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Simulation of Thermal Energy Storage Stratified Water Storage Tank for Solar Heating System

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Abstract: The past few decades have seen a steady increase in the use of solar water heaters in regions of the world that have a large amount of solar energy, however, since the sun can only provide energy for a fraction of every 24-hour sunshine. Cycle, there is a need to supplement solar water heaters with thermal energy storage systems. These systems use phase change materials (PCM) that can store additional energy to provide sufficient power, for example, to compensate for potential shortages that can arise from short production times, such as at night or on a very cloudy day. PCM can undergo solid to liquid phase transitions or conversion (that is melt cure) when heated to a temperature that is consistent with the heat input used. This study will explore ways to improve thermal efficiency in thermal water storage tanks by applying potential numerical modelling using PCMs containing Paraffin wax. Search for the most expedient PCMs for the finite element model, including the detection of changes in thermal conductivity and enthalpy at different temperatures. Elements that increase efficiency potentially include the use of encapsulated PCM for the spheres on the heat exchanger and changing the time required for the melt/cure process. This study also includes an overview of the Latent Thermal Energy Storage System (LHESS) and the theory behind it. The aim of this study is to developed and design a stratified storage water tank microencapsulate with PCM thermal energy storage. While other objectives are to simulate the thermal performance of the stratified water storage tank under varying hot water tank temperature and to analyze the charging and discharging process of the encapsulated PCM used as thermal insulator for the stratified storage water tank.

Keywords: Thermal Energy Storage, Solar Water Heating, Phase Change Material, Charging, Discharging.

1. Introduction

Renewable energy such as solar, geothermal, wind, marine, biomass, and hydropower energy have increase in demand due to current act to solve lack access to sufficient energy entirely, with terrible

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consequences to human and environment. Today's science has given rise to thermal energy management, and changing technology has given rise to a slew of new thermal energy applications, all of which are expected to drive up demand in the future. Stratified Water Storage Tank common technology that we use in thermal energy storage.

Alternative energy sources that help reduce greenhouse gas emissions are becoming more popular in light of the present global demand on countries to cut their carbon emissions. Solar energy is a very important alternative source, particularly in locations with a lot of sunshine. However, a finding way to save energy for later use remains a challenge. Energy-saving (ES) had to be capable of meeting high demands while remaining cost-effective [1]. Thermal energy storage systems can help save more energy from peak hours to off-hours of low power generation, which can improve generator integration into the grid. The ability to save thermal energy and use it later, either at the harvest source or wherever else, is one of the key advantages of thermal energy storage systems. Both have low thermal conductivity and this undesirable characteristic of phase change materials resulted in low thermal energy storage efficiency.

1.1 Solar Water Heating

For the heating of domestic hot water, solar energy has been proven to be efficient and cost effective and uses energy by capturing energy during high insulation. According to [2]. although water is preheated for use during periods of high demand, there is often a significant difference between the demand for hot water and the energy available; Thermal energy storage systems can help bridge the gap between energy supplies. Typical thermal energy storage systems include the infrastructure of hot water tanks, issues that can arise in buildings with small living spaces. Storage systems using PCM can solve space problems [3]. Energy is stored during the melting phase of PCM, which is also known as a latent thermal energy storage system, however the stored energy is released during the solidification phase [4]. Thermal energy storage can be classed as either latent or perceived. If a heated or cooled phase-transformed material undergoes a phase transition while keeping a steady temperature, latent heat is emitted and/or absorbed.

1.2 Properties and Selection of PCMs

Some desires properties of PCM according to [5] are as follows: (1) The melting point is within the application's intended temperature range, ensuring that heat is stored and released at a suitable temperature. (2) To attain a high storage density, the latent heat of fusion must be high. (3) Because the specific heat is so high, sensible heat-storage effects may be present. (4) Thermal conductivity is high, and the volume change during phase transition is minimal. (5) During solidification, there is little or no further cooling. (6) Materials utilized in LHESS have chemical stability, no chemical degradation, and no corrosive damage. (7) There are no combustible or explosive ingredients, and it is inexpensive and easy to obtain. PCM should be carefully chosen for a solar home hot water system in order to generate hot water at a variety of temperatures while minimizing safety concerns (such as PCM leaks in water supply in the building) [6]. So that in this research, paraffin wax is the chosen PCM.

2. Materials and Methods

This chapter explain thoroughly the methodology, experimental analysis and theoretical models implemented in this research. The equipment’s and materials list used in the project are presented, material analysis, design of thermal storage design, solar collector, and hydrodynamics of the transient analysis is shown. In order to achieve the research objective which was previously drafted, the discussion carried from the first stage to the end of the methodology adopted in the implementation of this study.

2.1 Materials

The materials for this research are Paraffin wax, polymer composite material, epoxy resin/ hardener. The materials were fill in the tank wall. The function is to absorb heat and release the heat when needed.

