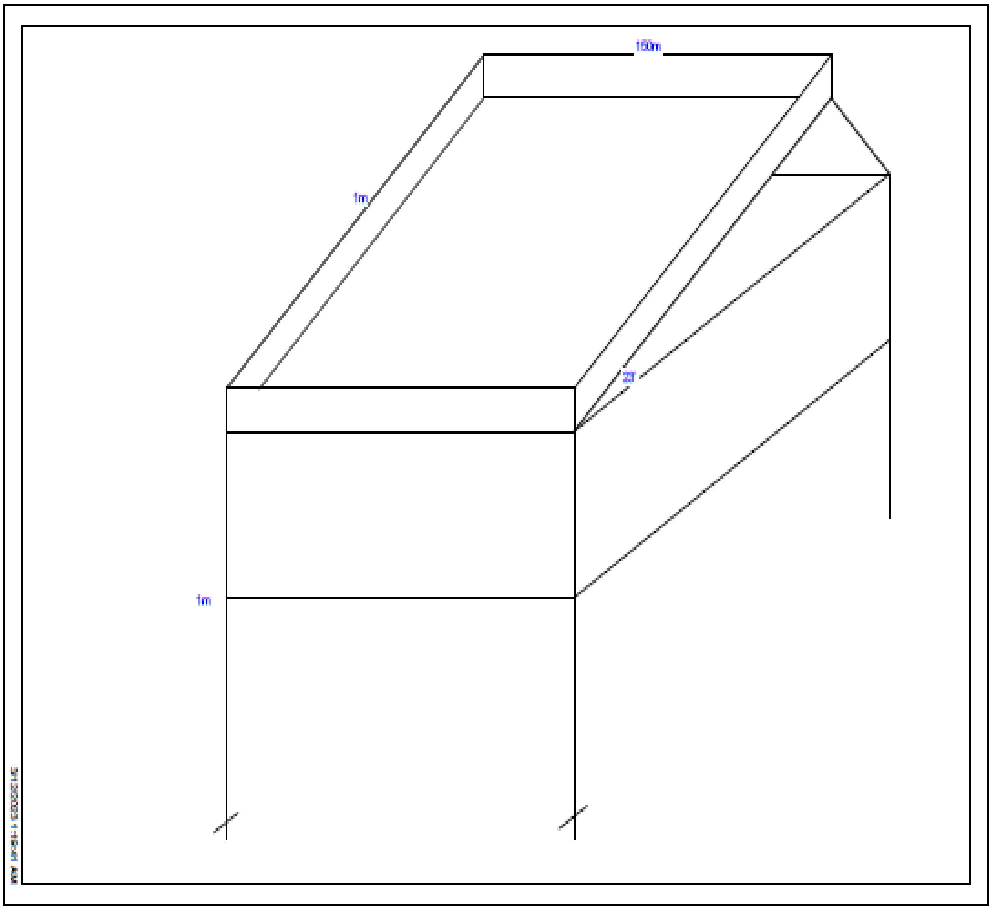

Figure 5. Serpentine tube solar collector collector stands

Figure 5 depicts the design of structure used as the stand for the collector. The flat and angle bars that make up the serpentine collector stand have a thickness of 3 mm and a combined weight of 40 kg. For correct support, it has four legs that are welded vertically at an angle to the base of the solar tube collector that is serpentine.

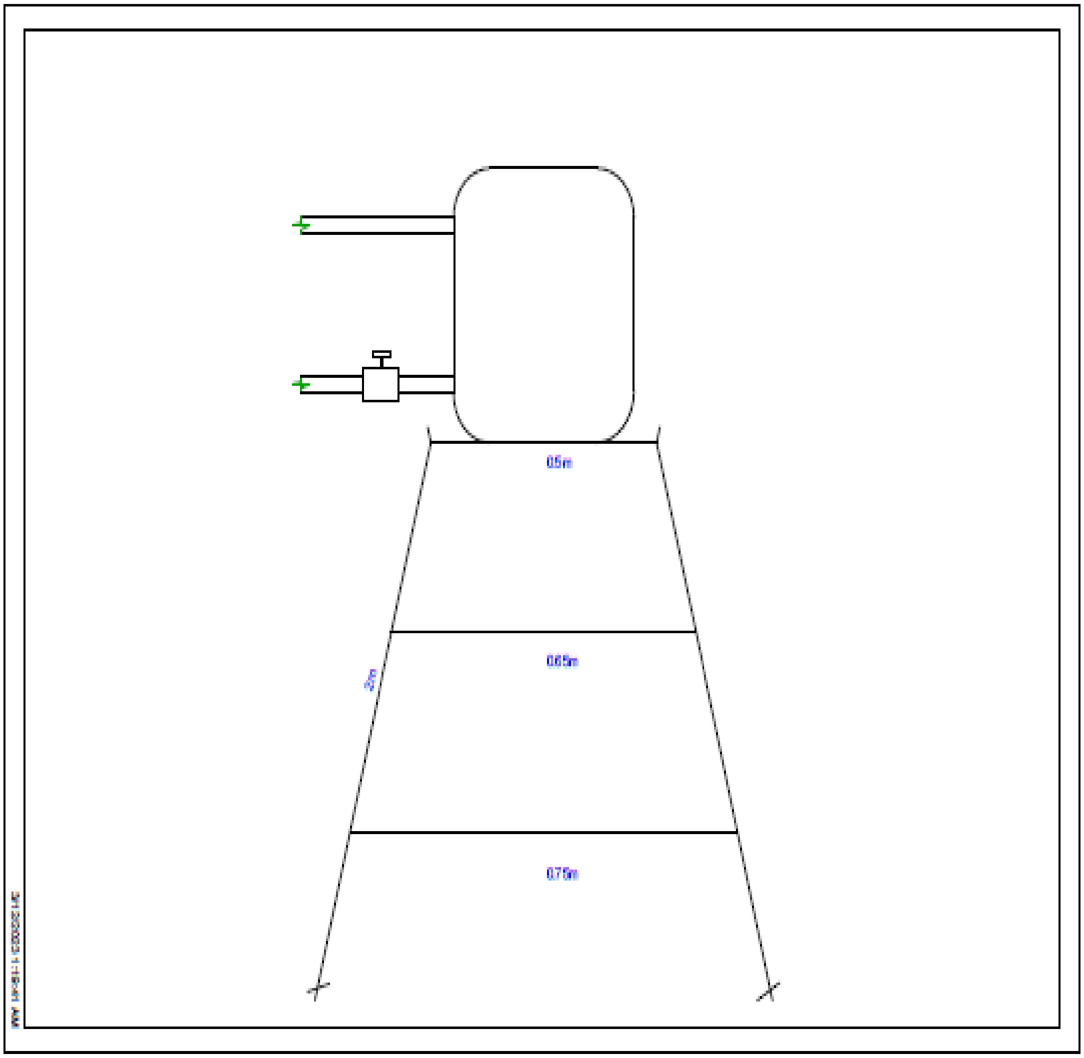

Figure 6. Water storage tank and stand

Figure 6 shows the water storage tank and stand. The storage tank has a capacity of 25 Liters and insulated for keeping the water warm.

3.2 Components of the serpentine setup

I. Absorber plate

The absorber plate's temperature rises in response to incident solar radiation. The working fluid receives this thermal energy. The operating temperature range, maximum stagnant temperature, operating flow rate, cost, and other factors are among the design requirements for the absorber plate that are taken into account. Thecomposition and characteristics of absorber plates have been extensively studied. Metals like copper, aluminum, and iron are the most frequently used materials for plates. Copper is the best material out of all of them because of its high corrosion resistance, specific heat of 0.385 J/g°C, and thermal conductivity of 398 W/m.K. Its melting and boiling points are, respectively, 1083°C and 2380°C. Generally, SSA materials are categorized as materials with good optical performance if they have absorptance values (α) greater than 90% in the solar wavelength range (0.3–2.5 mm)and thermal emittance values (ε) less than 10% in the mid/far-infrared wave-length ranges (42.5 mm) [4].

II. Absorber coating

For the absorber plate to absorb as much solar energy as possible, a surface coating— typically mat black—is applied. It should be the case that the coating has the highestabsorption capacity and lowest emission rate. Maximum solar radiation absorption is achieved by an ordinary blackened surface, but it also exhibits high emittance. It cannot, therefore, be used in applications that require high temperatures. Selective coating is used for absorber coating in solar water collectors to achieve efficiency.

The surfaces of optical components are frequently coated with black anodized coatings, such as zinc-plate with black passivate, because of their comparatively strong absorption characteristics in the UV and visible wavelength regions **[5]**.

III. Double Glazing

Reducing the amount of heat lost from the collector plate as a result of radiation and convection is the main purpose of the cover plate or glazing. Before the setup was changed, a single glazing surface was utilized. It has been demonstrated time and time again that doubling the glazing area will significantly reduce heat losses through radiation and convection. Spacing between the two glazing is essential to achieving the desired insulation effect. Usually, the maximum distance ranges from 15mm - 50mm. It is also called an **"Air gap"** The following qualities must be present in thecover plate:

a) High transmittance (low refraction) for visible solar radiation range.

b) Low transmittance at high refraction thermal radiation ranges.

c) Low absorption across the entire wave length.

d) Outstanding resilience and weather ability.

A cover plate can be made from a variety of transparent materials. Glass is used more often than any other material, including plastic. Despite being extremely fragile, it can withstand most chemicals and alkalis. In the visible portion, it has a consistent transmittance of 90%, an absorptance of 6%, and in the infra-red range, it is nearly opaque.

