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INVESTIGATION OF PARABOLIC PLATE SOLAR WATER HEATER WITH PCM

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ABSTRACT

The research of a parabolic plate solar water heater with phase change material (PCM) is intended to improve the efficiency of solar thermal energy storage and utilization. The research examines the thermal performance, heat retention, and energy efficiency enhancement by adding PCM to the system. The parabolic plate shape enhances solar energy absorption, while the PCM traps surplus heat and discharges it at times of low solar intensity to provide a steady supply of hot water. Experimental and analytical techniques are used to analyze temperature differences, heat transfer behavior, and system efficiency. The results confirm that combining PCM with a parabolic plate solar water heater greatly enhances thermal stability and prolongs heat availability, and thus it is a good option for sustainable water heating systems.

Keywords: Parabolic Plate, Solar Water Heater, Phase Change Material, Thermal Energy Storage, Heat Transfer, Energy Efficiency.

I. INTRODUCTION

Solar energy is a clean and renewable resource that can efficiently be used for water heating purposes. Among different solar water heating systems, the parabolic plate solar water heater provides better thermal performance because of its concentration and absorption of solar radiation. Nonetheless, one of the main drawbacks of traditional solar water heaters is the intermittent supply of solar energy, resulting in unstable temperatures of water. In order to overcome this constraint, phase change materials (PCMs) are integrated in this research. PCMs can absorb surplus solar thermal energy at times of maximum sunshine and supply it when there is low solar radiation, thereby providing a stable and longer duration hot water supply. This research emphasizes the thermal performance, heat retention capacity, and total efficiency of a parabolic plate solar water heater with PCM integration. By increasing heat storage and maximizing energy utilization, this system offers a sustainable and efficient system for domestic and industrial water heating.

II. LITERATURE REVIEW

Solar water heating systems have been widely researched as a renewable substitute for traditional water heating techniques. Engineers and scientists have tried different designs, materials, and storage methods to increase their efficiency and durability. One of the key developments in this area is the incorporation of Phase Change Materials (PCMs), which enhance heat storage and energy efficiency. Conventional solar water heaters use flat plate collectors or evacuated tube collectors to collect solar radiation and distribute heat to water. Parabolic plate collectors, which are more efficient, concentrate sunlight onto an absorber plate, resulting in better thermal efficiency. Research conducted by Sharma et al. (2020) has established that parabolic concentrators can reach higher temperatures than flat plate collectors and are, therefore, appropriate for domestic and industrial use.

PCMs have extensive applications in thermal energy storage because they can absorb and release latent heat upon phase transitions. Kumar and Saini (2019) showed through their study that the integration of PCMs in solar water heaters can minimize temperature fluctuations and prolong hot water availability. Paraffin wax and salt hydrates have been used extensively as PCMs because they possess high latent heat storage capacity and thermal stability.

Research by Zhang et al. (2021) identifies that the inclusion of PCMs in solar water heaters enhances heat retention and system efficiency, especially at night or during cloudy conditions. Experimental research by Singh and Verma (2022) shows that PCM-equipped solar water heaters can retain water temperatures 10-15°C higher than those of traditional systems without storage enhancement. Additionally, maximizing the PCM encapsulation and position within the system is vital for effective heat transfer.

In spite of the advantages, drawbacks like low thermal conductivity of PCM, leakage, and material degradation over time have to be resolved. Researchers are looking into nano -enhanced PCMs, better heat exchangers, and hybrid storage systems to eliminate these disadvantages. Future research should emphasize cost-effective and environmentally friendly PCM alternatives to increase the commercial potential of PCM-integrated solar water heaters.

In summary, research indicates that combining PCM with solar water heaters, especially parabolic plate systems, improves energy storage and thermal stability. More research is required to optimize PCM selection, enhance heat transfer mechanisms, and provide long-term reliability for mass adoption.

