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SOLAR THERMAL ENERGY STORAGE BY PHASE CHANGING MATERIAL (PCM): A COMPARATIVE ANALYSIS

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Abstract: Energy storage and supply in solar thermal collector systems are major functions of phase change materials (PCM). Optimal parameters for energy discharge time (tPCM) and net amount of stored energy (Qnet) in these materials must be obtained to maximise the performance of solar thermal collectors. This study utilises a MATLAB simulator built around a multi-objective evolutionary algorithm that uses a decomposition strategy for optimization. The simulation results show that these two goals are in direct opposition to one another. When everything is just right, tPCM is high and Qnet is low. Based on the results of the research into the impact of the input parameters on the goal functions, it has been determined that the mass of PCM and the mass flow rate of the input water are both at their minimum and maximum values, respectively, under ideal conditions. A closer look at the effect of tube inner diameter on tPCM's objective function reveals that as tube diameter grows, so does the amount of time it takes for the energy within to be discharged. The amount of energy stored in PCM grows when the tube diameter is increased while other system parameters are held constant.

Keywords: Solar thermal collector; PCM; Storage tank diameter; Building energy system; Energy storage.

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1. Introduction:

Phase change materials (PCMs) are often used in solar thermal storage systems to improve their performance and efficiency. When used in solar thermal storage, PCMs can store large amounts of thermal energy by absorbing and releasing heat during their phase transitions. Solar thermal storage systems using PCMs typically involve circulating a fluid, such as water or a heat transfer fluid, through a heat exchanger to absorb solar energy. The fluid is then circulated through a container filled with PCMs, which absorbs the excess thermal energy and stores it as latent heat[1]. As the fluid cools, the PCM releases the stored heat, maintaining a consistent temperature in the system. One of the main advantages of using PCMs in solar thermal storage is that they can store a large amount of energy in a relatively small volume compared to other storage materials [2]–[4]. Additionally, PCMs have high energy storage density, which means that they can store a large amount of thermal energy in a small mass. Using PCMs in solar thermal storage can also improve the efficiency of the system by reducing heat losses during storage and minimizing the need for additional insulation. Additionally, PCMs can help to extend the operating time of the solar thermal system by storing excess thermal energy for use during periods of low solar radiation or at night. Overall, the use of PCMs in solar thermal storage systems can help to increase the efficiency, reliability, and performance of the system while reducing its environmental impact [5].

A solar thermal storage system is a type of energy storage system that uses solar energy to heat a material, usually a fluid or solid, which is then stored for later use. The stored thermal energy can be used to provide space heating, domestic hot water, or to generate electricity using a steam turbine. Solar thermal storage systems have several advantages over other types of energy storage systems, such as batteries[6]. They have a longer lifespan, are more environmentally friendly, and are better suited for large-scale storage applications. Additionally, solar thermal storage systems can be combined with other renewable energy sources, such as wind and hydroelectric power, to provide a reliable and sustainable energy supply[7].

Solar thermal storage systems have several applications in different sectors. Some of the common applications of solar thermal storage systems include[8], [9]:

- Heating buildings: Solar thermal storage systems can be used to heat buildings by storing thermal energy during the day and releasing it at night or during periods of low solar radiation. This can help to reduce the energy consumption of buildings and lower heating costs.
- Domestic hot water: Solar thermal storage systems can be used to provide hot water for domestic use, such as showering and washing dishes. The thermal energy stored during the day can be used to heat water at night or during periods of low solar radiation.
- Industrial processes: Solar thermal storage systems can be used in industrial processes that require high-temperature heat, such as metal smelting and chemical manufacturing. The stored thermal energy can be used to generate steam, which can then be used in various industrial processes.
- Electricity generation: Solar thermal storage systems can be used to generate electricity by using the stored thermal energy to drive a steam turbine. This can be particularly useful in remote areas where access to the grid is limited or non-existent.
- Agriculture: Solar thermal storage systems can be used in agriculture to provide heat for greenhouses and to warm water for livestock.

Overall, solar thermal storage systems have a wide range of applications and can provide a reliable and sustainable source of energy in various sectors. Thermal energy storage systems have been extensively researched and studied in recent years due to their potential to improve the efficiency and reliability of renewable energy systems. Here are a few examples of recent literature on thermal energy storage systems.[8] This paper provides a comprehensive review of phase change material (PCM) thermal energy storage technologies, including the advantages and disadvantages of each technology. [10]This paper reviews recent developments in sensible heat thermal energy storage systems, including advancements in materials, designs, and applications. [11] This paper provides an overview of thermal energy storage systems used in concentrated solar power plants, including the different types of storage systems, their operation, and their integration with solar thermal power plants. [12]This paper provides a comprehensive review of thermal energy storage systems for buildings, including sensible and latent heat storage systems, and their applications in heating, cooling, and hot water systems. [13]This paper provides an overview of recent advances in thermochemical energy storage systems, including the use of different materials, designs, and applications.