IV. Insulation

Insulation is a crucial component that helps to minimize heat losses from thecollector plate's lower surface as well as its lateral edges. The thickness and thermalconductivity of the insulating material determine heat losses in the event that insulation is present. In a collector, low thermal conductivity, hydro-phobicity, andthe ability to withstand repeated thermal cycling up to 150 degrees Celsius as well as high temperatures of about 200 degrees Celsius are all desirable design requirements for an insulating material. This can be accomplished with glass wool or rock wool.

V. Bottom Side Frame

Plastic wood is typically used for the body of flat plate solar collectors because it ismore cost-effective than aluminum and can withstand variations in temperature. It isalso used in research projects.

VI. Water storage tank

There are thirty liters of water in the storage tank. The hot water is kept hotter longer by using a plastic drum with thick insulation around the tank externally. This keeps the heat from escaping the water and from escaping the environment.

VII. Steel frame and stand

Steel supports are built for the storage tank and collectors. The frames and the flat that served as the setting basin were built from 40mm square steel angles.

VIII. Copper tube

Science finds copper to be an appealing material due to a number of its properties. Among these is the high heat conductivity of it. This characteristic has made coppera crucial part of solar water heaters.

Copper makes up the tube that joins the building's water storage and distribution system to the collector. When the water inside the collector is exposed to sunlight, the copper lining absorbs the heat and transfers it to the water, heating it in the process.

As the sun's intensity varies throughout the day, the circulating pump modifies itsspeed accordingly. One of the best metals for heat conductivity is thought to becopper. The other end will heat up if you heat one because it is such an excellentheat conductor.

IX. Reflector Surfaces

Stainless steel sheet (ss sheet) and fiber glass are used to make the reflectors. It measures 120 cm in length and 70 cm in width, with an overall area of 8.4 m^2. This region reflects the region of the serpentine arrangement. This is done to guarantee

that all of the reflectors' surfaces fall on the setup and that the sun's rays are reflected as much as possible. The stainless-steel sheet is adhered to the fiber glass surface with glue and fastened with screw pins.

The highly desirable characteristic of these alloys, which also gives them the moniker "stainless," is their extremely slow rate of corrosion in the majority of ordinary atmospheres. These alloys have almost no oxidation rate in room temperature air after a very quick initial oxidation. After many years of regular use, they still have a shiny appearance, which makes them appealing to many consumers. An iron alloy that has more than 11% but less than 30% chromium is typically referred to as stainless steel. The term "stainless steel" refers to a wide range of standard compositions as well as variants sold under brand names by companies and unique alloys designed for specific uses. The composition of stain-less steel ranges from a relatively basic iron alloy with 11% chromium to complex alloys with 30% chromium, significant amounts of nickel, and six other useful elements. This class of steels is stainless due to the presence of chromium, regardless of the alloy's overall composition [7].

This keeps the sheet from separating from the fiber glass in the event of excessive sun exposure. The reflectors are positioned at a 57-degree angle to the ground and the tilted angle of the Bangladesh latitude based on the calculations that were done. The following justifications for using the SS sheet:

- **High reflectivity:** This is the most critical property. You'll want a sheet with a mirror finish, achieved through a high degree of polishing and buffing. This finish maximizes light reflection.
- **Surface smoothness:** A smooth surface with minimal imperfections is essential for optimal reflection. Scratches or defects will scatter light andreduce reflectivity.
- **Corrosion resistance:** Standard stainless-steel grades offer good corrosion resistance due to their chromium content. This is important to maintain a reflective surface over time, especially in outdoor environments.
- **Grade selection:** Some stainless-steel grades, like 304 or 316, are popular choices for reflectors due to their good balance of reflectivity, corrosion resistance, and cost.
- **Formability:** Depending on the application, the sheet's formability might be relevant. If the reflector needs to be bent or shaped, a more ductile stainless- steel grade might be preferred.

Note that it has been acknowledged since the inception of stainless steels that the chromium oxide **(Cr_2 0_3)** layer that forms on the surface is what gives stainless steels their characteristic. This thick, persistent layer of oxide stops the underlying alloy from further oxidizing. If this layer's integrity is maintained, the alloy won't oxidize or corrode any more [7].

Table 1 shows the dimensions of the collector.

Table 1. The technical specification of flat plat solar collector.

Parameter (units)	**Symbol**	**Dimensions**
Collector Length (cm)	L	120
Collector Breadth (cm)	b	70
Collector Area (m^2)	A_c	8.4
Absorber Thickness (mm)	t	1.00
Hydraulic tube diameter (mm)	d_h	10
Tube spacing (mm)	w	10
Tube width (mm)	d	10
Length of one serpentine segment (mm)	L	70
Reflector Area (m^2)	A_r	120

Figure 7. Materials used for the collector

The materials listed above were the noteworthy ones that were employed to construct theproject. Among them are matt black paint, glass cover, insulator, and plastic wood. Together, these resources achieve the project blueprint's standard. Table 2 listed the auxiliary parts needed to build the serpentine flat platecollector.

Table 2. List of components to build the serpentine flat platecollector

No.	Components	Quantity
1	Water tank 25 liter	1 piece
2	8 watts DC pump	1 piece
3	Serpentine copper tube (½ inches)	35ft
4	MS sheet plate (8” by 4”)	1 sheet
5	Plastic wood (8ft by 4ft)	2 sheets
6	Double plane glass (8” by 4”)	2 sheets
7	MS angle (1.5” by 1.5”) 3mm 40kg	121ft (40kg)
8	MS Flat bar 1inch (3mm) 40kg	29ft (40kg)
9	Hose pipe (plastic/nylon)	28ft
10	Gate valve 1inch (2.5mm)	1 piece
11	Glass tube thermometer	2 pieces
12	Copper tube U-bend	10 pieces
13	Silicon gum/glue	3 bottles
14	G.I clamp/ S.S clamp	12 nuts
16	Silver brazing stick (rod)	25 sticks
17	Insulation materials	Available at the lab
18	Reflectors (S.S sheet material)	2 pieces
19	Reflector support & hooks	2 pieces

3.3. Phases of the project construction and modification

First phase:

<u>*Cutting and assembling phase:*</u> This stage entails cutting the plastic wood, taking the necessary measurements, and smoothly finishing the material that has been cut. It also entails assembling different plastic woods that have been cut to create a special element. Figure 8 shows the activity of the first phase.

Figure 8. The cutting & assembling of phase.

Second phase:

<u>*Installation & polishing phase:*</u> This entails installing the reflectors, painting the interior of the serpentine setup with matt black paint, and smoothing the reflectors' surfaces to give them a high level of reflectivity as shown in Figure 9.

Figure 9. The installation and polishing phase

3.4 Design modification of the new setup of serpentine tube solar collector

Figure 10 illustrates the modified model of the serpentine tube water collector with double glazing and reflectors. The collector is placed on a steel frame and the reservoir water tank is placed at a height in another steel stand. The appropriate piping are used for circulation of water through the system.

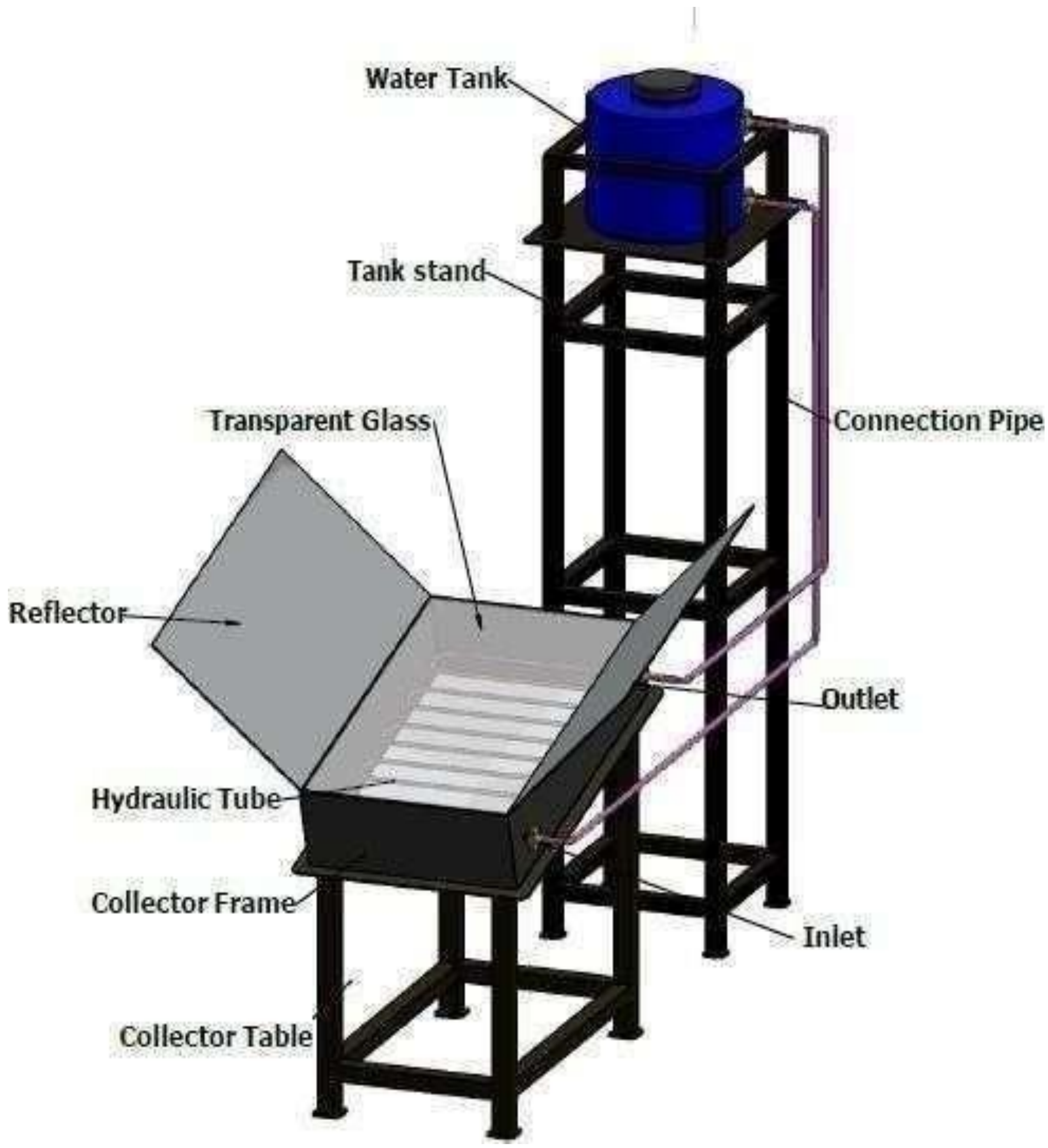

Figure 10. Modified design of the serpentine tube water collector.

