An optimisation analysis of the thermal storage system for heating applications

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Abstract:
Phase change materials (PCM) are used primarily for energy storage and generation in solar thermal collector systems. Achieving the optimal values indicated for the energy discharge time and the net quantity of energy stored (Qnet) in these materials is crucial for optimizing the efficacy of solar thermal collectors. The MATLAB simulator used in this research was developed using a multi-objective evolutionary method that achieves optimization via deconstruction. The simulation showed that the two objectives are mutually exclusive, hence they cannot be met at the same time. When everything is ideal, Qnet is at its lowest and the amount of time spent in the storage tank is at its maximum. Research into the effects of the input components on the objective functions indicates that under optimal circumstances, the mass of PCM and the mass flow rate of the input water are, respectively, at their smallest and maximum values. This was found by analyzing the effect of the input parameters on the objective functions. Considering the influence of the tube's inner diameter on the aim function of a storage tank, it is instantly clear that the time required to release the energy stored inside the tube increases as the tube's diameter increases. Increases in PCM energy storage are shown when tube width is changed while keeping all other system parameters constant.

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

In order to increase the effectiveness and efficiency of solar thermal storage systems, phase change materials (PCMs) are often employed. By collecting and releasing heat during their phase transitions, PCMs may store significant quantities of thermal energy when utilised in solar thermal storage. In order to absorb solar energy, solar thermal storage systems using PCMs often entail flowing a fluid through a heat exchanger, such as water or a heat transfer fluid. The extra thermal energy is subsequently absorbed and stored as latent heat while the fluid is cycled through a vessel containing PCMs [1]. The PCM releases the heat it has been holding onto when the fluid in the system cools down, keeping the system's temperature steady. When compared to other types of storage materials, one of the primary advantages of using PCMs for solar thermal storage is the fact that they are able to store a significant amount of energy in a very little amount of area [2]–[4]. In addition, given of the high energy storage density that they possess, PCMs have the potential to store a substantial amount of thermal energy while having a relatively low overall mass. PCMs might be employed in solar thermal storage to boost the efficiency of the system. This would be accomplished by reducing the amount of heat lost during storage and the need for additional insulation. PCMs have the potential to increase the operating life of solar thermal systems because of their ability to store excess thermal energy for later use, such as at night or during periods of low solar radiation. In general, the incorporation of PCMs into solar thermal storage systems has the potential to increase the system's performance, reliability, and efficiency while simultaneously reducing the system's impact on the environment [5].

Solar thermal storage is a kind of energy storage system that utilizes solar radiation to heat a substance, often a fluid or solid, which is then stored for later use. This type of energy storage system is also known as a solar thermal energy system. The thermal energy that has been stored may be put to use in a number of different ways, including the provision of space heating and household hot water, as well as the generation of electricity via the utilization of a steam turbine. There are a number of benefits that come with using solar thermal storage systems as opposed to other forms of energy storage systems, such as batteries [6]. They have a longer lifetime, are less harmful to the environment, and are better suited for applications requiring massive amounts of storage space. In addition, solar thermal storage systems may be integrated with other forms of renewable energy, such as wind and hydroelectric power, to provide a dependable and environmentally friendly source of energy[7].

Systems for storing solar thermal energy have several uses across numerous industries. Solar thermal storage systems are often used for a variety of purposes [8]:

- Using solar thermal storage systems, it is feasible to heat a building since these systems can store thermal energy during the day and then release it at night or at other times of the day when the sun is not shining as brightly. The building's overall energy consumption and associated heating costs might be reduced as a result of this.
- Domestic hot water may be produced using solar thermal storage devices for purposes like bathing and dishwashing. The thermal energy that is accumulated during the day may be utilized to heat water at night or when there is little sunlight.
- Solar thermal storage systems may be utilized in industrial processes like metal smelting and chemical production that need for high-temperature heat. Steam, which may be utilized in a variety of industrial operations, can be produced using the thermal energy that has been stored.
- Solar thermal storage systems may produce electricity by utilizing the thermal energy they have stored to power a steam turbine. This may be especially helpful in distant locations with little or no connection to the grid.
- Solar thermal storage devices may be used to warm livestock water and supply heat for greenhouses.

