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Parabolic Solar Water Heater Efficiency Enhancement Using Live Sun Tracking

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Abstract

This project proposes the development of a Parabolic Solar Water Heater with an automated real-time sun-tracking system to maximize solar energy absorption throughout the day. The system incorporates a parabolic reflector to focus sunlight onto a heat-absorbing pipe, efficiently heating water. To enhance efficiency, the system employs Light Dependent Resistor (LDR) sensors to detect sunlight intensity and DC motors to adjust the parabolic dish's orientation dynamically. The motors, controlled by a microcontroller, ensure optimal alignment with the sun, increasing energy absorption and overall system performance. A temperature sensor continuously monitors the water temperature and displays real-time data, enabling users to track heating efficiency. The system is designed to be energy-efficient, cost-effective, and eco-friendly, making it a viable alternative to conventional water heating methods. The incorporation of automated tracking significantly improves energy utilization compared to static solar heaters. This project aims to contribute to sustainable energy solutions by providing an efficient, renewable, and autonomous water heating system for residential and commercial applications. The proposed design ensures higher thermal efficiency, real-time monitoring, and automation, making it a promising advancement in solar thermal energy utilization.

Introduction

Solar energy has emerged as one of the most promising renewable energy sources, providing a clean and sustainable alternative to conventional fuels. Among its various applications, solar water heating has significant potential to reduce energy costs and dependency on non-renewable energy. However, traditional solar water heating systems suffer from limitations in energy capture due to their fixed orientation, which does not account for the sun's movement across the sky.

Solar energy over the last two to three decades have arisen as a sustainable source of renewable energy and are now used on a wide scale in both industrial and residential applications. Many applications of solar energy include solar cookers, solar water heater, solar energy converted to electrical energy, solar ventilation, etc. Water heaters are now common in most countries for almost every day use.

Traditional heaters, such as geysers and boilers, are environmentally damaging because the heating phase necessitates the combustion of fossil fuels and the release of greenhouse gases. Solar water heating is an alternative technology that can be used to heat water without damaging the atmosphere. Tracking system is used for accurate positioning and maximum efficiency. Solar tracking captures the movement sun moving in the sky in both axis and collects the solar energy.

There are mainly two types of tracking systems yet discovered which includes Electrical/sensor operated tracking system and mechanical tracking system. The tracking system which requires no sensors or electric supply for movement for tracking are named as mechanical tracking system. This project proposes a solar water heating system equipped with a sun-tracking mechanism that dynamically adjusts the solar collector's position. This ensures continuous alignment with the sun throughout the day,
maximizing the energy absorbed. By combining efficient heat transfer mechanisms, temperature control, and safety features, the proposed system not only enhances energy utilization but also ensures reliable operation.

This project presents the design and implementation of a solar energy-based water heating mechanism integrated with a sun-tracking system. The proposed system aims to optimize the capture of solar energy by dynamically adjusting the orientation of the solar collector throughout the day. Utilizing Light Dependent Resistors (LDRs) for real-time sun position detection, the system employs a microcontroller and motor mechanism to rotate the solar collector. The heated water is transferred to a storage tank using a water circulation system, ensuring energy-efficient heat transfer. This innovation enhances energy efficiency, improves water heating capacity, and contributes to sustainable energy solutions. A solar tracker is a device for orienting a day lighting reflector, solar photovoltaic panel or concentrating solar reflector or lens towards the sun.

The sun's position in the sky varies both with the seasons and time of day as the sun moves across the sky. Solar powered equipment works best when pointed at or near the sun, so a solar tracker can increase the effectiveness of such equipment over any fixed position, at the cost of additional system complexity. Sun is one of the oldest, greatest, and everlasting sources of energy. Solar energy is unlimited, has no negative environmental effects, and can be converted into a variety of other kinds of energy. Solar energy acquired can be processed and used in many applications such as solar heating process, thermal energy, generation of electricity etc. This paper presents the experiment of solar water heating with Mechanical tracking system. It focuses on the performance of dual axis tracking system with the application of water heater. Unlike electrical system of Arduinos, the tracking system applied is fully based on a mechanical simple machine.

The efficiency of the solar water heater with and without tracking was tested in the experimental analysis. The experimental setup has been put to test, and the results have been drawn. The results of water heater with tracking have been proven to be more effective and beneficial than of without tracking.