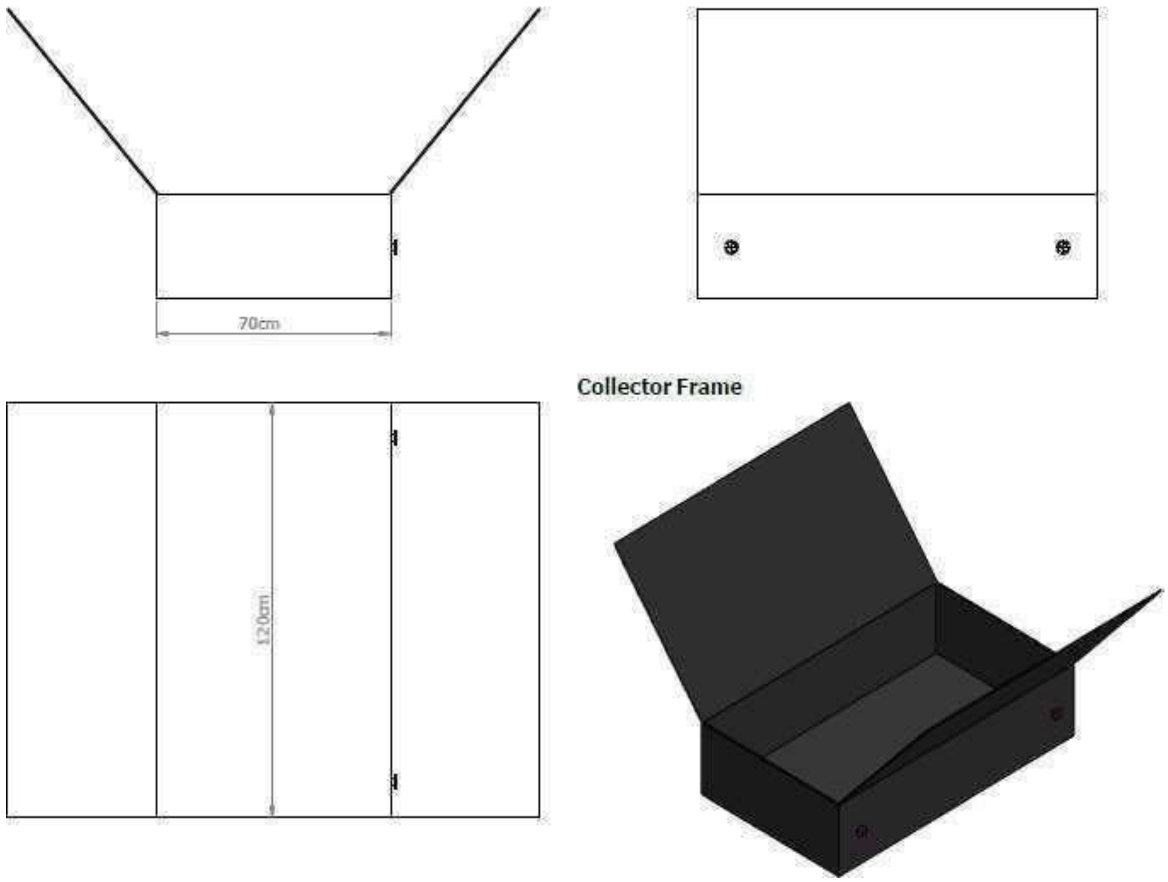

Figure 11. Collector Frame

The modified collector frame with reflectors integrated and flanked on both sides of the serpentine's length is shown in the figure. Its dimensions are 120 cm by 70 cm, which match those of the collector's base. The reflector is composed of a 0.4 mm thick SS sheet that is integrated into the 120 cm by 70 cm plastic wood surface (Figure 11). To reflect more radiation onto the glazing surface, the reflector is composed of shiny surfaces.

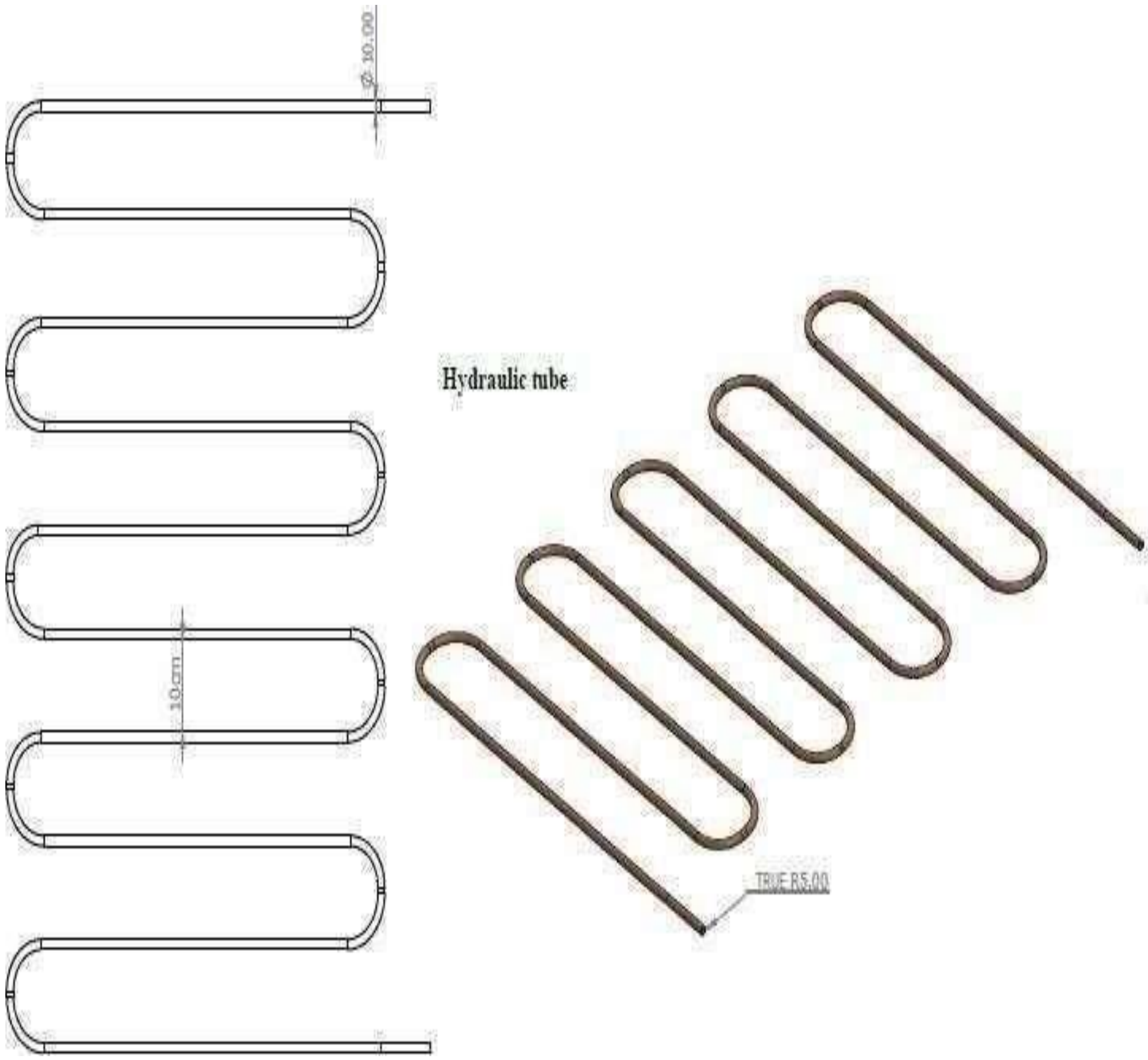

Figure 12. Serpentine Water Tube

Copper is used in the construction of the hydraulic tube because of its high conductivity. Its shape is serpentine, allowing the water to take longer to absorb the copper's heat as it passes through as shown in Figure 12. The tubes are made in a curved shape as a result.

