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A SOLAR ENERGY DRIVEN HEAT PIPE ASSISTED PCM THERMAL STORAGE SYSTEM FOR IMPROVED THERMAL MANAGEMENT

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Abstract — In contemporary engineering systems, efficient energy use and temperature control are significant issues, particularly in renewable energy applications. The design and analysis of a solar-assisted thermal management system that combines thermal storage units, copper heat transfer pipes, and phase change materials (PCMs) are presented in this research. The system's main heat source is solar energy, which is then transferred to a PCM storage module via a copper pipe construction. The PCM stabilizes temperature swings and increases energy efficiency by absorbing heat during the melting process and storing thermal energy as latent heat. In order to improve heat transfer between the pipe and the PCM chamber and enable quicker charging and discharging of stored heat, copper fins are included. A connected thermal storage system can subsequently release the thermal energy that has been saved for useful purposes. The project's main objectives are to design an effective heat transfer path, choose appropriate PCM materials, and assess the integrated system's thermal performance. It is anticipated that the outcomes will show superior energy storage capacity, better thermal management, and increased system efficiency. The development of sustainable solar-based thermal management and energy storage technology is aided by this research.

Keywords: Solar Thermal System, Phase Change Material, Copper Pipe Heat Transfer, Thermal Storage, Renewable Energy.

I.INTRODUCTION

The world's energy demand is constantly rising as a result of rapid industrialization and technological advancement. Fossil fuels and other conventional energy sources are scarce and greatly exacerbate climate change and environmental damage. Renewable energy technologies are therefore becoming more significant as sustainable substitutes. Solar energy is one of the most plentiful, clean, and accessible renewable energy sources. In many engineering applications, the efficient use and storage of solar thermal energy continue to be major issues.

The Systems for storing thermal energy are crucial for increasing solar energy systems' dependability and efficiency. Phase Change Materials (PCMs) are one of the best ways to store thermal energy. Large amounts of thermal energy are stored and released by PCMs during phase transitions, which usually occur between solid and liquid states. They are able to maintain thermal stability in the system by absorbing excess heat when temperatures rise and releasing stored heat when temperatures fall.

The efficiency of thermal storage systems also depends heavily on heat transmission mechanisms. Because of their longevity and high thermal conductivity, copper pipes and heat transfer fins are frequently utilized. These elements aid in the effective transport of heat from the solar source to the PCM chamber. By increasing the surface area for heat transfer, the use of copper fins allows the PCM material to absorb thermal energy more quickly.

In this project, a copper pipe heat transfer mechanism combined with a PCM storage chamber and thermal storage unit is used to construct a solar-powered thermal management system.

The copper pipe in the system transfers solar heat to the PCM chamber, where the PCM absorbs and stores the thermal energy. Later, the heat is moved to a thermal storage module at the system's bottom that is connected by fins.

This project's primary goal is to assess how well various PCM materials store and release solar thermal energy. The system attempts to increase thermal efficiency and energy use by combining solar energy with PCM-based thermal storage and copper pipe heat transmission mechanisms.

II. THEORETICAL BACKGROUND

A. Solar Thermal Energy Utilization

Solar thermal systems use solar collectors or absorbent surfaces to transform solar radiation into useful heat energy. For later usage, the heat that has been gathered is moved to working fluids or storage systems. Effective thermal energy storage devices are required since solar energy is sporadic owing to weather changes and the day-night cycle. By storing extra thermal energy during periods of high sunshine and releasing it when needed, solar-powered thermal storage technologies contribute to a steady supply of energy. The sustainability and dependability of thermal systems based on renewable energy are greatly increased when solar systems are integrated with effective storage methods.

B. *Phase Change Materials for Thermal Storage*

Phase Change Materials (PCMs) are widely used for thermal energy storage because they can absorb and release large amounts of latent heat during phase transition. When heat is supplied, the PCM absorbs thermal energy and melts, storing energy without a significant rise in temperature. When the temperature drops, the PCM solidifies and releases the stored heat. Organic PCMs such as paraffin wax are commonly used due to their chemical stability, non-corrosive nature, and suitable melting temperature range. However, a major limitation of PCMs is their low thermal conductivity, which reduces the rate of heat transfer. Therefore, integrating PCMs with efficient heat transfer systems is essential for improving thermal storage performance.

C. Heat Pipe Assisted Heat Transfer

Heat pipes are extremely effective passive heat transfer devices that use the evaporation and condensation of a working fluid inside a sealed pipe to transport heat. The three primary components of heat pipes are the condenser, adiabatic portion, and evaporator. The working fluid evaporates and moves toward the condenser section, where it releases heat and condenses, when heat is applied at the evaporator portion. The wick structure's capillary action allows the condensed liquid to return to the evaporator. Heat pipes can carry heat over great distances with little temperature difference because of their exceptionally high thermal conductivity. Heat dispersion is enhanced and the rate of thermal energy storage and release is accelerated when heat pipes are integrated with PCM storage devices.