Literature Review

Solar water heaters (SWHs) using parabolic concentrators have been extensively studied for their efficiency improvements in thermal energy collection. This literature survey compares various research contributions focusing on different design modifications, efficiency analyses, and tracking systems in parabolic solar water heaters. Avargani et al. (2020) conducted coupled optical and thermal analyses of a novel parabolic trough solar water heater. Their study highlighted enhanced efficiency through optimized reflector geometries and selective coatings. Panahi et al. (2019) focused on the thermal performance of an Integrated Collector Storage (ICS) system with a compound parabolic concentrator, emphasizing its applicability in semi-arid climates like Kerman, Iran.

Said et al. (2023) introduced an innovative system integrating an evacuated tube solar collector with a parabolic trough and helical coil heat exchanger. Their results demonstrated improved heat retention and energy transfer efficiency. Varghese et al. (2017) performed a parametric study on concentrating integral storage systems, showing the impact of design parameters such as aperture area and storage capacity. Bhakta et al. (2018) investigated cylindrical parabolic concentrators with twisted tape inserts to enhance thermal performance in copper absorber tubes. Another study by Bhakta et al. (2017) explored performance variations in cylindrical parabolic concentrators under different operating conditions, emphasizing material properties and absorber designs.

Jamar et al. (2016) reviewed various solar heating technologies, identifying key trends in energy conversion efficiency and economic feasibility. Their work provided a comprehensive overview of solar water heating advancements. Nath et al. (2018) conducted experimental analyses of solar water heaters with compound parabolic concentrators, highlighting significant efficiency improvements with optimized reflector angles. Across these studies, key advancements include the integration of novel heat exchangers (Said et al., 2023), thermal efficiency improvements through geometric optimizations (Avargani et al., 2020; Panahi et al., 2019), and performance enhancements via absorber modifications (Bhakta et al., 2018). However, real-time sun-tracking mechanisms remain underexplored in most studies, presenting an opportunity for further research in active tracking systems to maximize energy capture throughout the day. This survey underscores the growing interest in optimizing parabolic solar water heaters and the need for continued advancements in automation and material innovations to enhance efficiency and reliability.

Methodology

The development of the Parabolic Solar Water Heater with real-time sun tracking and temperature monitoring involves a systematic approach that includes the design, fabrication, and implementation of various components. The project begins with the system design and planning phase, where the required specifications for efficiency and performance are determined. This includes defining the dimensions of the parabolic reflector, selecting the appropriate materials for the absorber tube, and determining the optimal tracking mechanism to ensure maximum solar energy capture. Materials such as high-reflectivity aluminum sheets or mirror- coated surfaces are chosen for the reflector, while the absorber tube is typically made of copper or stainless steel to provide excellent heat conductivity. Furthermore, insulation materials are selected to minimize heat losses and improve the system's thermal efficiency. The electronic components, including LDR (Light Dependent Resistor) sensors, DC motors, a microcontroller (such as Arduino or ESP32), and a temperature sensor (DS18B20 or LM35), are carefully chosen to ensure precise tracking and monitoring.

Once the design is finalized, the fabrication phase involves constructing the parabolic reflector and absorber system. The parabolic reflector is designed to concentrate solar rays onto the central absorber tube, where water is heated due to the intense focus of sunlight. The absorber tube is mounted securely at the focal point, ensuring maximum heat absorption. The system is insulated using materials like glass wool or polyurethane foam to reduce heat loss and maintain the water temperature for extended periods. The structural support for the parabolic dish is also designed to allow smooth movement for sun tracking.

The sun-tracking system is a crucial part of this project, ensuring that the parabolic reflector maintains optimal alignment with the sun throughout the day. Multiple LDR sensors are placed at different positions on the dish to measure sunlight intensity. The microcontroller processes LDR sensor data and controls the DC motors, adjusting the dish's position accordingly. The tracking system is implemented in a dual-axis configuration, allowing precise movement both horizontally (azimuth) and vertically (altitude). This ensures that the system maximizes solar energy capture, significantly improving efficiency compared to fixed solar heaters.

In parallel, a temperature monitoring system is integrated to continuously measure the water temperature inside the heating system. The temperature sensor (such as DS18B20 or LM35) is placed inside the water storage tank to provide real-time temperature readings. This data is displayed on an LCD screen or transmitted to a web interface, enabling users to monitor the system's performance remotely.