In sum, solar thermal storage systems may serve as a dependable and long-term energy resource for a broad variety of industries. Thermal energy storage technologies have been the focus of a significant amount of research and investigation over the last few years due to the fact that they have the potential to both boost the efficiency and reliability of renewable energy systems. Here is some current writing on the topic of thermal energy storage devices to get you started. Pomianowski et al.[9] The benefits and challenges of several phase change material (PCM) thermal energy storage methods are weighed in this research. Borri et al.[10] New materials, concepts, and applications for thermal energy storage devices that use sensible heat are discussed in this study. Pelay et al.[11] Concentrated solar power plants use thermal energy storage systems, and this article gives a summary of such systems, how they work, and how they might be integrated with solar thermal power plants. Sarbu and Sebarchievici [12] Including both sensible and latent heat storage systems, as well as their respective applications in heating, cooling, and hot water systems, this study presents a thorough examination of the field of thermal energy storage for buildings. Nguyen and Bennici [13] The purpose of this study is to present an summary of current advancements in thermochemical energy storage systems. Topics covered include the use of various materials, designs, and applications.

In general, The importance of thermal energy storage systems to the efficiency and durability of renewable energy sources is shown by these research. In addition, they detail the various storage systems, their applications, and the constraints of each.

2. Design of Solar Thermal System:

The design of a solar thermal storage tank is contingent on a number of elements, some of which are shown in Figure 1. These considerations include the kind of storage technology that is used, the application that is being planned, and the resources that are readily accessible. The following is a list of some of the more general stages that go into the design of a solar thermal storage system: Find out which program it is: The first thing that has to be done when constructing a solar thermal storage system is to figure out what the system will be used for. This may include the heating of buildings, the provision of hot water, or the generation of electrical power. Choose the appropriate method of storage: The next step is to choose the most suitable thermal storage technology for the application at hand, taking into account any available resources. This might involve the storage of latent heat utilizing phase transition materials, as well as the storage of sensible heat and thermochemical energy. Determine the minimum and maximum capacities needed for storage: The quantity of thermal energy that must be supplied will determine the storage capacity of the system, which in turn will be determined by the application. This may be ascertained by doing an in-depth energy analysis on the application in question. Find out how much space is needed for the collection: The term "collection area" refers to the total surface area that must be covered in order to gather enough solar radiation to provide the necessary amount of power for the application. This may be determined by calculating the quantity of thermal energy that is needed in conjunction with the efficiency of the solar collector. Choose the most suitable fluid for the heat transfer: The solar collector and the thermal storage system are connected by the heat transfer fluid, which facilitates the transmission of thermal energy between the two systems. The selection of the optimal fluid will be determined by considerations such as price, performance, and the temperature range in which it will be used.

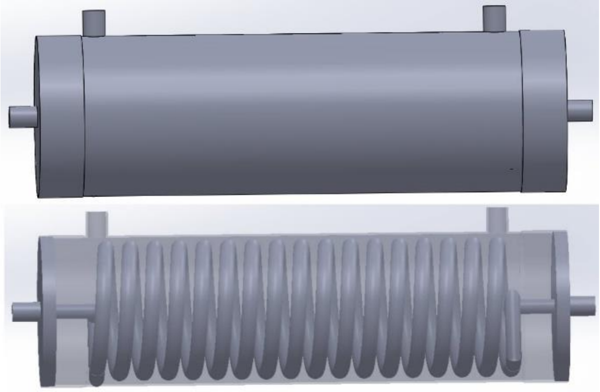

Figure 1: Design of thermal storage tank

3. Data Reduction

3.1 Mathematical formulation of energy and exergy

The following is a mathematical dissection of the process of melting into a solid and then solidifying again:

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

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

Ein is the symbol used to describe heat absorbed by the PCM, while Eout is the symbol used to denote heat absorbed by water. The mass flow rate is denoted by m, while the specific heat of the fluid is denoted by CHTF.

It is possible to calculate the thermal efficiency of the tank by using the following formula:

$$\eta = \frac{E_{out}}{E_{in}} \qquad (3)$$

The following equations may be used to calculate entropy and enthalpy.