III. OBJECTIVES OF THE PAPER

The key aim of the present study is to explore the performance improvement of a parabolic plate solar water heater with an integrated phase change material (PCM) for enhanced thermal energy storage. The thermal performance of the system with and without PCM is to be evaluated in this work, considering whether it can ensure better heat preservation and temperature control. In addition, the research is aimed at evaluating the effect of PCM on providing a constant supply of hot water even during low solar radiation. Another important aim is to optimize the design and material choice to achieve maximum heat transfer efficiency with minimum thermal losses. In addition, the energy efficiency of the PCM-based system is compared with traditional solar water heaters to emphasize its benefits. Finally, the research seeks to determine possible challenges and recommend enhancements in PCM use for solar thermal systems to ensure long-term reliability and sustainability of the system.

Key objectives of the study include:

- Examine the effectiveness of a parabolic plate solar water heater with and without the integration of PCM.
- Evaluate the capacity of PCM to absorb and release heat in maintaining consistent water temperatures.
- Compare the PCM-integrated system with typical solar water heaters to measure gains in energy usage.
- Enhance material choice and system design to achieve maximum heat transfer and losses.
- Discuss possible problems with integration of PCM and suggest solutions for long-term dependability and sustainability.

IV. METHODOLOGY

System Design And Configuration:

The configuration and design of the parabolic plate solar water heater with PCM are critical in determining its thermal efficiency and performance. The arrangement includes a parabolic plate collector, which is intended to focus solar radiation onto an absorber plate in order to achieve maximum heat absorption. The absorber plate, usually constituted by high thermal conductivity materials such as copper or aluminum, is covered with a selective surface for the reduction of heat losses. Below the absorber plate, a phase change material (PCM) storage device is incorporated for storing surplus thermal energy during intense sunshine hours and discharging the same when solar radiation is reduced. The PCM is properly chosen for its melting point, thermal conductivity, and latent heat storage, which are responsible for efficient retention and transfer of heat. The water storage tank is insulated to reduce heat dissipation and water temperature retention over long durations. Moreover, temperature sensors, flow meters, and data loggers are also provided to monitor system operation, such as temperature fluctuations, heat storage, and discharge cycles. The entire system configuration is designed to maximize heat transfer, reduce energy losses, and ensure a safe and sustainable supply of hot water.

Selection of Phase Change Material:

The choice of an effective phase change material (PCM) is an important factor for improving the thermal efficiency of a parabolic plate solar water heater. The desired properties of the PCM include high latent heat storage capacity, optimum melting point, good thermal conductivity, and chemical stability for improving the heat absorption and release. Paraffin wax, salt hydrates, and fatty acids are some of the common types of PCMs used for solar water heating purposes, with varying benefits derived from the thermal characteristics of each. Paraffin wax is popularly used because of its non-corrosive nature, thermal stability, and low cost, with salt hydrates having better thermal conductivity but being susceptible to super cooling and phase separation problems. The chosen PCM should have a melting point within the intended operating temperature range of the solar water heater to efficiently store and utilize energy. Furthermore, encapsulation techniques of PCM, including metal containers or composite materials, are taken into consideration to enhance heat transfer efficiency as well as avoid leakage. The appropriate PCM selection and its integration in the system go a long way in ensuring the stability of hot water supply, minimizing energy fluctuation, and enhancing the solar water heating system's overall efficiency.

- The chosen PCM must demonstrate stability over several thermal cycles with very little degradation or phase separation when subjected to repeat heating and cooling.
- The PCM must be eco-friendly, non-toxic, and non-flammable for safe operation and minimal environmental influence.
- The economic viability of the PCM, such as its availability, durability, and maintenance needs, needs to be assessed for viable implementation.
- The PCM must not chemically interact with the absorber plate, encapsulation material, or storage tank for water, preserving long-term performance and integrity.

Experimental Setup and Testing:

The parabolic plate and testing of the parabolic plate solar water heater with PCM entail designing and constructing a system to assess its thermal performance in actual working conditions. The setup is composed of a parabolic plate collector, an absorber plate, a water storage tank, and a PCM-integrated thermal storage unit. The parabolic plate is set to collect maximum solar radiation, concentrating heat on the absorber plate that transfers energy to the PCM and water. Thermocouples and temperature sensors are located at various points, such as the absorber plate, PCM storage device, and water inlet/outlet, to measure temperature changes. A flow meter is provided to monitor the rate of water circulation, while a data logger records temperature variations and system performance continuously during the day. Testing is performed under different solar radiation conditions, with parameters like ambient temperature, water temperature, PCM charging/discharging characteristics, and efficiency being examined. The performance of the PCM-integrated system is compared with a reference conventional solar water heater to evaluate enhancements in heat retention, temperature stability, and energy efficiency. Experimental data is also validated through multiple test cycles to ensure the system reliability and efficiency for hot water applications on a sustainable scale.