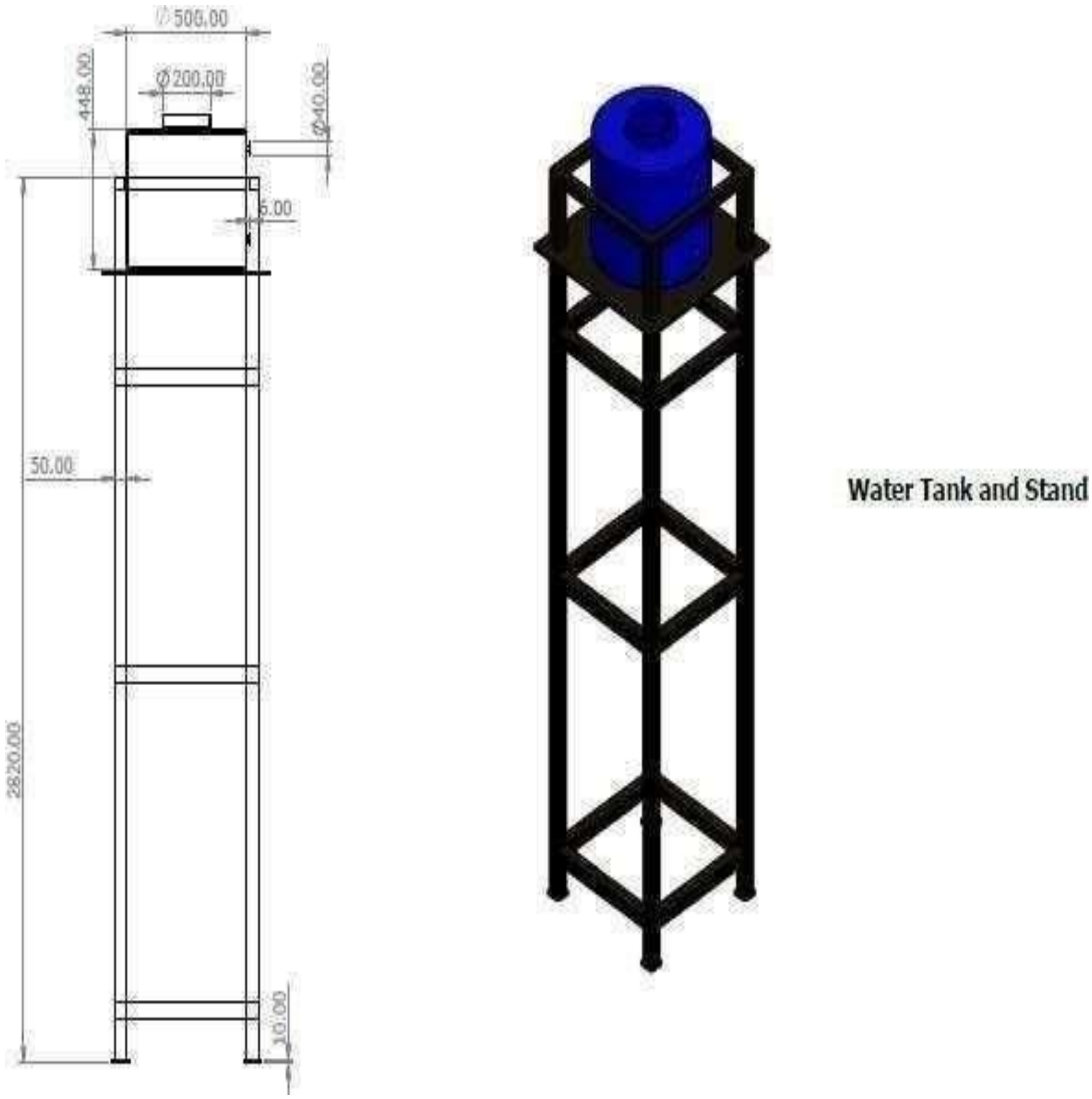

Figure 13. Water Tank and Stand

Four angle bars are welded vertically to the base of the water tank to form the collector water tank as illustrated in Figure 13. The water tank is better off hanging above the serpentine arrangement. This is done in order to raise the pressure when the water enters the copper tube and forms the serpentine configuration.

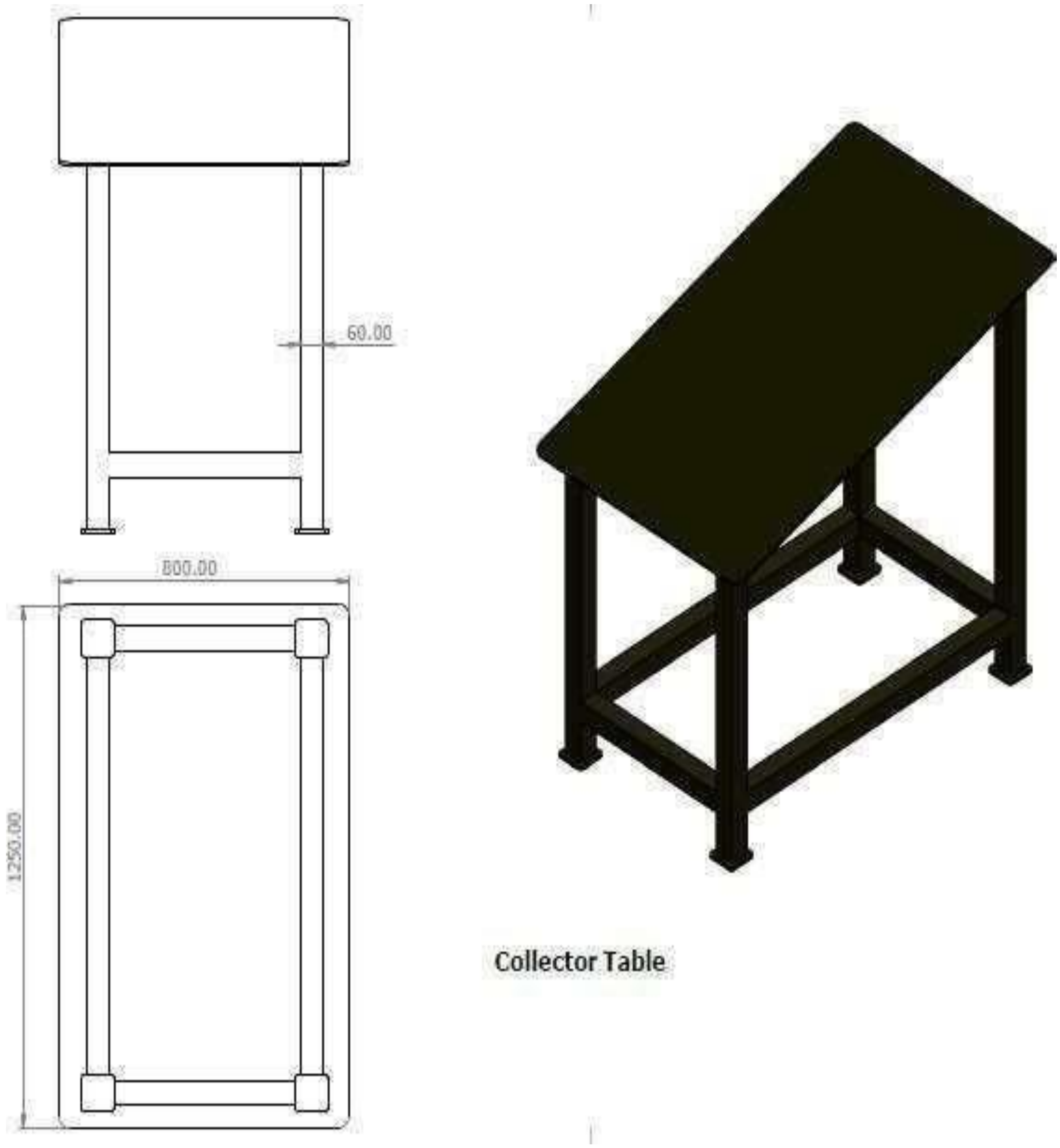

Figure 14. Collector Stands

3.5. Fabrication of serpentine tube solar collector

In accordance with the design, a serpentine tube solar collector was built in IUT Workshop, later it has been modified, and a performance analysis was done. Thecollector setup at the IUT Campus is depicted in Figure 15.