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

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

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

The input and output temperatures (Tin and Tout) and the melting and room temperatures (Tmelt and To) are as follows. Calculating the charging, discharging, and overall efficiency of a TES unit may be done with the use of the following formulae:

$$\varepsilon_{charging} = \frac{X_{stored}}{X_{in}} \quad (7)$$

$$\varepsilon_{discharging} = \frac{X_{out}}{X_{stored}} \quad (8)$$

3.2 Uncertainty analysis

δR, The total experimental result uncertainty may be attributed to a number of causes.

$(X_1, X_2, \ldots, X_n)$; Using the following formula, we can get Xn, the measurement error for a given individual:

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

In this study, the researchers evaluated the uncertainty that is connected with volumetric thermal storage's capacity, charging, and discharging processes. The accuracy of the volume measurement was within 1% of the whole reading.

4. Result and Discussion:

Discharge times for the PCM that were found to be optimum in light of the PCM's internal energy storage capacity are shown in Fig. 2. When the requirements for the greatest period of energy discharge in the PCM are satisfied (the left side of the picture), the quantity of the stored energy is at its lowest values. This is something that can be deduced from the figure, since it is clear that this is the case. On the other hand, it is crystal clear that the settings that are ideal for the highest amount of energy storage in the PCM lead to the smallest length of time that there is energy accessible during the nighttime. Under the circumstances shown in Fig. 2, the population of the computational data is set at the value of 500. The optimization may only make changes to two of the design parameters, which are the diameter (D) and the contact area (A). These factors need to be figured out and included into the system design in accordance with the ideal goal that is wanted. In the circumstances shown in Fig. 2, when it is necessary to have 7 hours of heating done throughout the night, the optimal values of diameter are. Fig. 3 depicts the differences in the amount of energy discharged as a function of the tube's inner diameter. It is expected that all other parameters will remain the same so that we may analyse how this one will affect the results.