Performance Evaluation Parameters:

The performance of the parabolic plate solar water heater with PCM is measured in terms of a number of important parameters that decide its efficiency, heat retaining capacity, and total thermal performance. These parameters are used to estimate the effect of PCM integration and compare it with that of traditional solar water heating systems. Stability of water temperature is an essential parameter, which measures how well the system maintains a stable hot water supply over a period of time, particularly during low radiation periods. Efficiency of retaining heat assesses the ability of the PCM to retain excess thermal energy during the most intense sunshine hours and release it when needed. Energy efficiency is studied by computing the ratio of useful heat obtained by the water to the amount of solar energy falling on the system. The charging and discharging behavior of PCM is studied to find the time taken for total melting and solidification so that efficient energy utilization is ensured. Also, thermal losses from the system are computed to evaluate insulation efficiency and reduce unnecessary heat loss. Through this analysis of parameters, the study offers insight into the efficacy of the integration of PCM towards improved solar water heating performance and the provision of a consistent, energy-efficient solution.

- It measures the system stability in keeping the water temperature uniform over time.
- It assesses the ability of PCM to retain and release heat efficiently.
- Measures the amount of useful heat received by the water relative to the amount of solar energy input.

- Identifies the amount of time that PCM takes to melt (charge) and solidify (discharge).
- Examines heat dissipation from the system in order to determine insulation efficiency and reduce energy loss.

Limitations and Uncertainties:

Despite the benefits of incorporating phase change material (PCM) within a parabolic plate solar water heater, there are certain limitations and uncertainties that influence its overall performance. One of the key issues is the low thermal conductivity of certain PCMs, which can restrict effective heat transfer, resulting in irregular temperature distribution and increased charging/discharging time. In addition, repeated thermal cycle degradation of PCM could diminish its long-term reliability and efficiency. A further uncertainty results from super cooling and phase separation concerns, especially with salt hydrates, which could have a negative effect on heat storage and discharge. External environmental conditions, such as solar radiation, ambient temperature, and wind speed changes, bring with them inconsistencies in system performance so that it becomes challenging to provide similar results across different test conditions. In addition, leakage and encapsulation failure of PCM materials are issues regarding durability, where high-end containment technologies are necessary. Finally, the economic viability of PCM-integrated systems is still a challenge due to the expense of high-performance PCMs and system adaptation potentially influencing mass-market uptake. These challenges will be overcome by enhanced material choice, thermal conductivity enhancements, and more advanced insulation solutions in order to optimize the efficiency and sustainability of PCM-based solar water heaters.

Architecture of Parabolic Plate Solar Water Heater:

The parabolic plate solar water heater with PCM architecture is made to effectively harness, store, and make use of solar energy for heating water while promoting retention of heat through phase change material (PCM) integration. The setup includes a parabolic plate collector, which concentrates and concentrates solar radiation on an absorber plate of high thermal conductivity material such as copper or aluminum. Underneath the absorber plate, a PCM storage unit is also included to save excess thermal energy during peak sunny hours and emit it when solar radiation is low, providing continuous hot water supply. The hot water is kept in a well-insulated water tank in order to minimize heat losses and ensure consistent temperatures for long periods of time. Sensors like thermocouples, flow meters, and data loggers are placed at strategic positions to track system performance, such as changes in temperature, heat retention, and energy efficiency. The whole configuration is designed for maximum heat collection, effective thermal storage, and low energy losses, which is a cost-effective and efficient alternative for residential and industrial hot water applications. Components of the Architecture

- Parabolic Plate Collector - Concentrates solar radiation on the absorber plate for optimal heat collection.
- Absorber Plate – Relays absorbed heat to the water as well as to PCM for proper thermal storage.
- Phase Change Material (PCM) Storage Unit – Stores heat and releases heat to keep water temperature constant.
- Water Storage Tank – Thermally insulated storage tank that keeps the hot water and reduces heat losses.
- Instrumentation and Sensors – Thermocouples, flow meters, and data loggers to measure system performance.
- Supporting Structure and Insulation – Provides stability, durability, and resistance to environmental heat losses.