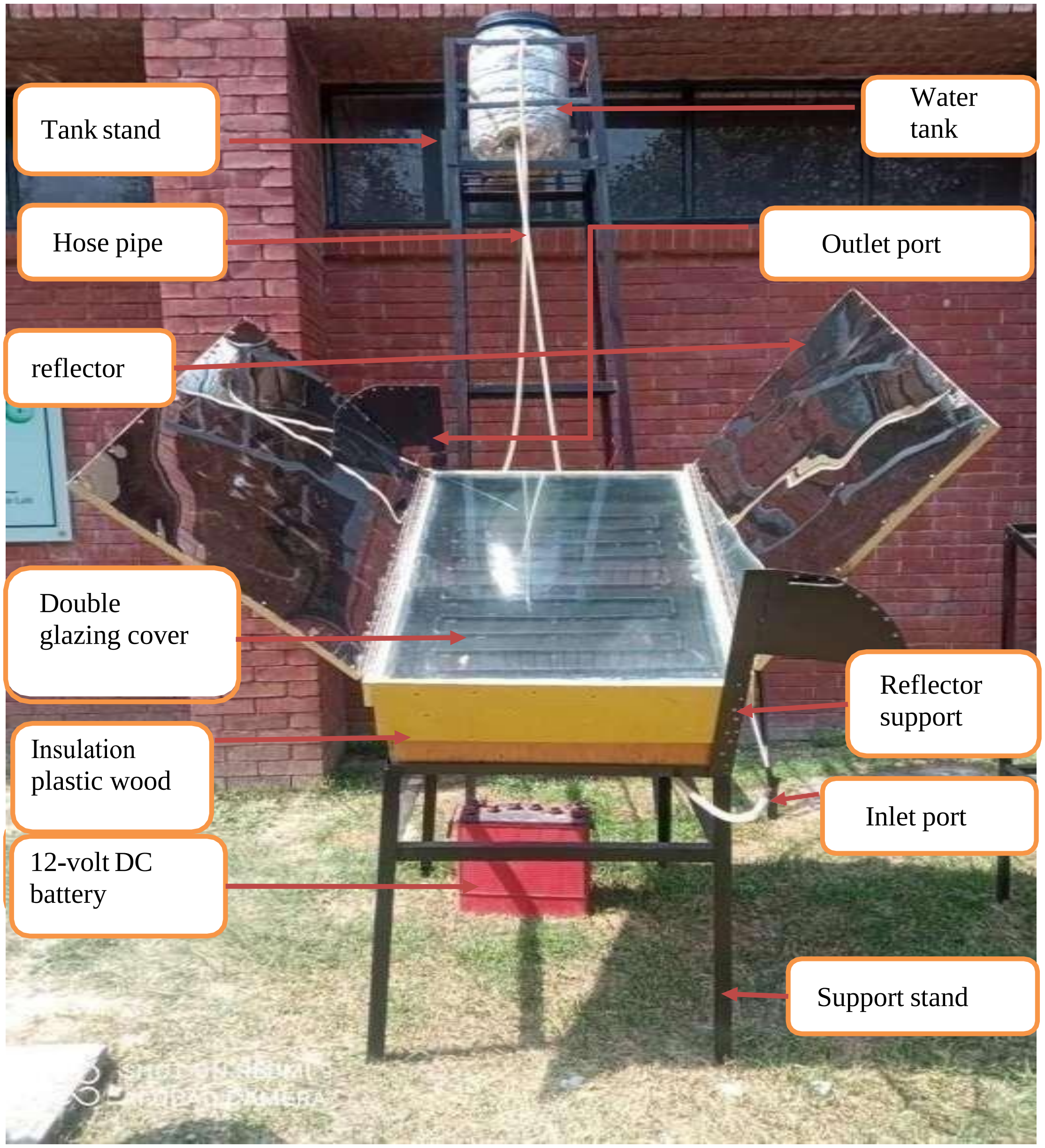

Figure 15. A modified serpentine tube solar collector build at IUT Lab

Figure 16. Samples of various readings taken in the serpentine setup

Figure 17. Irradiation data collection on the modified serpentine tube setup

Figure 18. Data collection on the modified setup

CHAPTER 4: METHODOGY

4.1 Experimental Procedure

In order to test the system, inlet and outlet pipes—also known as water pipes— were used to link the collector and the water storage tank. In order to help pump water into the setup through the inlet port. An 8-watt submersible water pump was connected to a 12-volt battery to provide electricity to activate the submersible pump inside the tank. The submersible pump is in charge of the system's water circulation. The collector's inlet and outlet were fitted with a glass tube thermometer to measure the water's temperature as it entered and exited the collector.

In the course of our investigation, we did, however, develop a plan for adding and installing an additional water tank to the arrangement. This occurs to us along the way because, after passing through the serpentine tube, the hot water is returned to the tank that supplies the setup with tap water; there isn't another reservoir in which it could be kept.

Having said that, we continue working on the design of the solar thermal collector, which is what gives the system the desired amount of heat. Heat from the sun's radiation is captured by the solar thermal collector and directed onto the absorber plate's surface, which warms the copper tubes further. A submersible pump located in the water storage tank then transfers the heat to the water flowing through the collector. Additionally, two 120-cm-long reflectors were mounted on the corners of the opposing lengths of the serpentine configuration. Plastic wood and 0.4mm thick stainless steel (SS) sheet were used to make the reflectors [8].

The reflector's area measured 8.4 cm square, with a length of 120 cm and a width of 70 cm. Using glue and a screw to securely fasten the SS sheet to the plastic wood screw, the sheet was adhered to the surface. The necessary reading that we had to take was measured using specific measuring tools. The ambient temperature was measured using a laser thermometer. The pyranometer, which measures solar radiation, was another measurement tool used. This was accomplished by positioning the instrument's head over the double-glazing surface, which finally provided the reading in the form of digital digits. It is important at this point in time to point out that the SS sheet was specifically used as reflector for a variety of reasons.

- ❖ **Corrosion resistance:** This differentiates stainless steel apart from other common metals such as copper or aluminum. This is particularly crucial for solar thermal projects because they are frequently left outside in inclement weather for extended periods of time. Stainless steel is resistant to pitting and rust, which over time can deteriorate the reflective surface and lower performance.

- ❖ **High reflectivity:** Stainless steel can efficiently reflect sunlight back towards the absorber plate due to its inherent high reflectivity for solar wavelengths. To maximize the quantity of solar energy that the system captures, this is essential. Depending on the grade and surface finish of the stainless steel, the specific reflectivity can range from 80% to more forcarefully chosen types [9].

- ❖ **Durability:** Stainless steel is an extremely robust and weather-resistantmaterial. It is impervious to elements that can harm solar collectors, such as wind,snow, hail, and high temperatures.

- **Formability:** The ability to easily shape stainless steel sheets into various shapes is crucial for producing the curved surfaces required to direct sunlightonto the absorber plate.
- **Weldability:** A wide range of SS grades are capable of welding,enabling the creation of intricate collector designs. Further information about the characteristics of SS sheets used in solar thermal reflectors are provided below:
- **Grade:** 304 and 316 are the most often utilized stainless steel grades forsolar thermal reflectors. These grades provide an excellent mix of affordability, reflectivity, and resistance to corrosion.
- **Finished surface:** The SS sheet's reflectivity may also be impacted by its surface polish. The highest reflectivity will be found in a polished, smoothfinish. On the other hand, light scattering can occasionally be enhanced andglare can be decreased by using an etched or roughened finish.
- **Thickness:** The particular application will determine the SS sheet's thickness. Although, thicker sheets will last longer, they will cost more. Typically, the thickness of most solar thermal reflectors ranges from 0.5 to 1.0 mm. In general, SS sheets have a good mix of qualities that make them ideal for use in solar thermal projects as reflectors. Solar collectors' longevity, ability to withstand corrosion, and high reflectivity all contribute to their long-term, effective operation.

4.2 Governing Equations and Sample Calculations

The equation below can be used to calculate the amount of heat absorbed by the collector

<u>Heat Absorbed:</u>

$Q_a = m\, C_p\, (T_2 - T_1)$ .... (1)

Where, C_p = specific heat capacity (J/kg.K)

m= mass flowrate (kg/s), T_1= inlet temperature (°C), T_2 =Outlet temperature (°C)

<u>Thermal Efficiency:</u>

The solar collector efficiency represents the ratio of the heat absorbed by the solar receiver Q_a and the incident solar radiation I, normal on the collector's aperture of area A_a.

$\eta = Q_a / I = m\, C_p\, (T_2 - T_1) / GA_c$ .... (2)

Where, G = Solar radiation on the collector (W/m^2), A_c=Area of the collector (m^2)

<u>Sample calculation:</u>

(i) *<u>Heat Absorbed:</u>* $Q_a = m\, C_p\, (T_2 - T_1)$

Volume flow rate = 25 lit/ 60 sec = 4.1667×10^{-4} lit/sec

Area of pipe = π/4d²

d = ½ inch = 0.0127m

$A = \pi/4 \times (0.0127)^2 = 1.2668 \times 10^{-4}$ m^2

Velocity, V= Volume flow rate/Area,

$V = 4.1667 \times 10^{-4} / 1.2668 \times 10^{-4} = 3.289$ m/s

Mass flow rate, $m = \rho A V$

ρ= 1000 kg/m^3

$A = 1.2668 \times 10^{-4}$ m^2

m = 0.4167 kg/s

Now, the heat absorbed by the collector (Q_a),

$Q_a = m\,C_p\,(T_2 - T_1)$, where Cp (specific heat capacity of water) = 4186 J/kg.K

$Q_a = 0.4167 \times 4186 \times (47\text{-}40)$ {Temp diff. between inlet and oulet of water at a time}

Q_a = 12210.1434 watts

(ii) Solar irradiation: $I = GA_c$

Incoming the solar radiation,

$I = GA_c$

G = 350 watts/m^2 (hourly)

A= (0.7m × 1.2m) = 0.84 m^2

I = (350 watts/m^2 x 0.84 m^2) = 294 watts

(iii) Thermal Efficiency: $\eta = Q_a / I$

Therefore, Efficiency η = (12210.1434 / 294)

= **41. 53%** (hourly)

4.3 Calculation for the tilt angle

To calculate the tilt angle of the reflecting surface following assumptions are made:

Sun at zenith. So zenith angle, $\theta_z = 0°$, Reflector angle, α2 = Constant = 0°

Tilt angle, β = Latitude - 15° = 23.45 - 15° = 8.45°

$G_{total.\ Collector} = G_{Direct\ .\ Collector} + G_{reflector\ 1+2} + G_{Diffused\ collector}$

Or, $G_1 = G_D + G_{r1} + G_{r2} + G_d$ ………………………………………………………..... (3)

Now, $G_D = G_{incident\ total} \times \sin(\alpha + \beta)$

$$G_{incident\ total} = \frac{24 \times 3600 G_{sc}}{\pi}\left(1 + 0.033 \cos\frac{360n}{365}\right) \times \left(\cos\phi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta\right)$$

……………………………..……… (4)

