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Design and fabrication of low temperature flat plate collector for domestic water heating

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Abstract. Solar energy, specifically using flat plate collectors, shows very promising as a renewable energy source for meeting global energy demands. These collectors, commonly used to capture solar energy and convert it into heat for various purposes, offer advantages over conventional water heaters in terms of lifespan and energy consumption. This study focuses on understanding flat plate collectors with region specific parameters for domestic use in Onaizah, Saudi Arabia. It includes a detailed design process based on site-specific data and featured with settings adjustable for different seasons. The use of double glazing with a gap between glass panels provides heat insulation from the front. Initial experiments conducted involved temperature measurements of outlet water and calculation of the solar collector's efficiency, resulting in the highest temperature recorded at 62.3°C and an efficiency of 53.5%.

Introduction

Traditional water heaters rely on burning fossil fuels or using resistive heating elements, leading to carbon emissions or wastage of electrical energy. They struggle to meet hot water demands efficiently, resulting in unnecessary energy consumption. These systems also have maintenance issues and a shortened lifespan [1]. Flat plate collectors (FPCs) have undergone significant developments to improve performance. Researchers have worked on enhancing efficiency, minimizing thermal losses, advancing materials and coatings, and exploring innovative designs. The performance of FPCs depends on factors such as solar irradiance, temperature, design, and operating conditions [2, 5]. With history dating back to early 20th century, FPCs water heaters gained popularity in the 1940s and 1950s. Researchers then focused on selective coatings and improved glazing materials leading to efforts to improve insulation with materials of fiberglass, polyurethane foam, and mineral wool. Potential strategies and research directions included cost reduction, performance enhancement, and integration with energy storage systems [5, 9].

Advancements in materials science, manufacturing techniques, and system designs have continued to shape and optimize the FPCs technology, developing high-performance absorber coatings, exploring novel materials, and optimizing the design of flow channels. Innovations included integral collector-storage systems (ICS) and evaluated flat plate collectors (EFPCs), offering improved thermal performance and energy storage capabilities [12]. The orientation and tilt angle of FPCs play crucial role in their performance, typically aligned to the latitude of the location [13]

Calculations are used to determine the performance and heat output of FPCs, taking into account incident solar radiation, fluid flow rate, temperature differentials, and heat transfer coefficients.

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Despite having advantages, FPCs have weather-coupled limitations of lower efficiency, having thus different types, including glazed, unglazed, hybrid, and high-temperature collectors [11,13].

FPCs are used in various applications such as residential water heating, space heating, commercial water heating, manufacturing processes, greenhouse heating, pool heating, and solar desalination. However, there are challenges that include improving thermal efficiency, minimizing heat losses, reducing costs, and developing efficient thermal energy storage systems. Supportive policies, financial incentives, and public awareness campaigns are important to promote the use of FPCs and maximize their potential usages. Continued research and collaboration among stakeholders are key to addressing these challenges and advancing FPC technology [10.13]

Problem:

The problem under focus inefficiency and high energy consumption associated with conventional water heaters used for residential and commercial purposes. Traditional water heaters often rely on fossil fuels or electric resistance heating elements. An ideal water heater should prioritize energy efficiency by utilizing renewable energy sources [13].

Objectives:

To determine the optimal design parameters for flat plate collectors in terms of the angle at which they are tilted to maximize solar energy absorption and overall system performance.

To assess the energy efficiency of flat plate collectors for domestic water heating by measuring heat absorption, transfer, and overall system efficiency under varying weather and operating conditions.

Significance of study

The significance of the study lies in addressing local needs by designing a flat plate collector tailored to the specific requirements and climatic conditions of the Qassim Region. Improving thermal performance using double glazing with a vacuum, reducing heat loss, and increasing overall system efficiency. Providing cost savings and affordability by reducing reliance on conventional energy sources and lowering utility bills. Supporting environmental sustainability by utilizing solar energy as a renewable and clean energy source.

Methodology

The design process involves considering various factors such as collector area, materials, fluid selection, and system configuration. The absorber plate area is a critical design parameter that determines the amount of solar energy that can be captured [12]. The solar radiation incident is measured throughout the day. For our application we need the measurements for a certain area in wintertime. Since, in Saudi Arabia the water heaters only needed in winter we need to take into consideration Daylight Time. Daylight Time in Saudi Arabia is 10 hours, this information can be used to calculate solar radiation incident on a specific area [6]. From the information about the location, we designed our collector for this application using equation (1).

$$A = \frac{Qu}{G\eta} \tag{1}$$

Where Ais the collector area in square meters, Qu is the desired heat output in Watts, G is the solar radiation incident on the collector in watts per square meter, and η is the collector's thermal efficiency as in equation (2).

$$Qu = \dot{m}\, C_p (T_{out} - T_{in}) \tag{2}$$

Where $\dot{m}$ is the mass flow rate of the fluid in kilograms per second, C_p is the specific heat capacity of the fluid in joules per kilogram per °C for water, T_{out} is the outlet temperature of the fluid in degrees Celsius and T_{in} is the inlet temperature. The mass flow rate can be calculated from the capacity of the flat plate collector. If we assume that the capacity for our tank is 20 liters. To determine the required area for FPC, factors such as solar insolation data, daily energy demand, and assumed efficiency are considered. Design parameters of diameter, spacing, and number is crucial. The riser diameter is chosen based on cost, flow rate, and efficiency. A diameter of 9mm is selected in this case. The spacing between risers is decided on heat transfer, pressure drop, and cost. The number of risers is calculated based on the width of the absorber plate, riser diameter, and spacing. These parameters optimize performance, efficiency, and cost-effectiveness. Fig.1 shows a wooden case with insulation, absorber plate, pipes, and glazing.

