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Conical Collector Solar Water Heater for Rural Applications

Anand, Achinth V N, Satyanarayana B, Suchinth V N

Undergraduate Students, Dept. of Electrical & Electronics Engineering, SJB Institute of Technology, Bengaluru, India

Vijay Kumar K

Assistant Professor, Department of EEE, SJBIT, Bengaluru, India

ABSTRACT: This project explores the design, fabrication, and application of a conical collector solar water heater (CCSWH) tailored for rural areas. The CCSWH utilizes conical collector geometry to enhance solar energy absorption and maximize thermal efficiency. By concentrating sunlight onto a centralized absorber, the conical design improves heat retention compared to flat-plate collectors, making it particularly effective in areas with limited sunlight hours or inconsistent weather patterns. The system operates on a passive circulation mechanism, ensuring simplicity, low maintenance, and reduced dependency on external power sources, making it ideal for remote and resource-constrained regions. Experimental testing demonstrates that the CCSWH can achieve water temperatures ranging from 30–60°C under typical rural climatic conditions, suitable for domestic purposes such as cooking, cleaning, and bathing. The use of locally available materials like aluminum and glass further reduces production costs, enabling widespread adoption. This project highlights the potential of sustainable and cost-effective solar technology to address the challenges of rural energy access, reduce reliance on conventional fuels, and promote environmental sustainability.

KEYWORDS: conical collector, solar water heater, rural applications, renewable energy, thermal efficiency, sustainable design, passive circulation.

I. INTRODUCTION

Solar water heating systems are a cost-effective and sustainable solution for generating hot water, particularly in rural areas where access to conventional energy sources may be limited. These systems harness solar radiation to heat water, providing an alternative to traditional water heating methods that rely on fossil fuels. Among various designs, the conical collector solar water heater stands out for its efficiency and suitability for rural applications. Conical collectors effectively grab and concentrate solar power compared to flat-plate collectors. Because of their geometric configuration, a higher surface area is exposed to the sun throughout the day, enhancing the absorption of heat. This is very vital in a rural setup, which needs to maximize the capture of energy since there may not be auxiliary sources of power. The thermal performance of conical solar water heaters has been studied by different researches. It was established that these systems have higher temperatures and greater efficiency compared to traditional flat-plate collectors, which makes them fit for use in domestic and small-scale industrial applications in rural areas.

The implementation of conical collector solar water heaters among rural communities brings a lot of benefits. First, it reduces dependence on non-renewable sources of energy, hence adding to environmental sustainability. Secondly, the reliable supply of hot water improves the living standards and supports local economic activities that require thermal energy. Further, these systems save the user money in the long term since they use free solar energy and have low maintenance costs.

Different departments of energy and agencies are supportive of the use of solar water heating systems, such as those with conical collectors. For example, the U.S. Department of Energy emphasizes that solar water heaters can be operated in any climate and that the fuel they use, namely sunshine, is free.

II. RELATED WORKS

Comprehensive research has been conducted on solar water heaters, particularly to enhance efficiency and cost-effectiveness for rural applications. Popular flat plate and evacuated tube collectors are marred by reduced efficiency at unfavorable solar incidence angles. To counter these limitations, conical collectors have been suggested as an alternative since they have high solar radiation collection efficiency during the daytime, with better thermal performance. Studies indicate that the use of conical configurations facilitates enhanced heat transfer and thermal stratification and hence they are most suitable for off-grid rural applications.

More recent research has explored the application of nano fluids, selective absorber coatings, and phase change materials (PCMs) to enhance the thermal efficiency of solar water heaters. Experimental research indicates that these improvements result in enhanced energy absorption and efficient heat retention. Simply put, the utilization of locally available, low-cost materials has been emphasized to make the technology economically feasible for rural applications. In addition to performance enhancement, studies also indicate the socio-economic benefits, including reduced dependence on conventional fuels, reduced carbon emissions, and enhanced living standards. Despite the promise of conical collector-based solar water heaters, extensive experimental validation and field investigations need to be conducted to optimize design parameters and provide long-term reliability under diverse environmental conditions.