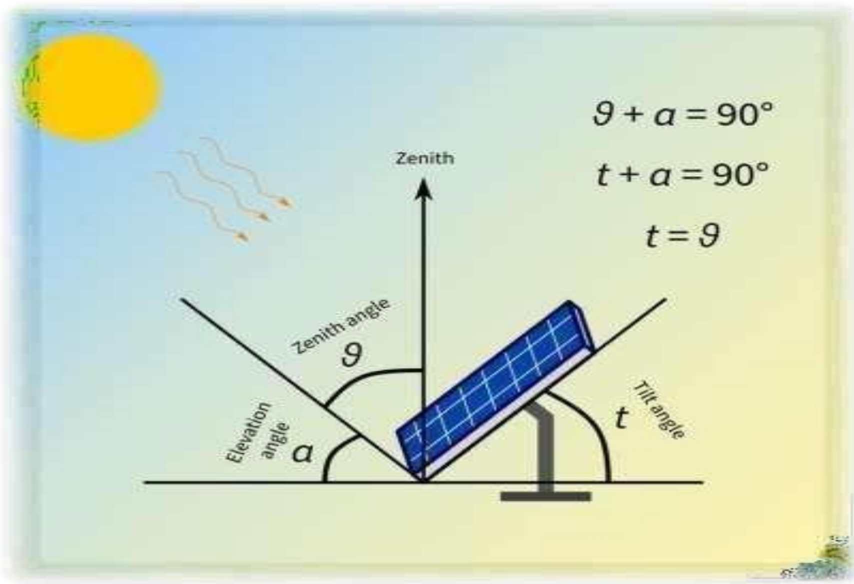

Figure 19. Estimation of tilted angle of the serpentine reflector

So, the value will change accordingly from the paper considering β=45°, α1 becomes 40° [11]. According to our estimation the results are the same. Similarly for the other two sides considering same procedure for convenience the tilt angle is found around 58° with ground.

4.4 Data Collection

Under the typical summertime weather of Gazipur in April and May, the experimental work was carried out at the MPE Solar Park of Islamic University of Technology, outside the workshop. From 8:00 am to 17:00 pm, data were gathered for each hour. The collector was angled at a 23° because the terrain was level also resonating with the geographical latitude of the country.

The sky in Gazipur was generally clear from April to June, with occasional cloudy or partly cloudy spells. In order to accurately observe the performance of the sun's rays, data collected during periods of more consistent weather was examined and taken into consideration.

However, due to the weather, certain days were disregarded in the analysis. The wind speed and relative humidity ratio's instantaneous values, or average mean values, were obtained from the city office and were recorded hourly. T_{in}, T_{out}, wind speed, relative humidity ratio, solar intensity radiation, and temperature at three separate, equal locations along the collector were the variables that were measured. The temperature data for the solar collector design for this project's inlet (T_{in}) and outlet (T_{out}) are displayed in the following tables (Table 3-7).

Table 3. Data table on the 26 April, 2024

Time (hours)	T_{in} **(˚C)**	T_{out} **(˚C)**	**Ambient** T_{amb} **(˚C)**	**Irradiation (watts/m²)**
8:00 AM	34	36	35	385
9:00 AM	41	44	35	479
10:00 PM	49	53	36	581
11:00 PM	52	57	37	724
12:00 PM	58	61	38	582
13:00 PM	62	65	40	810
14:00 PM	64	71	41	865
15:00 PM	62	68	34	421
16:00 PM	46	59	33	97
17:00 PM	42	48	33	75

The temperatures recorded during the daily reading on the 26 April, 2024 are shown in Table 3 above. These temperatures comprise the hourly measurements of solar radiation as well as the ambient temperature T_{amb}, the outlet temperature T_{out}, and the inlet temperature T_{in}. The data indicates that the fluid's maximum temperature was 71 degrees Celsius, its lowest was 34 degrees Celsius, and the maximum ambient temperature was 41 degrees Celsius. Thesun's maximum recorded hourly radiation was 865 watts/m².

Table 4. Data table on the 03 May,2024

Time (hours)	**T_{in} (˚C)**	**T_{out} (˚C)**	**Ambient T_{amb} (˚C)**	**Irradiation (watts/m²)**
8:00 AM	32	41	36	400
9:00 AM	36	43	36	345
10:00 PM	40	47	36	490
11:00 PM	52	58	37	567
12:00 PM	56	60	38	450
13:00 PM	59	63	38	465
14:00 PM	62	65	39	595
15:00 PM	65	70	39	650
16:00 PM	53	56	35	560
17:00 PM	41	48	35	550

The temperatures recorded during the daily reading on the 03 May, 2024 are shown in Table 4 above. These temperatures comprise the hourly measurements of solar radiation as well asthe ambient temperature T_{amb}, the outlet temperature T_{out}, and the inlet temperature T_{in}. Thedata indicates that the fluid's maximum temperature was 70 degrees Celsius, its lowest was32 degrees Celsius, and the maximum ambient temperature was 39 degrees Celsius. The sun's maximum recorded hourly radiation was 650 watts/m^2.

Table 5. Data table on the 06 May,2024

Time (hours)	T_{in} (˚C)	T_{out} (˚C)	Ambient T_{amb} (˚C)	Irradiation (watts/m²)
8:00 AM	32	41	36	298
9:00 AM	36	43	36	345
10:00 PM	40	47	36	350
11:00 PM	52	58	37	390
12:00 PM	56	60	38	450
13:00 PM	59	63	38	465
14:00 PM	65	68	39	592
15:00 PM	73	80	39	650
16:00 PM	63	67	35	435
17:00 PM	51	58	35	399

The temperatures recorded during the daily reading on the 06 May, 2024 are shown in Table 5 above. These temperatures comprise the hourly measurements of solar radiation as well as the ambient temperature T_{amb}, the outlet temperature T_{out}, and the inlet temperature Ti_{n}. The dataindicates that the fluid's maximum temperature was 80 degrees Celsius, its lowest was 32 degrees Celsius, and the maximum ambient temperature was 39 degrees Celsius. The sun's maximum recorded hourly radiation was 650 watts/m².

In order to make a comparison on thermal performance of collector with and without the effect of reflectors, data were taken without reflectors in several days. The temperatures recorded without reflectors during the daily reading on the 13 May, 2024 are shown in the Table 6 below.

Table 6. Data table on the 13 May,2024 **(The setup without reflectors)**

Time (hours)	**T_{in} (˚C)**	**T_{out} (˚C)**	**Ambient T_{amb} (˚C)**	**Irradiation (watts/m²)**
8:00 AM	26	30	29	298
9:00 AM	34	38	30	345
10:00 PM	40	45	32	350
11:00 PM	43	47	35	390
12:00 PM	45	48	38	450
13:00 PM	45	48	36	465
14:00 PM	45	48	34.5	590
15:00 PM	48	52	34	655
16:00 PM	48	51	32	435
17:00 PM	45	48	32	399

These temperatures comprise the hourly measurements of solar radiation as well as the ambient temperature T_{amb}, the outlet temperature T_{out}, and the inlet temperature T_{in}. The dataindicates that the fluid's maximum temperature was 52 degrees Celsius, its lowest was 26 degrees Celsius, and the maximum ambient temperature was 38 degrees Celsius. The sun's maximum recorded hourly radiation was 655 watts/m². In a similar sunny day, the maximum fluid temperature was recorded 80 degrees Celsius (Table 5) which suggests a significant improvement in thermal performance when reflectors are attached.

Table 7. Data table on the 16 May,2024 **(The setup without reflectors)**

Time (hours)	**T_{in} (˚C)**	**T_{out} (˚C)**	**Ambient T_{amb} (˚C)**	**Irradiation (watts/m²)**
8:00 AM	27	30	30	298
9:00 AM	28	32	32	345
10:00 PM	32	36	34	350
11:00 PM	41	45	34.5	390
12:00 PM	34	38	36	450
13:00 PM	37	41	39	465
14:00 PM	36	40	37	591
15:00 PM	37	41	34	670
16:00 PM	38	42	31.5	435
17:00 PM	36	38	31	399

The temperatures recorded during the daily reading process are shown in the data table above. These temperatures comprise the hourly measurements of solar radiation as well as the ambient temperature T_{amb}, the outlet temperature T_{out}, and the inlet temperature T_{in}. The data indicates that the fluid's maximum temperature was 41 degrees Celsius, its lowest was 27 degrees Celsius, and the maximum ambient temperature was 39 degrees Celsius. The sun's maximum recorded hourly radiation was 670 watts/m².

CHAPTER 5: RESULTS AND DISCUSSIONS

Below is a summary of the overall results obtained from the modified serpentine tube solar collector during the performance test study. The graphs illustrate the different temperature readings of the inlet and outlet temperatures of the serpentine collector as well as the irradiation data obtained on an hourly basis, based on the setup used to take the readings.