After assembling all components, the system undergoes extensive testing and optimization. Initial trials are conducted to evaluate the efficiency of the solar heater by comparing water temperature readings with and without sun tracking. The sensitivity of LDR sensors, motor response time, and reflector positioning is fine-tuned to maximize solar energy absorption. The energy consumption of the tracking system is also analyzed to ensure that the overall setup remains energy-efficient and sustainable. Additional testing is performed in various weather conditions to assess system reliability and durability.

By following this structured methodology, a high-performance, automated, and sustainable solar water heating system is developed. The integration of real-time sun tracking and temperature monitoring significantly enhances efficiency, making this system an eco-friendly and cost-effective alternative to conventional water heating methods.

Parabolic trough solar collectors consist of a parabolic reflector. This parabolic sheet can be made by bending a sheet to parabolic shape. The sheet should be highly reflective and be constructed as a long parabolic reflecting mirror. In this type, the solar collector should be pointed directly into the Sun, and since the solar radiation is parallel, all light waves can reflect on focal from all parts of the trough-shaped as shown in Figure 1. This consequently causes the central pipe to heat up.

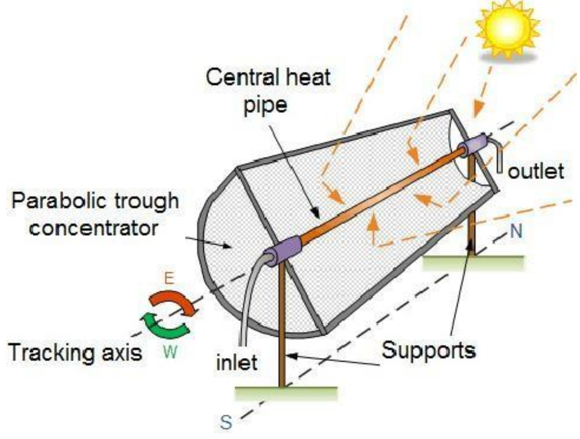

Figure 1. General conceptual form of a parabolic trough collector (PTC)

The parabolic trough solar collectors consist of different parts:

- Parabolic reflectors
- Receiver tube
- Support structure
- Tracking system

The receiver tube which is located at the focal line of parabolic trough reflective surface can transfer the absorbed solar energy to the fluid flowing inside. The tube usually consists of two layers to make it more efficient. An outer layer is made out of glass which is transparent and anti-reflecting to solar radiation and can reduce convection and radiation losses and maintain strength and transmittance under high temperatures, as well as an inner layer of copper or selective blackened nickel which, inside of it, circulates the heat transfer fluid.

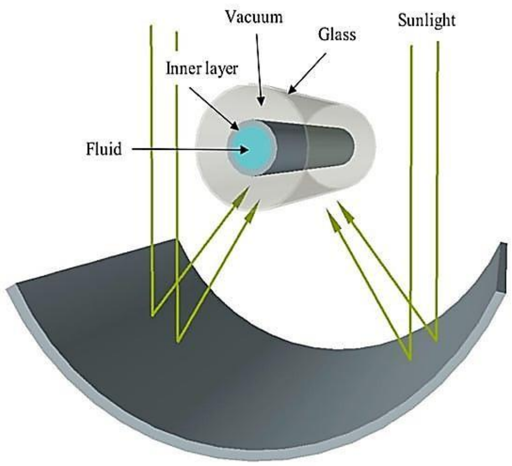

Figure 2. Detail of parabolic trough solar collector.

Coating of the inner layer makes it capable of reducing thermal radiation losses by absorbing the short length solar radiation and also low emissivity for long wave energy spectrum. The device also includes one-axis solar tracking to align the trough with sunlight and make sure the maximum amount of radiation will be reflected on the focal line. Parabolic troughs are rotated to track the Sun as it moves across the sky each day from morning to night. This is one of the crucial sections which can increase the efficiency and maximize the solar heat gain. The critical section of parabolic trough solar collector is the heat transfer fluid flowing inside the tube, which is usually a mixture of water or thermal oil and other additives like nanofluids which enhance thermal conduction. The fluid is pumped through the tube and absorbs the solar heat reaching temperatures of over 200 °C. The hot water is then directed to a heat exchanger where it can heat a storage tank for different applications. As mentioned above, PTC is used in large scales as solar concentrating technology. Nanofluid-based concentrating parabolic solar collectors (NCPSC) provide better energy absorption and conductive heat transfer compared with conventional parabolic trough concentrators. Recently, the use of nanofluids as the working fluid in parabolic trough solar collectors (PTC) is getting more common.