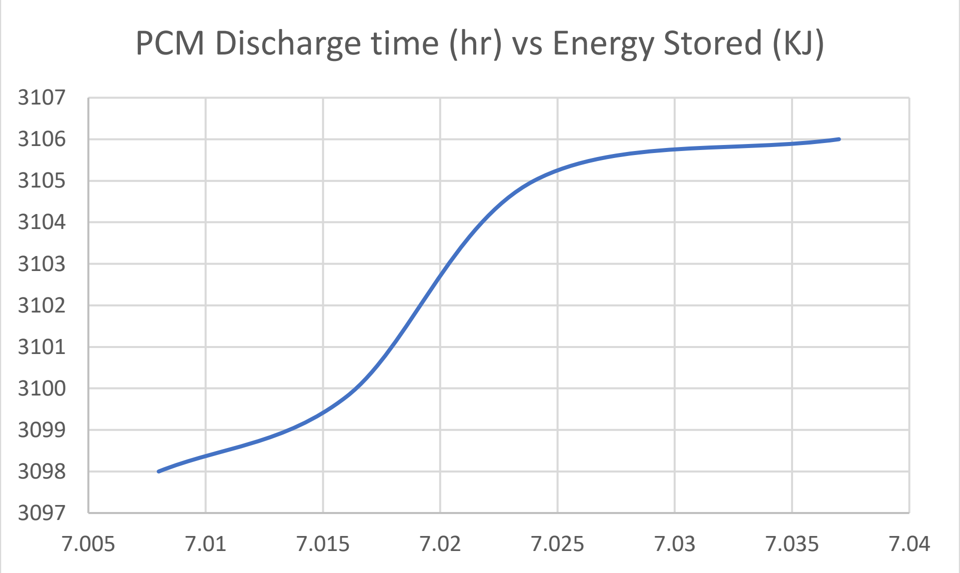

Figure 2: Variation of Energy stored in PCM and discharge time

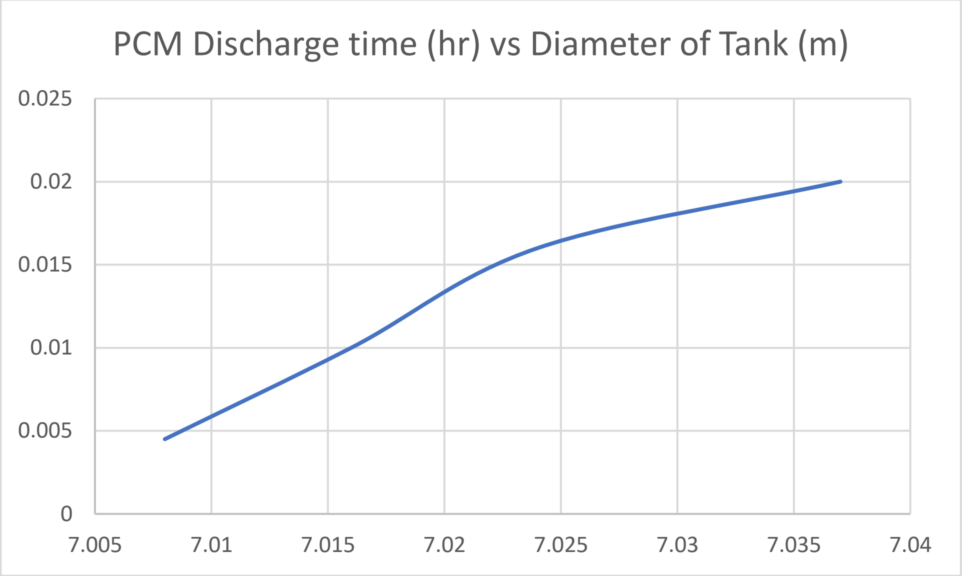

Figure 3: Variation of Diameter and PCM discharge time

The pattern of fluctuations in the amount of net energy stored in the PCM (Qnet) is shown in Figure 4, which shows how these patterns change depending on the inner diameter value. The trend may be described as nonlinear and progressive. As a result, increasing the diameter of the tube while maintaining the same operating parameters of the system results in an increase in the quantity of energy that is stored in PCM.