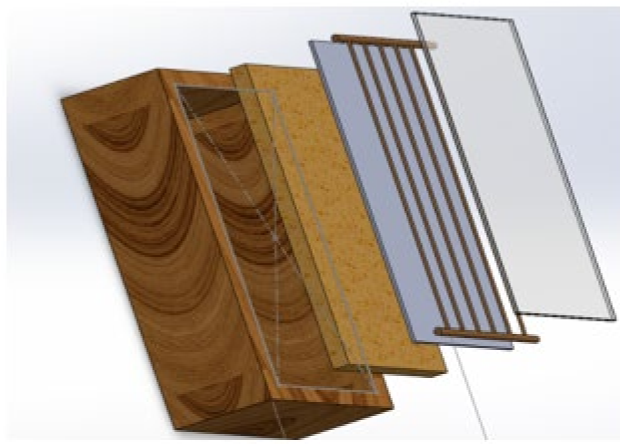

Figure 1: The rendering of the flat plate collector configuration

Material Selection

The selection of materials is important when designing a flat plate solar collector. Factors like cost, availability, installation ease, and lifespan should be considered. Copper, aluminum, steel, and stainless steel are common materials for the absorber plate, each offering different thermal conductivity and corrosion resistance properties. Risers and headers are typically made of copper, aluminum, or stainless steel. Insulation materials like rock wool, cellulose, Styrofoam, polyurethane foam, and polyisocyanurate foam are commonly used. Glazing options include tempered glass, low-iron glass, and polycarbonate. The orientation of a solar collector should be such that it faces south for maximum solar radiation with tilt angle at around 26°±5° from the horizontal plane, with adjustable mechanisms. The apparent solar time can be determined by considering the time zone offset and longitude.

Results

The design of the solar water heater is based on the region average solar irradiation, which stands at 6000 kWh per day for Onaizah, and since the heater is used in the winter, which has ten hours of daylight, the average solar radiation per hour is 600 kW [14]. Assumptions are made for the inlet temperature (25°C), outlet temperature (70°C), and operation time (five hours). Assuming an efficiency of 50%, the area of the collector is calculated to be 0.6 square meters. The dimensions of the collector, including the number of risers, flow rate, and absorber plate area, are determined based on the desired specifications. The chosen dimensions for the design are 1m x 0.6m (length x width), with a header diameter of 22.225mm, riser diameter of 9mm, and a spacing of 90mm.

Copper is often chosen for risers and headers due to its high thermal conductivity and corrosion resistance. To enhance thermal absorbability, the plate and pipes are usually painted black. Insulation materials such as rock wool, cellulose, Styrofoam, polyurethane foam, and polyisocyanurate foam are considered, with the choice depending on factors such as thermal conductivity, moisture resistance, and cost. Rock wool is typically chosen when balancing these factors. For glazing material, options include tempered glass, low-iron glass, and polycarbonate.

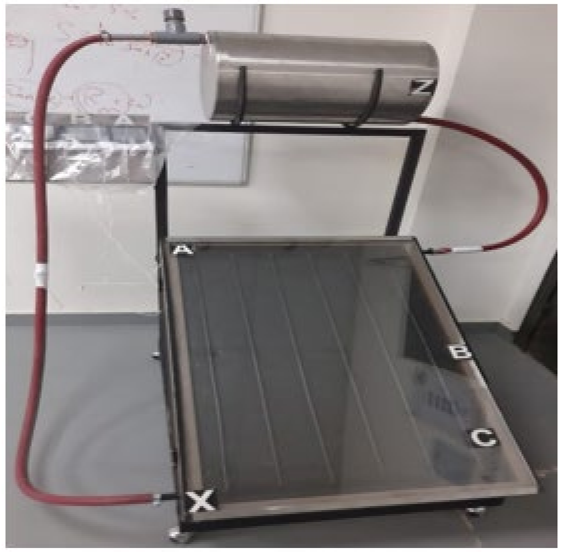

Figure 2: The fabrication of the design

Each offers advantages in terms of durability, transparency, and solar transmittance. The recommended spacing usually ranges from 10 to 25mm. In the described design, the spacing is 10mm and vacuumed to minimize heat loss from the glazing [13].

There are several different mechanisms that can be used to change the tilt angle of a flat plate solar collector. This design's mechanism is manual since it is the most reliable and can withstand the wight of the collector. The mechanism is two sets of steel tubes. One set is attached to the collector by a T-joint. And the other set is attached to a steal base holding the collector by a T-joint. As shown in Fig 3.

Figure 3: The mechanism of angle change.