Proposed System

Figure 3: Proposed system hardware Side View

Figure 4: Proposed system hardware Front View

Solar angle and sun tracking are two important concepts in the field of solar energy. Understanding these concepts can help individuals and businesses optimize their use of solar energy and increase the efficiency of their solar power systems.

Solar Angle:

The solar angle refers to the angle at which the sun's rays hit the earth's surface. This angle varies depending on the time of day, the season, and the latitude of the location. When the sun is directly overhead, its rays are perpendicular to the earth's surface, resulting in the maximum solar angle. At other times of the day, the angle of the sun's rays decreases, resulting in less energy being absorbed by solar panels. The solar angle is important for solar power systems because it determines the amount of energy that can be captured by solar panels. If the panels are not angled properly to capture the sun's rays, the efficiency of the system can be significantly reduced. In order to optimize the efficiency of a solar power system, it is important to understand the solar angle and to position the panels accordingly.

Sun Tracking:

Sun tracking is the process of adjusting the position of solar panels throughout the day to ensure that they are always facing the sun. This is achieved through the use of solar trackers, which are devices that follow the movement of the sun and adjust the orientation of the panels accordingly.

Sun tracking is an effective way to increase the efficiency of solar power systems. By adjusting the position of the panels to match the changing solar angle, more energy can be captured throughout the day. This is particularly important in locations where the angle of the sun's rays varies significantly throughout the day or throughout the year. There are two main types of sun trackers: single-axis trackers and dual-axis trackers. Single-axis trackers adjust the orientation of the panels along one axis, typically east-west. Dual-axis trackers adjust the orientation of the panels along both the east-west and north-south axes, allowing for more precise tracking of the sun's movement.

The solar angle, denoted by θ, is the angle between the sun's rays and the horizontal plane at a given location on Earth. It varies throughout the day and depends on the latitude of the location, the time of day, and the season. The solar angle can be calculated using the following equation:

$$\theta = \sin^{-1}(\sin(\delta)\sin(\varphi) + \cos(\delta)\cos(\varphi)\cos(h))$$

where δ is the declination angle of the sun, φ is the latitude of the location, and h is the hour angle, which is the difference between the local solar time and solar noon. The solar angle is maximized when the sun is directly overhead, which occurs at solar noon. Sun tracking refers to the process of adjusting the orientation of solar panels to follow the movement of the sun and maximize the amount of solar radiation they receive. This is achieved using sun trackers, which can be classified as either single axis or dual-axis trackers.

Dual-axis trackers adjust the orientation of solar panels along both the east-west and north-south axes. The angle of the panels can be calculated using the following equations:

$$\alpha x = \alpha xs + Kpx\Delta Tx \quad \alpha y = \alpha ys + Kpy\Delta Ty$$

where αxs and αys are the solar angles at solar noon for the east-west and north-south axes, respectively, **Kpx** and **Kpy** are the tracking gain coefficients for each axis, and **ΔTx** and **ΔTy** are the time differences between solar noon and the current time for each axis.

Conclusion

The proposed Parabolic Solar Water Heater with Real-Time Sun Tracking and Temperature Monitoring presents a highly efficient, sustainable, and cost-effective solution for solar water heating. By integrating a parabolic reflector, the system effectively concentrates sunlight onto an absorber tube, significantly improving heat absorption compared to conventional flat-plate solar heaters. The incorporation of an automated sun-tracking system using LDR sensors and DC motors ensures that the reflector continuously aligns with the sun throughout the day, maximizing solar energy capture and optimizing thermal efficiency. Unlike fixed solar water heaters, this dynamic tracking feature enhances performance, even in regions with variable sunlight angles. Furthermore, the inclusion of a temperature monitoring system enables real-time tracking of water temperature, ensuring users can monitor and optimize system performance. The use of energy-efficient electronics ensures that the additional tracking mechanism does not lead to excessive power consumption, making the system self-sustaining when integrated with solar-powered electronics. This innovation is particularly beneficial for residential, commercial, and rural applications, where access to conventional energy sources may be limited or expensive. By utilizing renewable solar energy, the system reduces dependency on fossil fuels, contributing to a greener environment and promoting sustainable energy solutions. The proposed system serves as a viable alternative to traditional water heating methods, offering enhanced efficiency, automation, and long-term cost savings while supporting global efforts toward energy conservation and environmental sustainability.

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