III. PROPOSED SYSTEM

The proposed Conical Collector Solar Water Heater is an environmentally friendly and efficient water heating solution for rural applications. The system integrates a conical solar collector, reflector, water storage tank, and ESP8266 microcontroller-based automation system for ease of use and performance enhancement. The conical collector with its innovative geometry maximizes solar radiation absorption throughout the day, improving heat transfer efficiency. A strategically placed reflector maximizes solar energy collection by reflecting more sunlight on the collector surface.

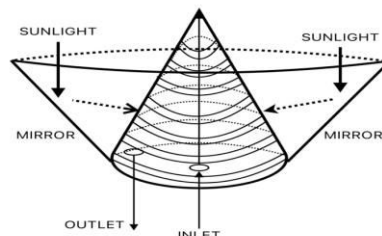


Fig: Proposed system design

The hot water is stored in an insulated water storage tank, which holds thermal energy for an extended period, providing hot water supply at any time. The system is automated using an ESP8266 microcontroller, which manages different components such as water pumps, battery, and different sensors. Temperature sensors provide heat level monitoring in the collector and storage tank, allowing real-time adjustments for optimal efficiency. A proximity sensor provides safe operation, while an LDR (Light Dependent Resistor) sensor provides solar intensity monitoring, allowing the system to adapt to different sunlight levels. A battery pack powers the control system and auxiliary components, allowing continuous operation even in low-light conditions. The smart and cost-effective solar water heating system is ideal for sustainable rural applications, minimizing the dependence on conventional energy sources while providing an efficient, automated, and easy-to-use solution for hot water supply. IoT-based monitoring integration enhances system performance, making it an effective and scalable solution for off-grid communities.

3.1 Block diagram

Fig 3.1.1: Block diagram of the proposed system

Block diagram Explanation

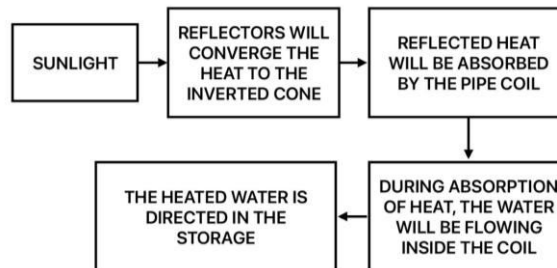


Fig: Hardware system block diagram

The block diagram of the Conical Collector Solar Water Heater represents the interconnections between key system components, ensuring efficient solar energy utilization and automated water heating. The system consists of four primary sections: solar reflector, conical collector, water inlet, and storage tank, each contributing to the overall functionality and efficiency of the heating Process.

1. Solar Reflector & Conical Collector:

The solar reflector is strategically positioned to enhance the absorption of solar radiation by directing additional sunlight onto the conical collector. The conical collector, with its optimized geometry, ensures uniform heat distribution and maximum solar energy capture throughout the day, overcoming the limitations of conventional flat plate collectors.

2. Water Inlet & Heating Process:

Cold water enters the system through the water inlet, which is controlled by a pump. As the water flows into the conical collector, it absorbs heat energy, raising its temperature. The use of high-efficiency materials and coatings on the collector surface minimizes thermal losses and enhances the heat transfer process.

3. Water Storage & Temperature Regulation:

The heated water is transferred to an insulated water storage tank, where it is preserved for extended use. A temperature sensor continuously monitors the water temperature, sending real-time data to the ESP8266 microcontroller. Based on the temperature readings, the controller regulates the operation of pumps and valves to maintain optimal heating and prevent overheating.

4. Automated Monitoring & Control System:

The system is coupled with an ESP8266 microcontroller, which regulates data from a number of sensors such as temperature, proximity, and LDR (Light Dependent Resistor) sensors. The LDR sensor detects sunlight intensity, regulating the operation of the system accordingly, while the proximity sensor maintains safety by identifying any outside interference. The control system is powered by a battery unit, guaranteeing continuous functioning even during low-light conditions. This energy-efficient and intelligent system offers an eco-friendly water heating solution for rural use with increased reliability, ease of operation, and long-term performance through automated monitoring and solar optimization.