The tank has many configurations based on the system design expected pressure and temperature. The tank is made from two sheets of galvanized steel and a layer of rock wool for insulation. The tank has an inlet at the bottom and an outlet at the top. From the picture below in Fig 4 it is demonstrated that the tank is connected to the collector though two hoses. The hoses are flexible to move with collector when changing the angle.

Figure 4: The tank for the

There are five sensors in the collector which are A, B, C, Z, and X as illustrated in Fig. 1. Sensors A, B, and C are temperature sensors on the plate, which provide the average temperature of the absorber plate. Sensors Z and X are the outlet and inlet sensors, respectively. All five monitors for the sensors are on the board on the side of the collector.

On Wednesday the twenty-first of February 2024 a preliminary test was performed on the collector. From this test the efficiency of the collector is calculated. The water outlet temperature increased to maximum value 62.3˚C at around 4:00 PM and then decreased as shown in Fig. 5.
As shown in Fig. 6 the efficiency of the collector increased with time and reached its maximum value 53.5% around 4:00 PM and then decreased.

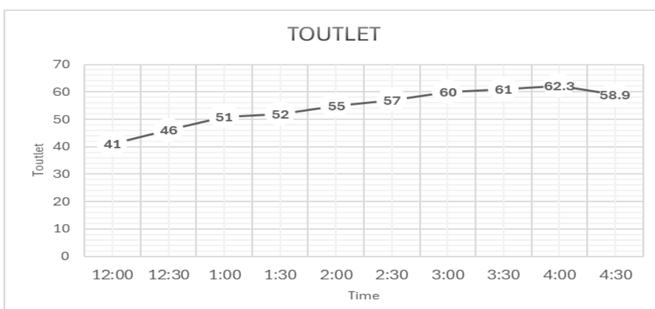

Figure 5: The temperature in the outlet vs

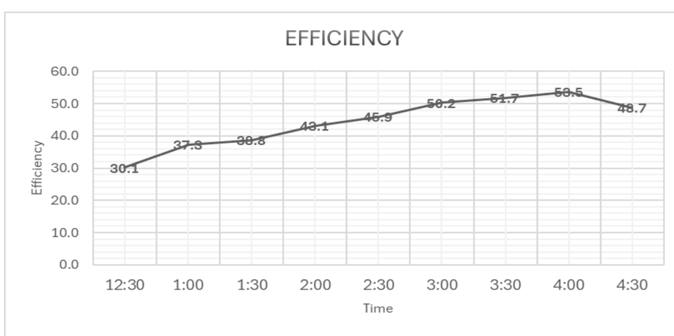

Figure 6: The Efficiency VS time chart.

Recommendations

The performance of the flat plate collector has been assessed after fabrication and testing, where its efficiency is a key factor. The actual collector efficiency may differ from the theoretical efficiency depending on the design, mainly due to system losses. These losses can vary across regions and collectors but can be evaluated using specific criteria. These parameters must be tested in different conditions and in different seasons. The performance of a flat plate solar collector is evaluated based on its efficiency, which can vary from theoretical values due to system losses. These losses can be assessed using specific criteria such as the useful thermal load, thermal losses, and the heat removal factor. The useful thermal load refers to the amount of thermal energy provided by the collector to meet the desired demand, taking into account the heat energy transferred from the collector to the load. It depends on various factors including the collector's performance, heat transfer characteristics, specific requirements, and thermal losses within the system. The thermal losses are determined by calculating the overall heat loss coefficient, which considers the major areas of heat loss in the collector such as the top, bottom, and sides. The heat removal factor measures how effectively the collector transfers heat from the absorber plate to the heat transfer fluid, and it is calculated as the ratio of the actual heat transfer rate to the maximum possible rate under ideal conditions. This factor can be used to determine the absorbed useful energy by considering parameters such as the collector area, irradiance, absorptance and transmittance of the collector, overall heat loss coefficient, and the temperature difference between the fluid inlet and ambient temperature. These parameters should be tested under different conditions and seasons to accurately evaluate the performance of the flat plate collector.

Conclusion

In summary, the design and optimization of a flat panel solar collector involves various considerations. The collector is oriented south-ward to maximize solar radiation, with the tilt angle manually adjusted based on the latitude of Onizah, Saudi Arabia. Dimensions are determined based on the number of risers, water flow rate, and absorption plate area. Vertical orientation is preferred, with dimensions of 1m x 0.6m. Copper is chosen for risers and headers because of its thermal conductivity and resistance to corrosion. Black coating enhances thermal absorption ability. Rock wool insulation provides thermal insulation and moisture resistance. Tempered glass serves as glazing material to ensure durability and transparency. A 10mm vacuum gap between the glazing and absorber plate reduces heat loss. Manual adjustment includes two sets of steel tubes and a steel base to reliably change the tilt angle. Flexible hoses connect the collector to the tank, allowing for angle adjustments. Sensors monitor temperature variations. Initial tests show a maximum efficiency of 53.5%. Calculations evaluate thermal load and losses. This optimized collector effectively harnesses solar energy for domestic water-heating applications, providing a sustainable and cost-effective solution for the region's thermal energy requirements.

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