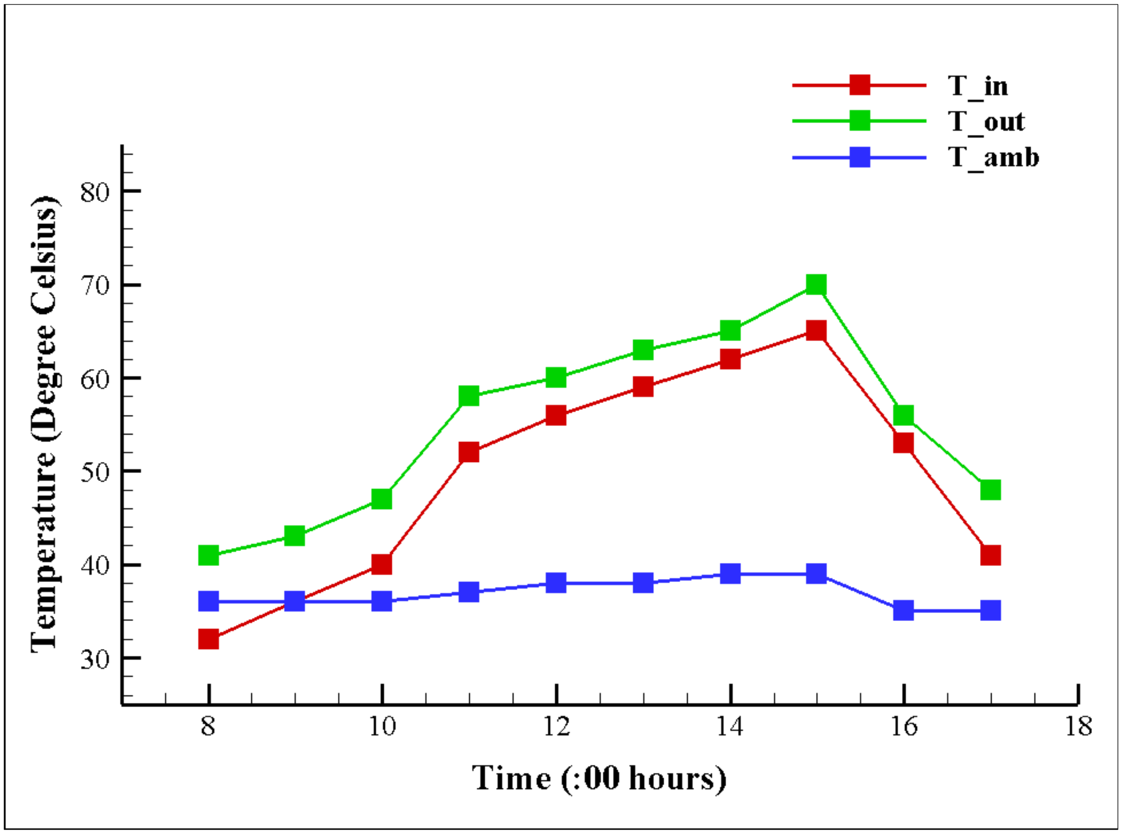

Figure 20. Temperature vs Time graph with reflectors for 26 April, 2024.

The temperature versus time graph shown above was created using data that was gathered on April 26, 2024. The green line indicates the fluid's maximum temperature, which is 70 degrees Celsius in the water outlet. The red line indicates the fluid's lowest temperature, which was 62 degrees Celsius at the water inlet. The blue line, representing the ambient temperature, reaches its maximum recorded temperature of 38 degrees Celsius for the day.

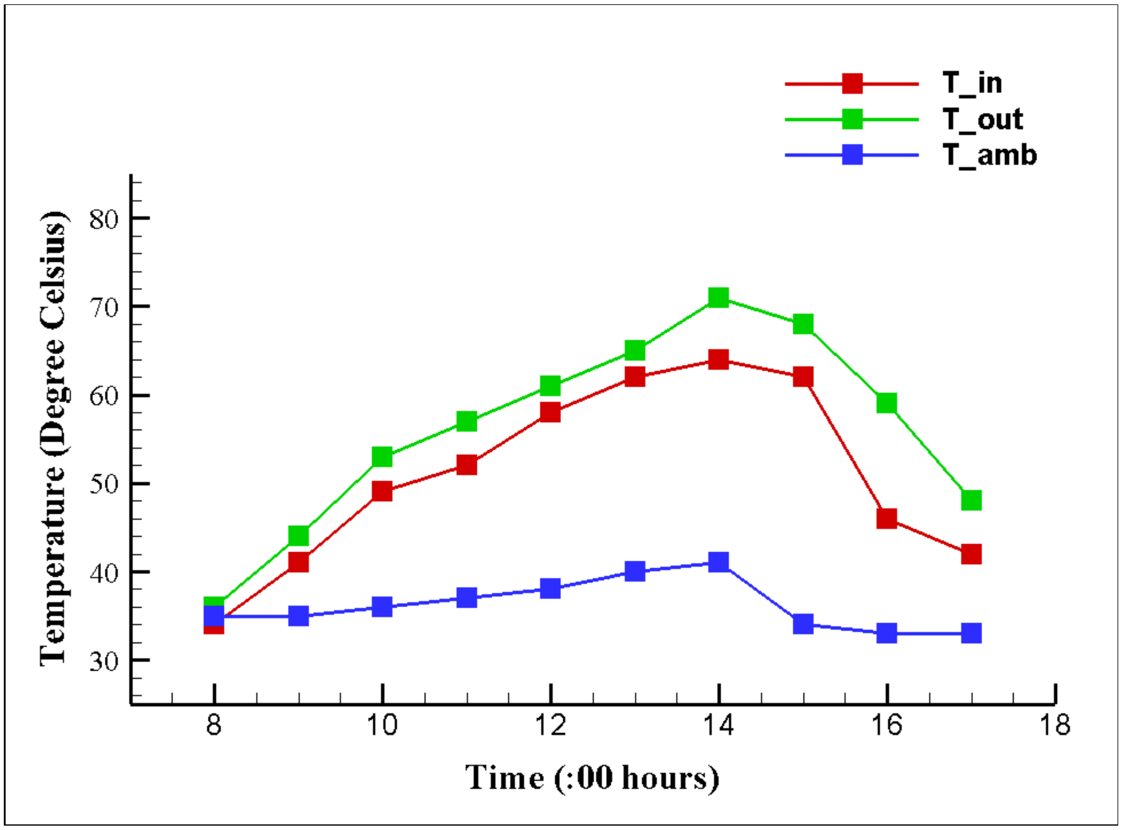

Figure 21. Temperature vs Time graph with reflectors for 03 May, 2024.

The temperature versus time graph shown above was created using data that was gathered on May 03, 2024. The green line indicates the fluid's maximum temperature, which is 71 degrees Celsius in the water outlet. The red line indicates the fluid's lowest temperature, which was 61 degrees Celsius at the water inlet. The blue line, representing the ambient temperature, reaches its maximum recorded temperature of 39 degrees Celsius for the day.

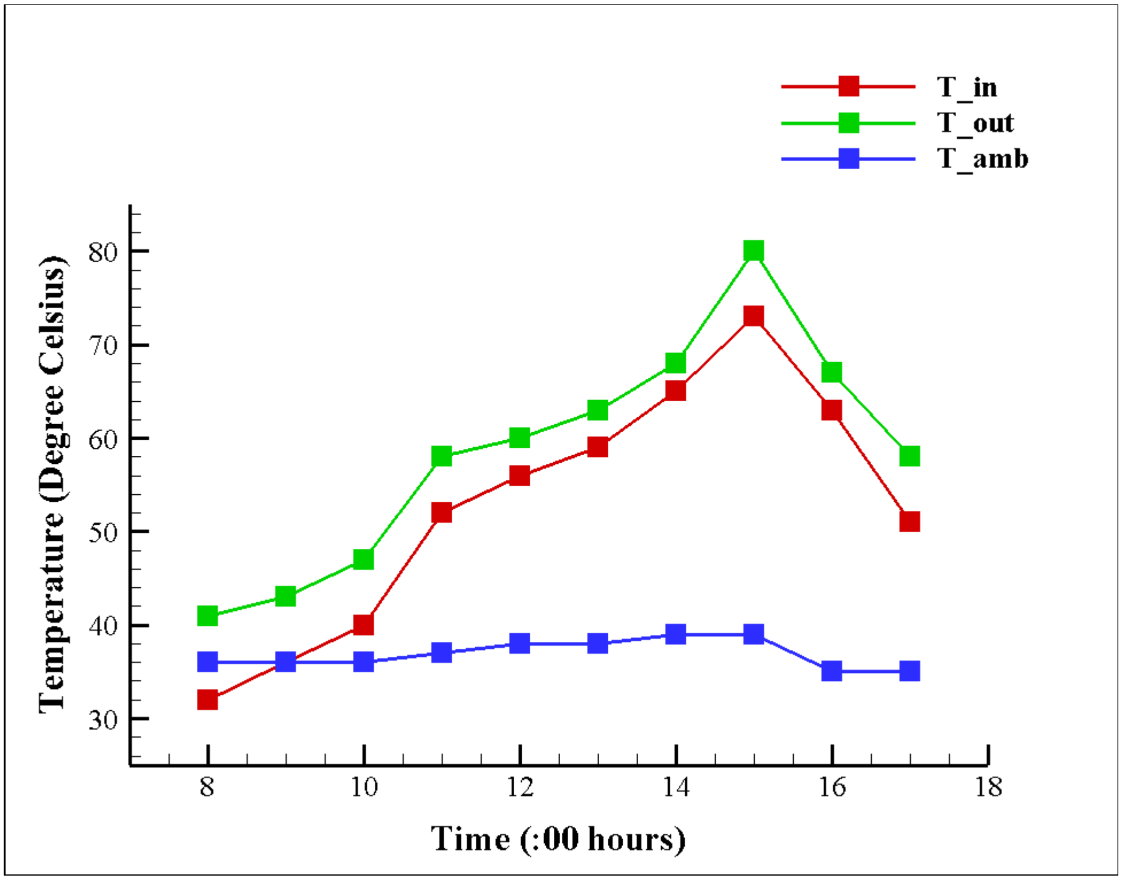

Figure 22. Temperature vs Time graph with reflectors for 06 May, 2024.