IV. IMPLEMENTATION DETAILS

Objective: In order to design and build a conical collector-based solar water heating system that optimizes the utilization of solar energy, optimizes efficiency under low sun conditions, optimizes heat storage for extended use, and offers an environmentally friendly means of reducing the utilization of traditional energy sources.

System construction: The Conical Collector Solar Water Heater uses a conical collector with a reflector to maximize energy absorption. The hot water is stored in an insulated tank to conserve heat to the maximum. A microcontroller from ESP8266 regulates the operations with temperature, LDR, and proximity sensors to provide maximum efficiency. A power module with battery backup ensures stable, off-grid operations.

Control circuits: The control circuit utilizes an ESP8266 microcontroller to compute temperature, LDR, and proximity sensor readings to achieve maximum system efficiency. Relay modules are utilized to energize the water pump and heating depending on sensor readings to achieve automated and guaranteed operation.

Process of Implementation:

Hardware assembling: The hardware assembly consists of a conical collector mounted firmly on a base support for stability and optimal sun exposure. A solar reflector is mounted strategically on the collector to maximize radiation absorption. A heating pipe is threaded through the collector to transfer heat to the water, which is stored in an insulated tank. The entire structure is designed to be long-lasting, efficient in heat transfer, and easy to incorporate in rural application.

IOT integration: The ESP8266 microcontroller allows real-time monitoring by interfacing temperature, LDR, and proximity sensors and transmitting data over Wi-Fi for remote monitoring. Pumping and heating are controlled by relay modules via sensor input, enabling efficient, self-sustaining operation with minimal energy loss.

Cataloguing: The ESP8266 logs the sensor readings of temperature, solar irradiance, and system status to a mobile app via Wi-Fi for on-time monitoring. Data is logged to an Excel file for performance assessment as well. Meanwhile, the display unit provides real-time on-site measurement, allowing efficient monitoring and system optimization.

Execution logic: Execution logic of ESP8266 reads temperature sensors, LDR, and proximity sensors in an effort to control system operations. It toggles relay modules according to threshold values set in advance for the purposes of efficiency and automation, such as the pump and heating system. The display system provides real-time status.

DEMONSTRATIVE UNIT

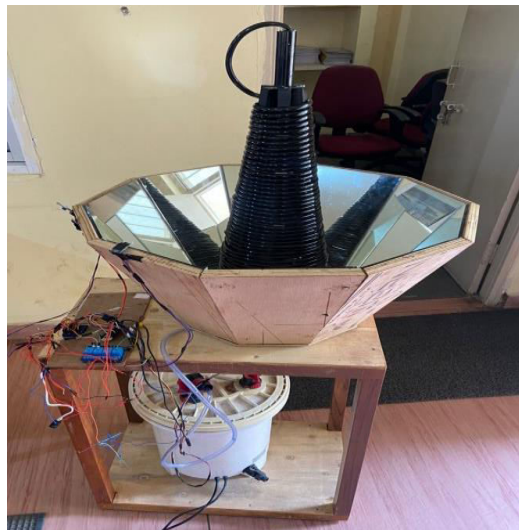


Fig: Operational model

The Conical Collector Solar Water Heater efficiently collects and utilizes solar radiation for water heating. A reflector of the sun enhances radiation collection by concentrating the sun's light onto the conical collector to attain uniform heat

distribution. Water passes through a heating tube within the collector, gaining heat energy before storage in an insulated tank for long-term storage.