III. PROPOSED SYSTEM DESIGN

The absorber surface absorbs solar light and transforms it into thermal energy. After that, the heat is moved into the PCM chamber via the copper pipe. Copper is used because of its longevity, high thermal conductivity, and resistance to corrosion.The PCM stores thermal energy as latent heat by absorbing the incoming heat and changing from a solid to a liquid. The PCM chamber's copper fins expand the surface area available for heat transfer and evenly disperse heat throughout the storage medium. The PCM solidifies and progressively releases the heat it has accumulated during the cooling phase, preserving the system's temperature stability.This design guarantees improved heat management for solar thermal systems and increases the efficiency of thermal energy storage.

IV. WORKING PRINCIPLE

The suggested system's operation is predicated on latent heat storage, conduction heat transfer, and solar heat absorption. Thermal energy is produced when solar radiation strikes the absorber plate. Conduction carries this heat to the PCM chamber via the copper pipe. The PCM melts when the temperature rises because it absorbs heat. The PCM retains a lot of energy during this phase transition without experiencing a noticeable rise in temperature.

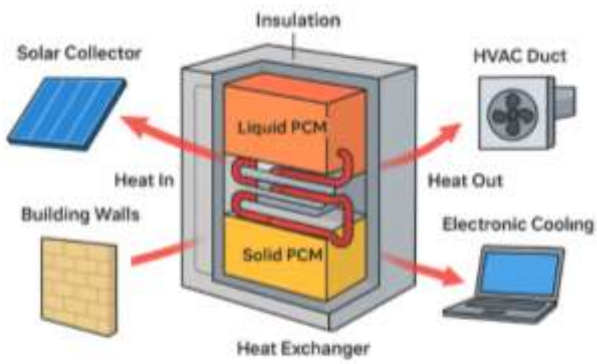

Fig. 1 Working Concept of PCM-Based Thermal Management System

The PCM's melting rate is accelerated and heat is distributed more evenly thanks to copper fins installed inside the PCM chamber. Until the ambient temperature drops, the thermal energy that has been stored stays inside the PCM. The PCM starts to solidify and gradually releases the heat it has collected during the cooling phase. Even when solar energy is diminished, this process keeps the temperature steady and offers a steady supply of heat.

V. EXPERIMENTAL SETUP

The experimental setup consists of a fabricated thermal storage unit integrated with a copper heat transfer pipe and PCM chamber. The main components of the setup include:

PCM material is filled inside the storage container surrounding the copper pipe and fins. When heat is supplied to the system, the copper pipe transfers heat to the PCM

Fig. 2 Fabricated Experimental Setup for PCM Based Thermal Management System

Temperature measurements are taken at different locations including the heat source, copper pipe, PCM chamber, and outer surface. The melting and solidification behavior of the PCM is observed and recorded to analyze the thermal performance of the system. A heat source, a copper pipe for heat transfer, a PCM storage chamber, fins, and temperature measurement devices make up the experimental setup of the suggested solar-powered heat pipe assisted PCM-based thermal storage system. Heat is transferred to the PCM chamber via the copper pipe by the heat source, which mimics solar thermal input. After absorbing the heat, the PCM changes from a solid to a liquid, storing thermal energy as latent heat. The PCM's melting rate is increased and heat transport is improved by the introduction of copper fins. To track the dispersion of heat and assess the system's thermal performance, temperature sensors are positioned at various points.

VI. EXPERIMENTAL ANALYSIS

To assess the PCM-based thermal storage system's thermal performance under regulated heating settings, experimental testing was carried out. The PCM progressively absorbed heat during the heating phase, changing from a solid to a liquid. Latent heat absorption was indicated by the temperature's relative stability during the phase transition. The use of copper fins shortened the time needed for the PCM to melt completely and enhanced heat dispersion. The PCM released its stored heat as it solidified during the cooling phase. Compared to traditional sensible heat storage systems, the system sustained a constant temperature for a longer period of time. The findings show that thermal storage capacity and heat transfer efficiency are greatly increased when PCM and copper heat transfer components are combined.

VII. CONCLUSION

The design and experimental analysis of a solar-powered heat pipe assisted PCM-based thermal storage system for improved thermal management were given in this study. The system efficiently regulates temperature by combining latent heat storage with solar thermal energy gathering. Large amounts of thermal energy can be stored during phase transition when PCM is used, and heat transport between the heat source and the storage medium is enhanced using copper heat pipes. The PCM's charging and discharging capabilities are further improved by copper fins, which further increase heat distribution. The suggested system can efficiently store and release thermal energy, according to experimental data, which makes it appropriate for thermal management systems and renewable energy applications.

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