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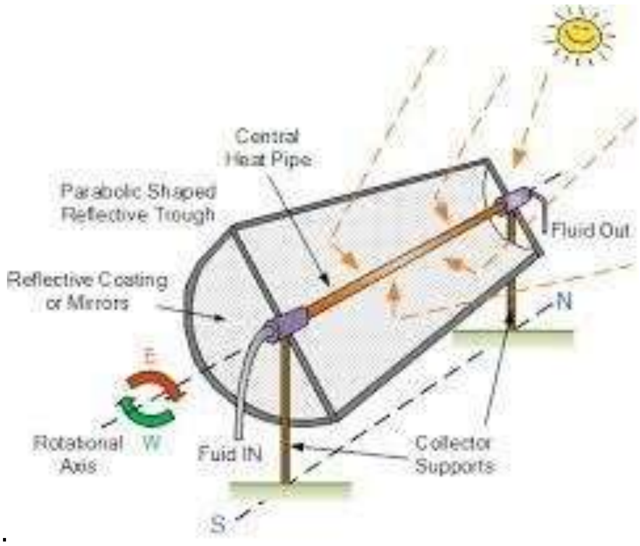

Fig 1: Parabolic Plate Architecture

Flow Diagram:

The operation of a parabolic plate solar water heater with PCM is based on a methodical process in order to effectively harness, store, and use solar energy. The process starts with the parabolic plate collector, which is made in such a way that it will concentrate and focus solar radiation on the absorber plate. The absorber plate, constructed of a high thermal conductivity material like copper or aluminum, takes in the incoming heat and distributes it to the water-carrying tubes and the phase change material (PCM) storage unit below it. At the time of maximum sunshine, the PCM stores and absorbs surplus thermal energy in the form of latent heat as it transforms from a solid to a liquid state. As the water passes through the system, it picks up heat from both the absorber plate and stored thermal energy in the PCM.

When solar radiation is low, for example, in the evening or during cloudy weather, the PCM releases stored heat gradually, providing a steady supply of hot water even when direct sun is not available. The hot water is then stored in an insulated storage tank, reducing heat loss and ensuring a constant temperature for prolonged periods. Sensors like thermocouples, flow meters, and data loggers constantly measure temperature fluctuations, system efficiency, and PCM phase change. The entire system runs on a thermosiphon or pump-assisted circulation system, depending on the system configuration, to achieve maximum heat transfer and energy efficiency. By combining PCM with a parabolic plate solar water heater, this system greatly increases thermal storage capacity, stabilizes water temperature, and prolongs heat availability, rendering it a secure and energysaving option for residential and industrial uses.