The temperature versus time graph shown above was created using data that was gathered onMay 06, 2024. The green line indicates the fluid's maximum temperature, which is 80 degreesCelsius in the water outlet. The red line indicates the fluid's lowest temperature, which was 70 degrees Celsius at the water inlet. The blue line, representing the ambient temperature, reachesits maximum recorded temperature of 39 degrees Celsius for the day.

In order to make a comparison on thermal performance of collector with and without the effect of reflectors, data were taken without reflectors in several days. Following figures (Figure 23 and 24) illustrates the data of the collector without reflectors.

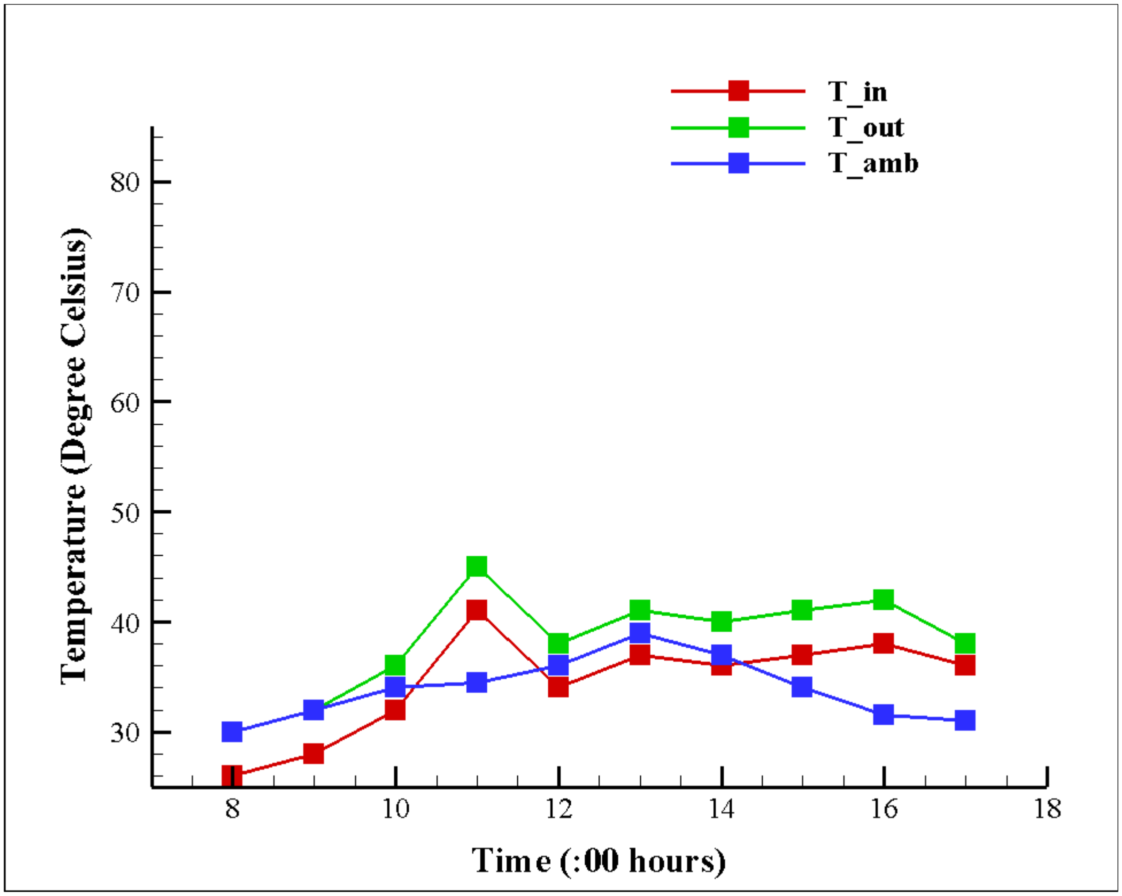

Figure 23. Temperature vs Time graph without reflectors for 13 May, 2024

The temperature versus time graph shown above was created using data that was gathered onMay 13, 2024 without using the reflectors in the setup. The green line indicates the fluid's maximum temperature, which is 47 degrees Celsius in the water outlet. The red line indicatesthe fluid's lowest temperature, which was 41 degrees Celsius at the water inlet. The blue line,representing the ambient temperature, reaches its maximum recorded temperature of 35 degrees Celsius for the day.

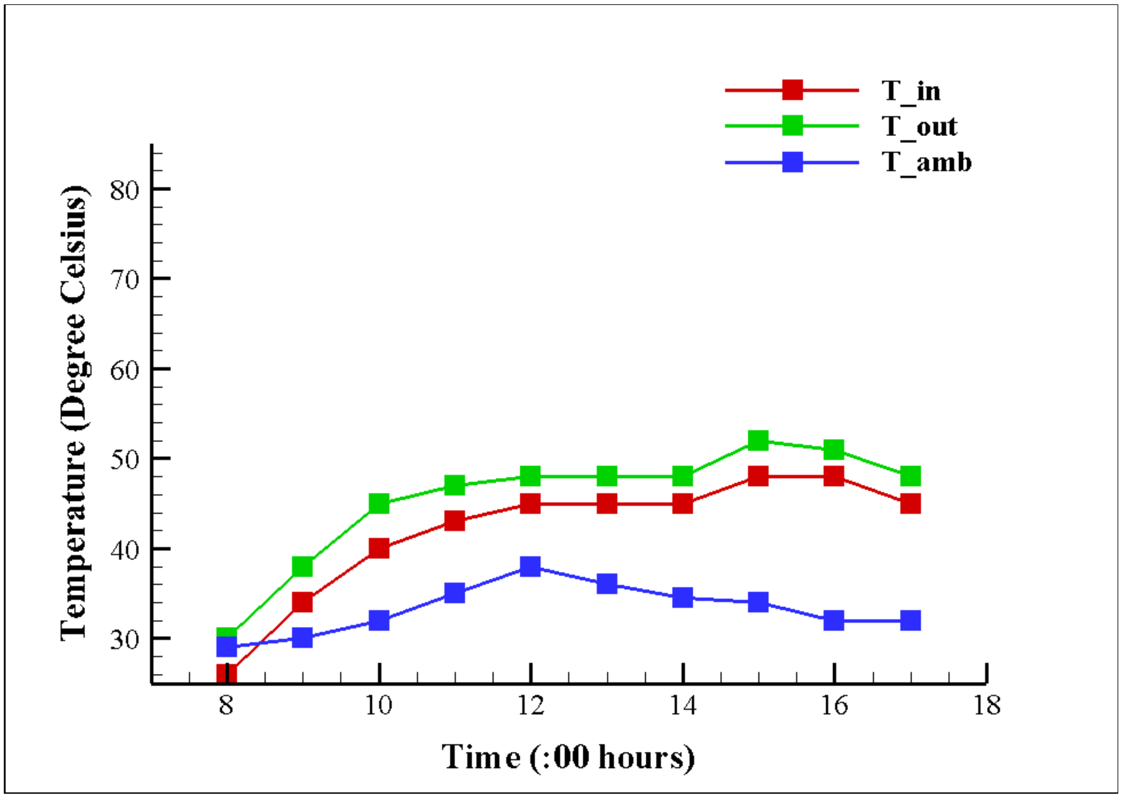

Figure 24. Temperature vs Time graph without reflectors for 16 May, 2024

The temperature versus time graph shown above was created using data that was gathered on May 16, 2024 without using the reflectors in the setup. The green line indicates the fluid's maximum temperature, which is 47 degrees Celsius in the water outlet. The red line indicatesthe fluid's lowest temperature, which was 41 degrees Celsius at the water inlet. The blue line, representing the ambient temperature, reaches its maximum recorded temperature of 35 degrees Celsius for the day. So, it is clearly evident that, the performance with reflectors are much better than without reflectors.

The aforementioned analysis indicates that three distinct days with varying weather conditions were used to collect the results. The application determines the solar vapor absorption system's design condition. Because flat plate collectors are stationary devices, they must be oriented correctlyto capture the most solar radiation energy possible [12].

The above figures show the temperature and time graph that the solar thermal collector received from **8 a.m. to 17:00 p.m.** Between **13:00** and **15:00 pm**, the experiment's peak temperatures, which are measured in degrees Celsius and range from 65˚ to 80˚,are recorded. It is noteworthy to note, though, that on one occasion during the daily readings, an outlet temperature of **80 ˚C** was recorded. The range of **65˚C** to**71˚C** was chosen because it was the same temperature that we consistently recorded during the reading period. We used the reflectors on the setup during this time to take readings. This is sufficient to heat the water to the appropriate temperature so that it can beused for household and purposes.

CHAPTER 6: CONCLUSION

It has been demonstrated that solar energy systems can save energy when compared to traditional standard solutions. The system's functionality and design have a significant impact on the amount of energy saved. In this study, design modification and performance study of a serpentine tube solar collector has been carried out experimentally. In summary, we can thus confidently say that the project's goals—which included designing, modifying, and assessing the collector's performance test—have been achieved. The temperature increased in the modified version from 57˚C (degrees Celsius) in the previous setup to **80˚C**. Moreover, an efficiency increment in the modified setup from **27%** in the previous setup to **41%** in the new set up.

By switching the flat plate solar collector's heat transport system configuration from solar absorber to heat storage system, its thermal performance can be increased. System performance is generally impacted by the size, shape, and flowrate of solar collectors. The thermal system that was suggested by various literatures served as the foundation for the design of the serpentine flat plate collector. In future studies, different hat transfer fluid may be used for increased thermal performance and energy storage. Also, year round performance of the setup is necessary to asses its acceptability for household applications.

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