Overall, these studies highlight the importance of thermal energy storage systems in improving the efficiency and reliability of renewable energy systems and provide insight into the different types of storage systems, their applications, and their limitations.

2. Design of Solar Thermal System:

The design of a solar thermal storage system depends on several factors, including the type of storage technology used, the intended application, and the available resources. Here are some general steps involved in the design of a solar thermal storage system: Determine the application: The first step in designing a solar thermal storage system is to determine the intended application. This could include heating buildings, providing hot water, or generating electricity. Select the storage technology: The next step is to select the appropriate thermal storage technology based on the application and available resources. This could include sensible heat storage, latent heat storage using phase change materials, or thermochemical storage. Determine the required storage capacity: The storage capacity of the system will depend on the application and the amount of thermal energy required. This can be determined through a detailed energy analysis of the application. Determine the required collection area: The collection area refers to the surface area required to capture solar radiation to meet the energy requirements of the application. This can be calculated based on the amount of thermal energy required and the efficiency of the solar collector. Select the appropriate heat transfer fluid: The heat transfer fluid is used to transfer thermal energy between the solar collector and the thermal storage system. The selection of the appropriate fluid will depend on factors such as cost, efficiency, and operating temperature range.

3. Data Reduction

3.1 Energy and exergy mathematical formulation

The following is a mathematical breakdown of the melting and solidifying processes:

$$E_{in} = \dot{m}C_{HTF} \int_0^t [T_{in} - T_{out}]dt \tag{1}$$

$$E_{out} = \dot{m}C_{HTF} \int_0^t [T_{out} - T_{in}]dt \tag{2}$$

Heat absorbed by the PCM is denoted by Ein, and heat absorbed by water is denoted by Eout. The specific heat of the fluid is CHTF, and the mass flow rate is m.

The thermal efficiency of the tank can be determined as

$$\eta = \frac{E_{out}}{E_{in}} \tag{3}$$

Exergy can be determined using the following formulae.

$$X_{in} = \dot{m}C_{HTF}\int_0^t[\,(T_{in} - T_{out}) - T_0\ln\left(\frac{T_{in}}{T_{out}}\right)] \tag{4}$$

$$X_{out} = \dot{m}C_{HTF}\int_0^t[\,(T_{out} - T_{in}) - T_0\ln\left(\frac{T_{out}}{T_{in}}\right)] \tag{5}$$

$$X_{stored} = \dot{m}C_{HTF}\int_0^t[\,(T_{in} - T_{out})\left(1 - \frac{T_0}{T_{melt}}\right)]dt \tag{6}$$

These are the input and output temperatures, as well as the melting and room temperatures, respectively: Tin and Tout, Tmelt and To. The following equations can be used to determine the charging, discharging, and total efficiencies of a TES unit:

$$\varepsilon_{charging} = \frac{X_{stored}}{X_{in}} \tag{7}$$

$$\varepsilon_{discharging} = \frac{X_{out}}{X_{stored}} \tag{8}$$

3.2 Uncertainty analysis

δR, several factors contribute to the overall uncertainty of experimental results.

(X_1, X_2, …, X_n); An individual's measurement error, denoted by Xn, is calculated as follows:

$$\delta R = \sqrt{\sum_{n=1}^{N}\left(\frac{\delta R}{\delta X_n}\delta X_n\right)^2} \tag{9}$$

This study analyzed the uncertainty associated with charging, discharging, and capacity of volumetric thermal storage. Accuracy of the measurement of volume was within 1%.

4. Result and Discussion:

Fig. 1 represents the optimal values of the discharge time of the PCM based on the optimal values of the stored energy within the PCM. As it can be elicited from the figure, when the conditions for the maximum time of energy discharge in the PCM are met (the left side of the diagram), the amount of the stored energy is at its lowest values. On the other hand, it is evident that the optimized conditions for the maximum amount of energy storage in the PCM leads to the least time of available energy at night-time. The population of the computational data in the conditions of Fig. 1 is equal to 500. Only two design parameters of diameter (D) and contact area (A) can be manipulated by the optimization. Based on the desired optimum objective, these parameters must be determined and used in the development of the system. In the conditions of Fig. 1, when 7 hours of heating is required during night-time the optimum values of diameter. Fig. 2 shows the variations of energy discharge versus the inner diameter of the tube. In order to determine the effect of this parameter, other parameters are assumed to be constant.