Workflow Sequence

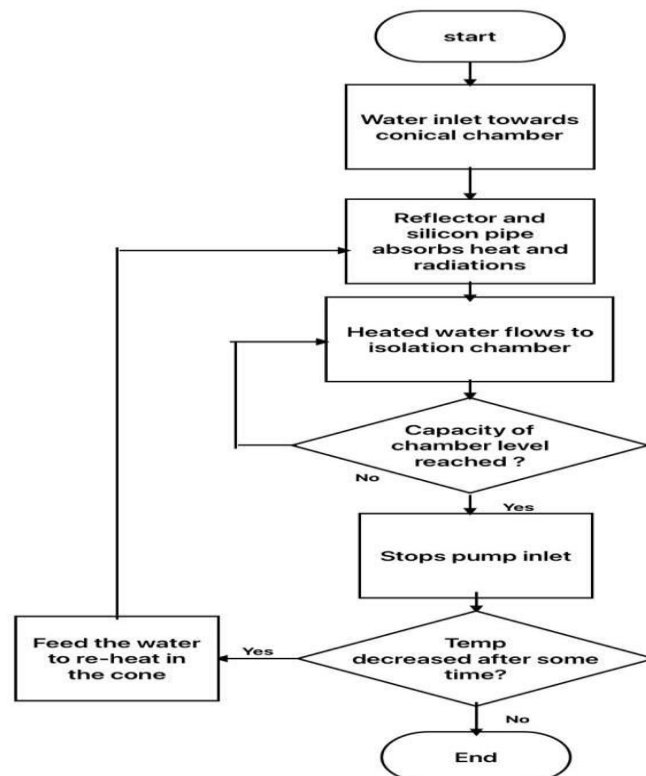


Fig: Flowchart of the process implemented.

V. HARDWARE DETAILS

ESP8266 Microcontroller

The ESP8266 microcontroller supports sensor data processing, automation, and wireless communication. It operates the pump and heating system via relay modules, processes temperature, LDR, and proximity sensor readings, and transmits data to a mobile application and Excel sheet to monitor remotely. It also updates the display unit for real-time system status.



Fig: ESP8266 NodeMCU

Proximity Sensor

The water level sensor monitors water levels in the storage tank by detecting the presence or absence of water at certain points. It sends real-time data to the ESP8266, which regulates the pump operation in a bid to optimize capacity and prevent dry running or overflow.



Fig: proximity sensor (water level detector)

Light dependent resistor (LDR)



Fig: LDR

LDR stands for Light Dependent Resistor. It is a resistor whose resistance depends on the intensity of light incident on it. In darkness, an LDR has high resistance, which decreases with the increase in light intensity. Because of this property, LDRs are used in automatic lighting circuits, light meters, and alarm circuits

Relay module



Fig: 4 Channel Relay modules

The relay module controls the water pump and heating system by switching high-power devices on and off according to ESP8266 signals. The module is automated, switching devices on or off according to sensor readings, to provide efficient and safe system operation.

Temperature Sensor

The DS18B20 temperature sensor is utilized to sense the water temperature of the conical collector and storage tank precisely. The DS18B20 temperature sensor is connected to the ESP8266 using a one-wire interface and gives real-time temperature output for system control. Based on readings, the microcontroller regulates the relay module to achieve maximum heating and prevent overheating.



Fig: DS18B20 Temperature sensor

IR Sensor

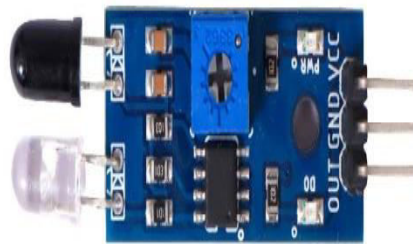


Fig: Infrared sensor

The IR sensor detects objects or liquid levels through emission of infrared signals and detecting reflected response. It monitors water levels in the storage tank and provides correct flow control in the Conical Collector Solar Water Heater. The ESP8266 microcontroller reads the data from the sensor to control pump operation automatically without causing overflow or dry running, hence enhancing system efficiency and reliability.

Display module

The small LED display provides real-time system status by displaying temperature, water level, and sensor data. It receives signals from the ESP8266 microcontroller, which processes inputs from temperature, proximity, and LDR sensors. This ensures users can monitor system performance at a glance, enhancing efficiency and ease of operation.



Fig: Display unit

Water pump



Fig: water pump (DC motor)

The controlled water supply is provided by the water pump from the conical collector to the storage tank. The pump works according to the ESP8266 signals, which calculate the input from level and temperature sensors. The relay module controls its operation, providing effective water circulation, avoiding dry running, and optimal heating performance.