2.2 Methods

CFD is the numerical solution approach for analyzing fluid flows. To model the physics of the fluid dynamics problem, partial differential equations regarding the pressure, velocity, temperature, and fluid characteristic are written for the system. CFD solvers convert these equations to algebraical equations and generate the corresponding matrix of equations, which are subsequently solved using numerical methods. It is possible to set different values for the initial conditions to solve the equations. These phenomena make the CFD simulation a powerful tool that can conduct every simulation possible with every range of initial values. While doing the experiment is limited to a specific range of initial values, and it takes a long time to come up with results. Engineers should be aware that CFD simulations are only a rough approximation of a true physical solution, and that they cannot completely rule out physical testing processes. Tests should still be run for verification purposes. Flow chart is essential to allowed more visual procedure of a research. In this study, the simulations will begin by getting the measurement of tank. A 3D model of the tank is then built in SolidWorks. After that, a test of grid independence and meshing is done to make sure higher accuracy of the result can possibly achieve. After improvement have been made and the result from grid independence test is satisfied, the solution is then run. Later, a comparison of pcm materials and comparison between numerical with experiment is analyzed from the result obtain.

3. Results and Discussion

The results and discussion section presents data and analysis of the study. This section can be organized based on the stated objectives, the chronological timeline, different case groupings, different experimental configurations, or any logical order as deemed appropriate.

3.1 Thermal analysis using ANSYS

The investigation starts with grid sensitivity test. As the time passes heat loss from the uninsulated walls of the tank takes place. Through the walls of the tank cool water settles down and forms stratified water tank. Slowly the level of cold water rises from the bottom part of the tank. Figure 14 shows meshing of stratified storage tank.

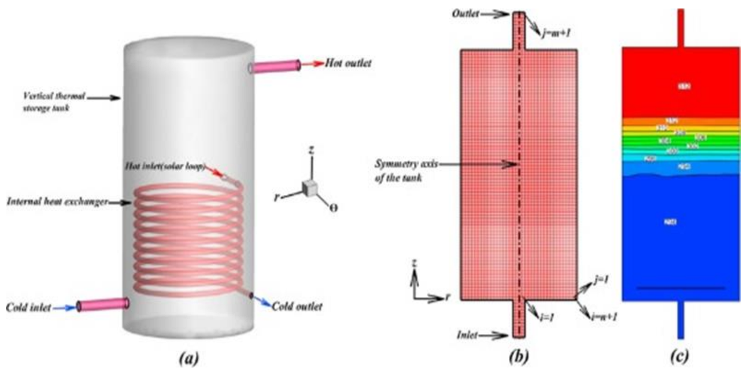

Figure 14: Meshing condition in the stratified storage water tank

It is seen that the tank cools as the time progresses. The darker regions indicate cooler temperature when the heater is in off mode. Due to buoyancy driven natural convection currents and heat loss from the tank walls, the higher denser cold water settles down at the bottom of stratified storage tank. A steady-state thermal analysis calculates the effects of steady thermal loads on a system or component. Steady-state thermal analysis to determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time, red colour of tube shows the maximum temperature of water inside the copper tube.

Thermal energy storage used combined sensible and latent heat storage concept. The stratified storage water tank used the paraffin wax and epoxy resin as thermal encapsulant. This is to maintain the average water temperature in the stratified tank at 45°C, for domestic water heating purposes. The mass flow rate contributes to the temperature gradients of the hot water inside the tank. The temperature difference is flow rate dependence. In addition, the water draw-off characteristics. Because this simulation considered no water drawn-off profile, thus, the temperature gradient is also time dependent. The stratified storage tank with PCM encapsulation as thermal insulation resulted thermal stability for the tank thermal performance. Heat losses in the stratified storage water tank is presented by 45%, over the heating times simulated. The investigation has revealed that hot water can be increased by using PCM integration as thermal insulation in the tank. Storing of hot water system plays an important role in sustainable energy management globally and can help mitigate carbon emission from residential and commercial sectors.

3.2 PCM Encapsulate

The charging and discharging process of the epoxy resin encapsulated PCM is shown in Figure 15. In the simulation, the temperature of the water inside the stratified storage tank is kept at 80oC at the initial hour of 7am in the morning until 7pm in the evening same day. The temperature distribution of PCM during charging and discharging was hourly simulated under no water drawn-off to represent a steady state condition in the stratified storage tank. The flow mass flow rate is considered zero since no water drawn-off occur. The charging and discharging distribution curve of the encapsulated PCM, the PCM stratified tank temperature (water temp 1) and stratified tank temperature (water temp 2) is plotted for variation of temperature at each point.