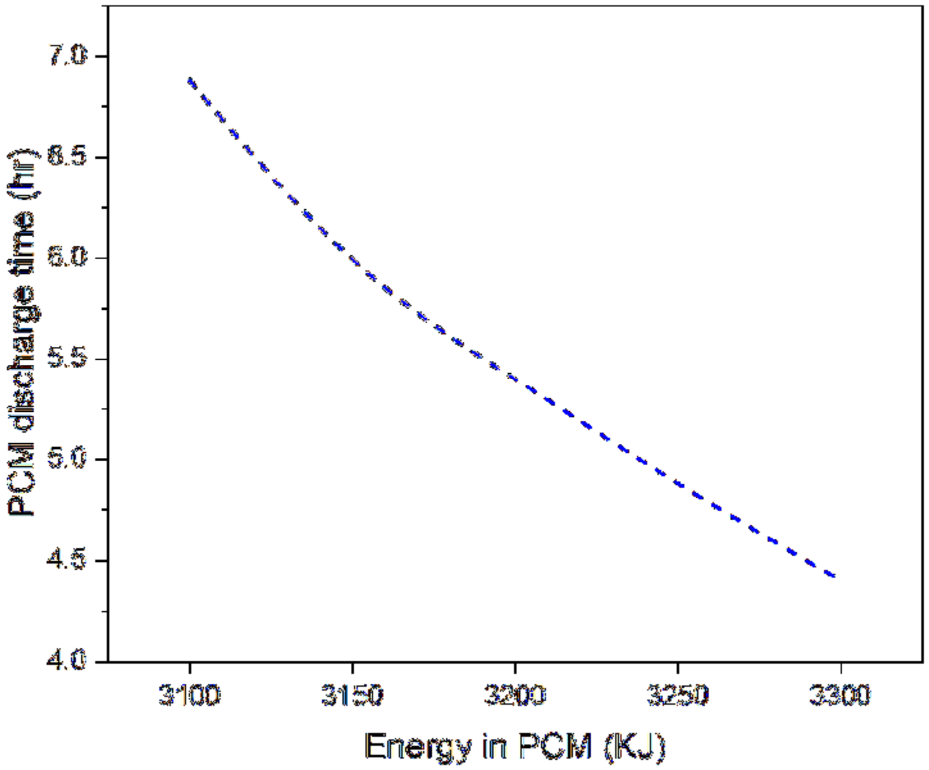

Figure 1: Variation of Energy stored in PCM and discharge time

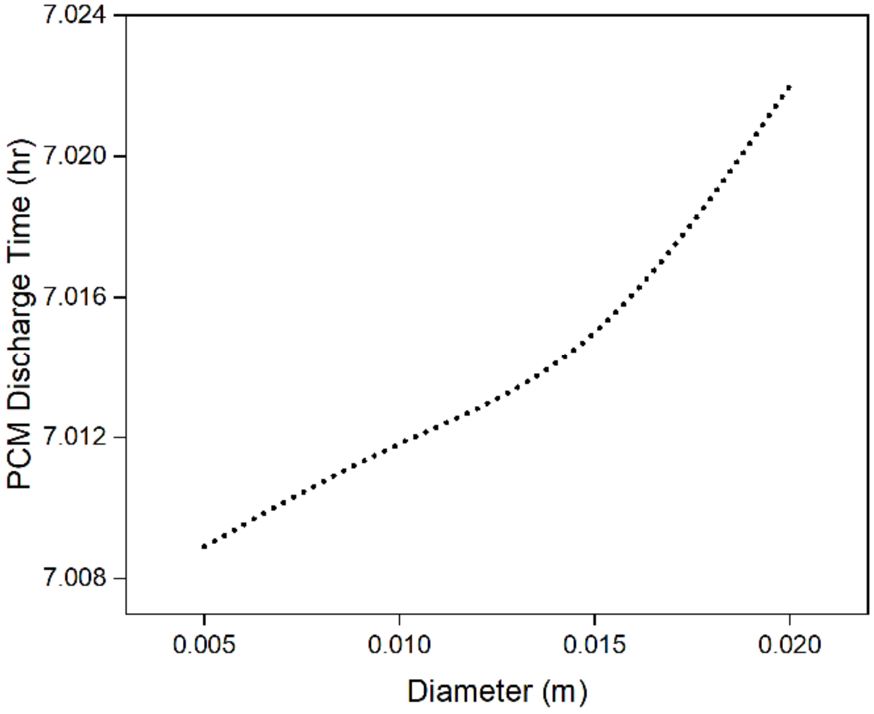

Figure 2: Variation of Diameter and PCM discharge time

Fig. 3 represents the trend of variations in the net energy stored in the PCM (Qnet) for different values of the inner diameter. The trend is nonlinear and incremental. Therefore, by keeping the system conditions constant and increasing the diameter of the tube, the amount of energy stored in PCM also increases.

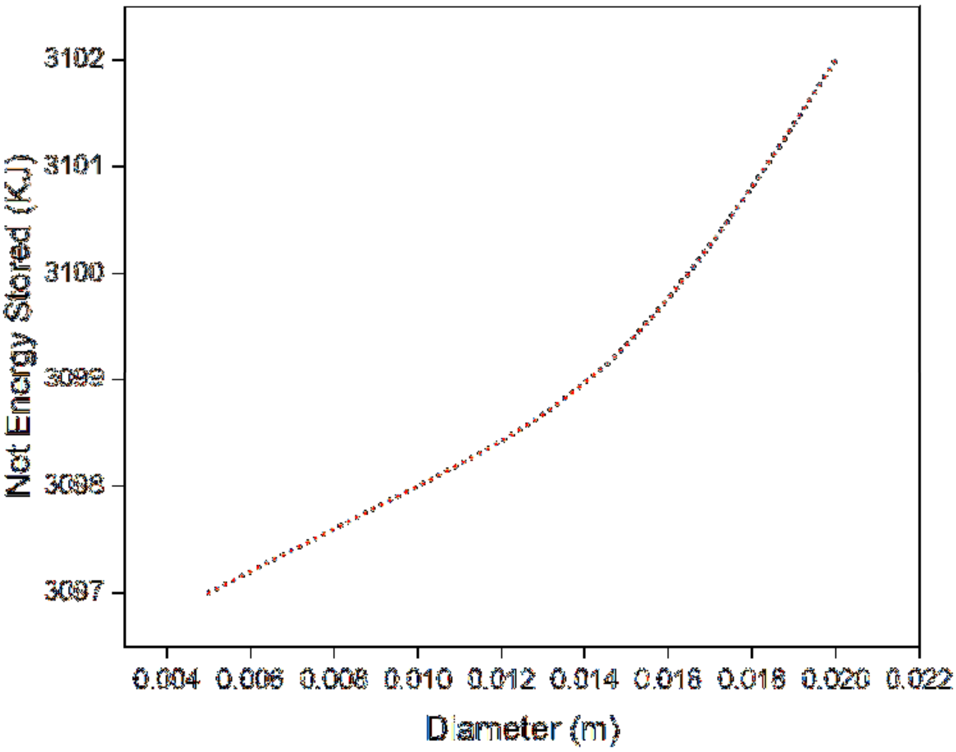

Figure 3: Variation of Diameter and PCM energy stored

It is worth mentioning the given values in Fig. 4 are obtained using the RSM method. In LINMAP method, it is assumed that the decision maker chooses from the two assumed choices; the one that is nearest to the desired, and the distance from the desired is considered as the weighted Euclidean distance (di) on choice Ai. The variable related to weights (Wj) is also used to change the existing scales into unified ones, which clearly show the degree of importance of the indexes. In LINMAP method, a number of m choices with n indexes through m vector points are shown in a three-dimensional space, and it is assumed that DM opts the choices with the least distance to the ideal point in this space.