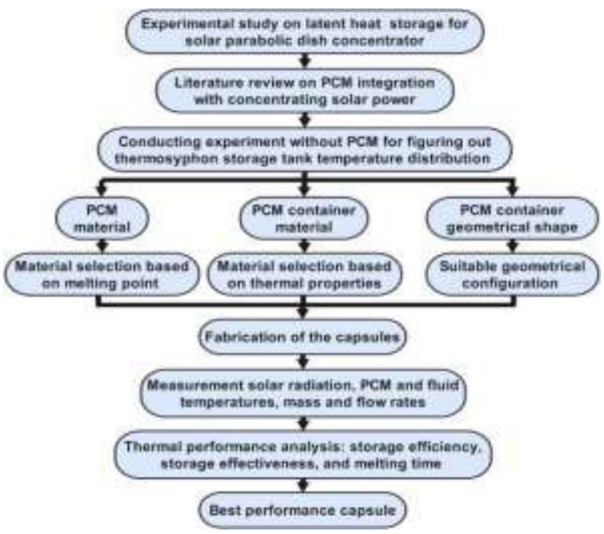

Fig 2: Flow Diagram

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V. IMPLEMENTATION

The implementation of a parabolic plate solar water heater with PCM involves a well-organized process to ensure efficient energy capture, storage, and utilization. The process starts with the parabolic collector design and fabrication, which is curved to concentrate solar radiation onto an absorber plate for optimum heat absorption. The absorber plate is provided with a selective surface material to maximize heat retention and is integrated with a water circulation system and a PCM storage unit. The PCM is selected with great care considering its melting point, thermal conductivity, and stability to efficiently store and release heat. The system is placed at an optimum tilt angle to ensure maximum solar exposure during the day. The thermal performance is assessed by real-time monitoring with the help of thermocouples, data loggers, and flow meters to monitor temperature fluctuations, energy efficiency, and heat retention properties.

The water storage tank is properly insulated to reduce heat losses, and a circulation system thermosiphon or pump-assisted flow is integrated for effective heat transfer. Periodic maintenance and optimization are necessary to overcome possible issues like PCM leakage, degradation, or low thermal conductivity. By effectively adopting this system, users can gain increased thermal energy storage, less reliance on traditional heating sources, and greater sustainability, which makes it a perfect solution for residential, commercial, and industrial uses. Other

Important Points regarding Parabolic Plate Solar Water Heater with PCM

- Increased Efficiency – The parabolic shape guarantees optimal solar energy absorption, enhancing overall heating efficiency.
- Improved Thermal Storage – Incorporation of PCMs enables extended heat retention, making hot water available even after sunset.
- Environmentally Friendly and Sustainable – Minimizes dependence on traditional fossil fuels, encouraging use of renewable energy.
- Temperature Stability – PCM facilitates stabilization of water temperature fluctuations, ensuring consistent heating performance.
- Energy and Cost Savings – While higher initial installation costs, long-term energy bill savings make it economically worth it.
- Scalability and Uses – Can be tailored to small household use or large industrial space heating applications.
- Integration with Smart Systems – Can be integrated with IoT -based monitoring for enhanced efficiency monitoring and remote operation.

VI. FUTURE SCOPE OF PARABOLIC PLATE SOLAR WATER HEATER

- Development of Advanced PCM Materials – Research on high thermal conductivity PCMs, nano enhanced PCMs, and composite materials can enhance heat storage efficiency and minimize thermal losses.
- Integration with Smart and IoT-Based Monitoring Systems – Incorporating automated control systems, sensors, and IoT-based real-time monitoring can facilitate performance tracking and optimization.
- Hybrid Solar Water Heating Systems – Blending parabolic plate solar water heaters with other renewable energy sources, including photovoltaic (PV) panels or wind power, can enhance efficiency and reliability of the energy.
- Advanced PCM Encapsulation Techniques – Creating waterproof and resistant encapsulation techniques for PCMs can lengthen their lifespan and thermal efficiency and reduce degradation problems.
- Scalability for Industrial Uses – Scaling up the application of PCM-integrated solar water heaters to industrial-scale processes, hotels, hospitals, and agriculture can foster sustainable heating practices.
- Cost Reduction and Commercial Feasibility – Studies on low-cost materials, better manufacturing processes, and government subsidies can reduce the cost of PCM-based solar water heaters and make them commercially viable for mass use.

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VII. CONCLUSION

The parabolic plate solar water heater with PCM is an extremely efficient and sustainable water heating solution using solar energy and thermal energy storage. The use of phase change material (PCM) increases the system's capability to store and release heat, providing a steady supply of hot water even during low or zero sunlight periods. The parabolic plate collector minimizes energy loss from solar energy, while the PCM enhances heat storage and energy efficiency, minimizes dependence on traditional forms of heating, and experimental and performance assessments show that the use of PCMs in solar water heaters provides better temperature stability, enhanced thermal storage ability, and long-term energy savings. In spite of some limitations like PCM thermal conductivity constraints and initial installation expenses, innovation in material selection, system design, and intelligent automation can further enhance its efficiency.

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