VI. PERFORMANCE ANALYSIS

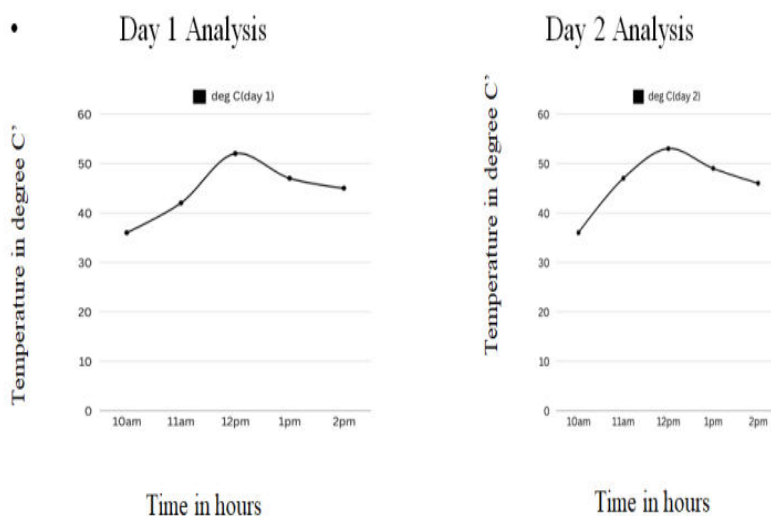


Fig: Shows the 2 days of heating process

The above figure illustrates a graph of temperature vs. time for two successive days, comparing the performance of solar water heating. Both the graphs have the same pattern, with temperature rising from 10 AM, reaching a peak around 12 PM, and then gradually falling after that. The peak temperature is around 50–55°C on both days, indicating proper absorption of solar energy. The pattern of falling temperature after noon indicates lesser solar intensity, which affects the retention of heat. This analysis illustrates the effectiveness of the system in trapping and retaining thermal energy throughout a day.

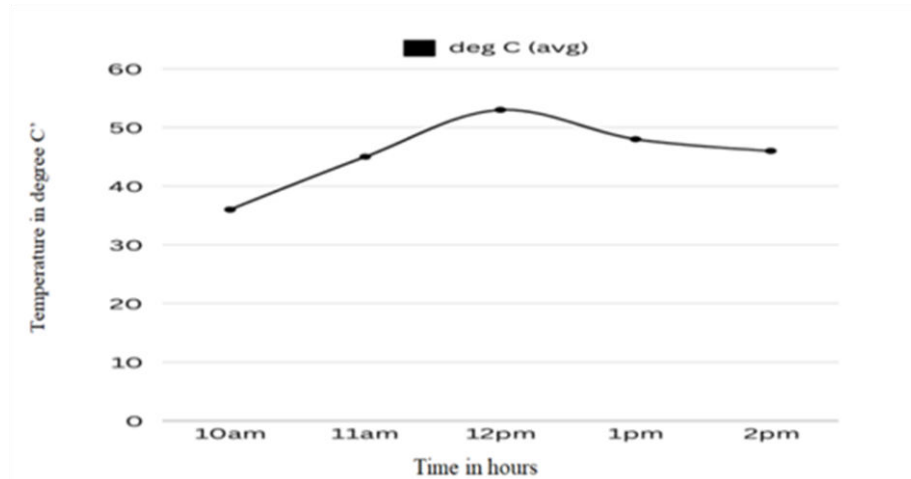


Fig: Average performance of 2 days

The above graph indicates the temperature variation with time in a solar water heater. The temperature increases slowly from 10 AM, peaks at around 12 PM at a level of about 50–55°C, and then decreases. This indicates efficient absorption of solar energy and storage of the heat during the day.

VII. CONCLUSION

The design maximizes heat uptake during sunlight peak hours using spirally located heating pipes for optimal radiation collection and a 60-degree inclined reflector for greater energy utilization. Effective recirculation is ensured in the storage chamber by several inlets and outlets, with continuous heating of water. IoT integration enables real-time temperature, water level, and solar radiation monitoring for effective system operation. A new recirculation mechanism enhances efficiency further by reheating cooled water, ensuring stable thermal performance and reliability.

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