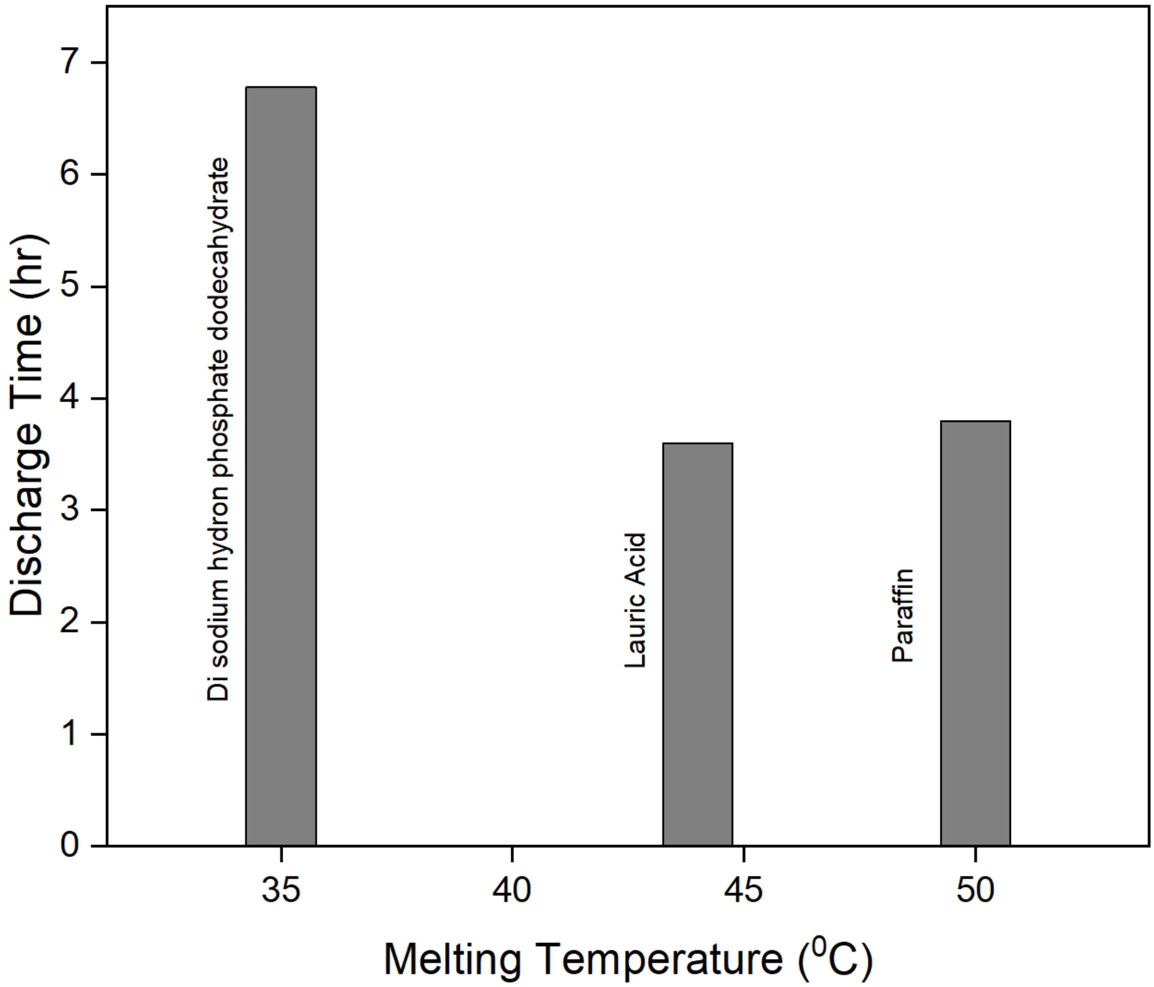

Figure 4: Variation of PCM melting temperature and discharge time

5. Conclusion:

The thermal collector systems have a high capacity for energy storage and supply. In study, for storing solar energy in the daytime, the phase change materials (PCMs) are used. These substances store the energy received from the sunlight in forms of latent or sensible heat within themselves. In this work, using the multi-objective optimization algorithm of MOEA/D, the performance of the solar thermal collector has been optimized for the objective functions of energy discharge time (tPCM) of PCM and net stored energy in PCM (Qnet). Investigation of the effect of the inner diameter of the tube on objective function tPCM shows that with the increase in the inner diameter of the tube, the energy discharge time of the PCM also increases. In other words, the time of heat accessibility during the night increases. The rising trend of tPCM is nonlinear and the diagram slope at higher diameters is larger which indicates that energy discharge time at higher diameters is more sensitive to tube diameter, compared to smaller diameters. The objective functions of tPCM and Qnet both change linearly with the contact area. The changes in these two objective functions are directly related to the parameter of the area. Investigation of the trend of variations in the net stored energy in PCM (Qnet) for different values of tube diameter shows that this fashion is nonlinear and increasing. Accordingly, by keeping the system conditions constant and increasing the tube diameter, the amount of saved energy in PCM also increases. Qnet is more sensitive to the alternation of the inner diameter of the tube in higher diameters. Therefore, if large tanks are used in a collector system, the diameter must be precisely chosen since it affects the Qnet amount with a higher sensitivity.

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