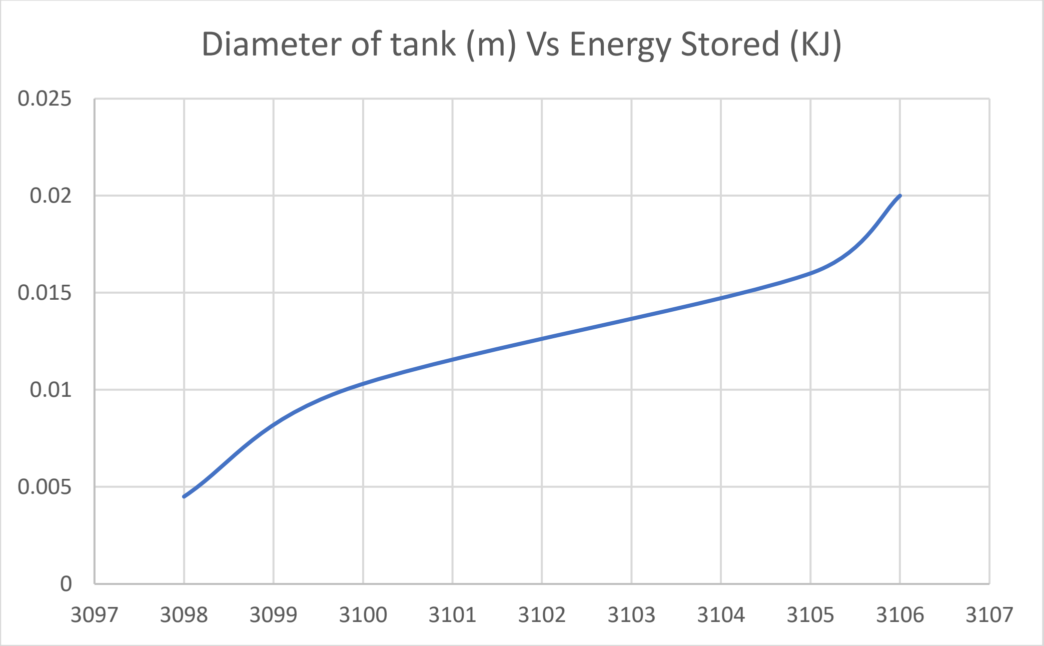

Figure 4: Variation of Diameter and PCM energy stored

It is important to note that the RSM approach was used in order to achieve the results that are shown in Figure 5. The term "Phase Change Material" (PCM) refers to a substance that, in the context of thermodynamics and the transfer of heat, is understood to refer to a material that is capable of absorbing or releasing a considerable quantity of heat while experiencing a phase shift, such as changing from solid to liquid or vice versa. The amount of heat that a phase change material (PCM) takes in or gives out during its phase transition is referred to as its enthalpy. When a phase change material (PCM) is used to store thermal energy in a tank, the discharge duration and the fluctuation in enthalpy during the discharge process might differ from one position of the PCM to another within the tank. This is because the placement of the PCM within the tank is determined by the phase change material's orientation. There may be a temperature differential inside the PCM material itself depending on the manner in which the tank is charged with PCM and the level of thermal insulation present in the tank. There is a possibility that the areas that are closest to the heat source or heat sink will have a greater temperature. This might result in varying enthalpy values at various places. How heat is transmitted into or out of the PCM determines the amount of time it takes for the PCM to release its contents. It is possible that the discharge time will be rather consistent throughout the tank if the primary mode of heat transmission is conduction through the PCM material. On the other hand, if there are other heat transmission processes at play, such as natural convection or radiation, the discharge time might differ depending on the location.

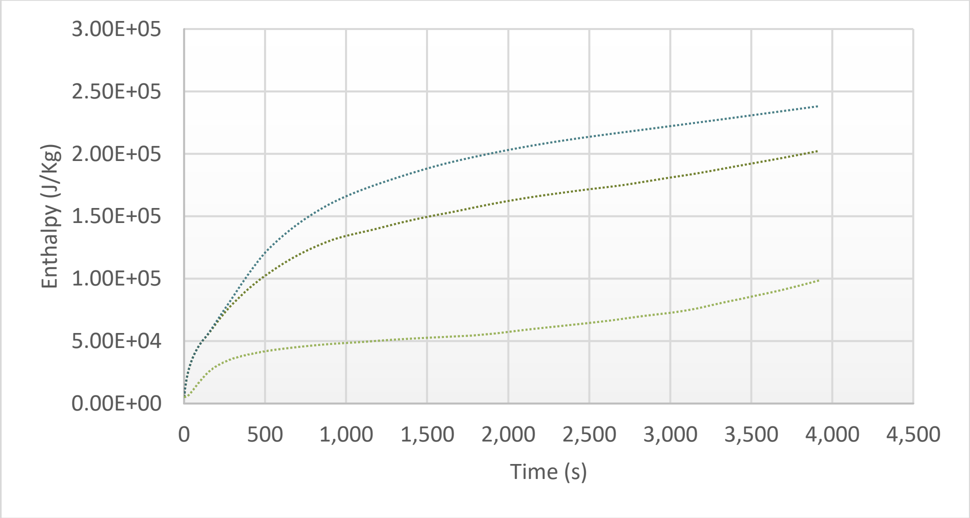

Figure 5: Variation of PCM enthalpy and discharge time at different location of tank

5. Conclusion:

Thermal collector systems store and distribute energy well. Phase change materials (PCMs) have been studied for daylong solar energy storage. These molecules utilise solar energy by storing latent and sensible heat. This work used multi-objective optimization to increase solar thermal collector performance. PCM energy discharge time and net stored energy (Qnet) were the goal functions. As the tube's inner diameter rose, the PCM's energy discharge time increased. In other words, heat is available longer at night. The increasing trend of PCM is nonlinear and rises as tube diameter grows, suggesting that energy discharge time is more sensitive to tube diameter at larger diameters. The contact area changes tPCM and Qnet goal functions linearly. These two objective functions directly affect a region parameter. An research into the net stored energy in PCM (Qnet) for different tube diameters found a nonlinear and rising trend. As a result, increasing PCM tube width while preserving system conditions saves more energy. Higher diameters make Qnet more sensitive to tube inner diameter fluctuations when rotated. If large collection system tanks are employed, their diameters must be properly determined. The diameter affects Qnet more.

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