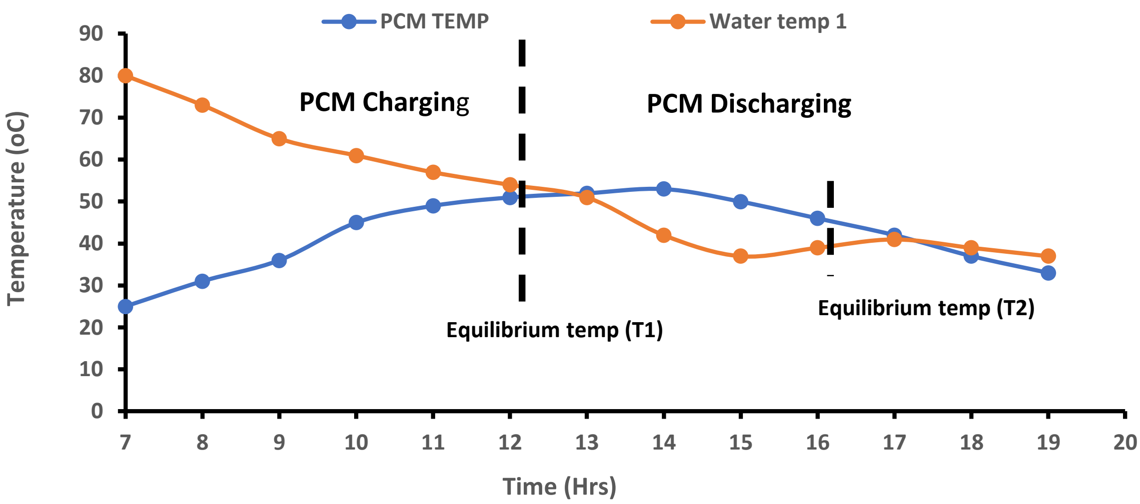

Figure 1: Charging and Discharging process of the encapsulated PCM epoxy

3.3 PCM Temperature Vs time (Charging process)

It can be observed from Figure 15 that the charging stage of the PCM started as the hot water inside the storage tank begin to loss heat to the PCM. After an hour, as the temperature of the hot water in the stratified storage tank begins to decrease the PCM temperature begins to increase. The peak temperature of the PCM was 54oC at around 2pm. At this temperature the PCM had pass the melting temperature range, thus, transit from the solid form to liquid by gradually melting. As the PCM melts it absorbs heat that is lost from the hot water and keep in form of latent heat. Whereas at same period the water temperature had dropped to 38oC. It can be said that after 7 hours of the hot water inside the storage tank more than half of the heat is lost to the environment.

3.4 PCM Temperature Vs time (Discharging process)

In this case, temperature variation of discharging process is reflected in Figure 15. During this time, when the hot water temperature had fallen below the melting temperature of the PCM. The PCM now, gradually start to solidify. As the PCM is solidifying, heat is released back to the stratified storage tank and by large the water inside. Thus, the water temperature begins to gain heat from the melting PCM and does its temperature rises. By 3pm the water temperature had fallen to the lowest temperature of 33oC, whereas at same period the PCM temperature was around 53oC. Between the next three hours, the PCM discharges its heat and is absorbed by the water thereby raising the water temperature to a point where the water and PCM temperature are same, at equilibrium. The noted equilibrium temperature was 41oC at around 6pm. Thus, the heat has been retrieved from the PCM with respect time and temperature variation and the PCM had enhanced the stratified storage water tank thermal performance.

3.5 Results when the tank was filled with encapsulated PCM

Results for Case 1:

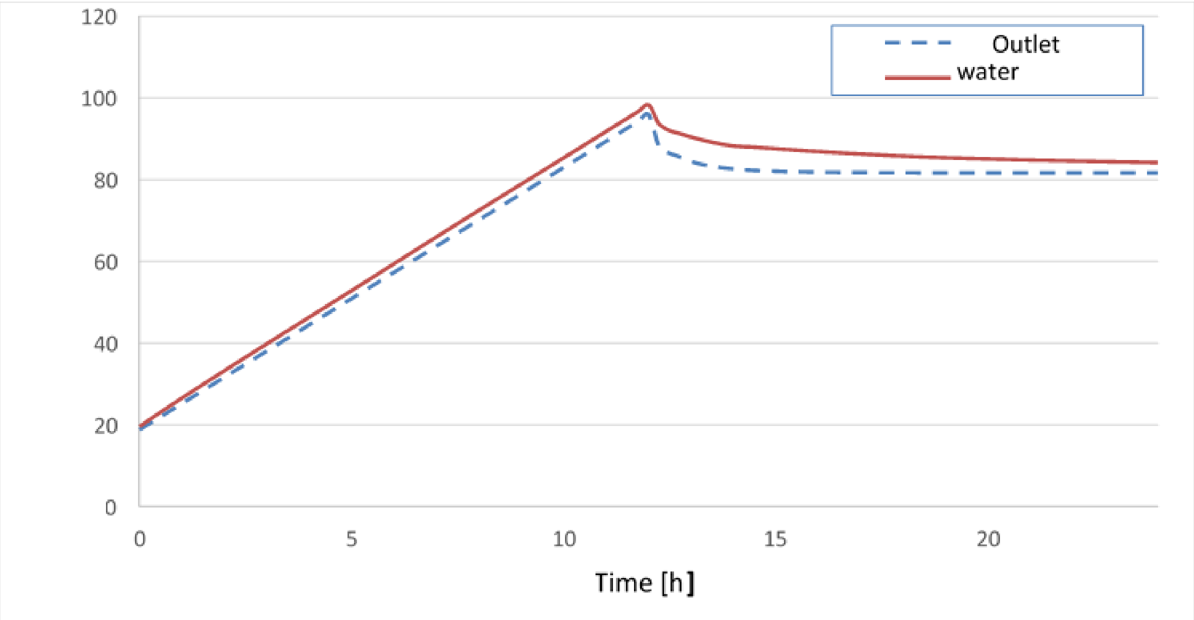

Figure 2: The outlet water and PCM temperatures changes over the time.

Results for Case 2:

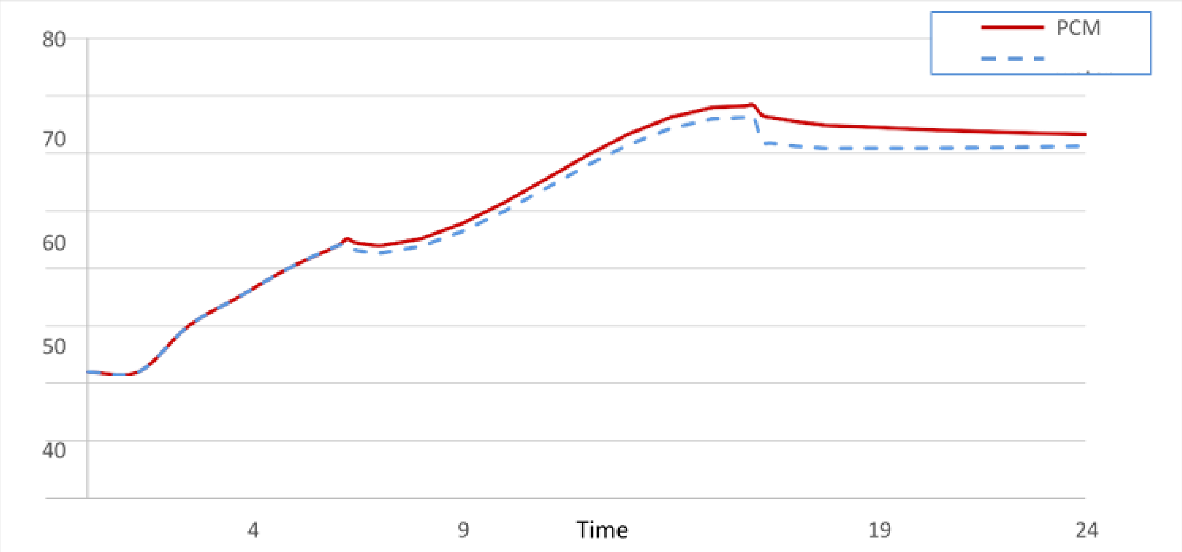

Figure 3: The outlet water and PCM temperature changes over the time

The following conclusions are inferred from the previous results, it can be seen that when the inlet water temperature drops during the day, PCM can conserve and maintain the outlet or output water temperature. The minimum outlet water temperature for Case 1 at the end of the working day 19% lower than the maximum inlet water temperature. This percentage is obtained by dividing the maximum inlet water temperature (99) by the minimum out water temperature (80), which is a percentage of the highest inlet water temperature (99):

$$\frac{99-80}{99} = 19\%$$

The minimum outlet water temperature for Case 2 at the end of the working day is 11% lower than the maximum inlet water temperature. This percentage is derived by dividing the maximum inlet water temperature (69) by the minimum outlet water temperature (58), and then multiplying the result by the maximum inlet water temperature (69):

$$\frac{69-58}{69} = 11\%$$

4. Conclusion

This chapter sums up the drawn conclusion from this study. Where numerical analysis is performed on stratified storage water tank encapsulated with epoxy PCM for thermal performance enhancement. The design of the stratified storage water tank and the material classification of the thermal energy storage PCM was analyzed. ANSYS simulation was performed on the stratified storage water tank using varying meshing conditions. From the analysis, it can be concluded that thermal stratification in storage water is essential to maintain the water temperature. Besides, prolonging the hot water level requires energy storage materials which can act as latent heat storage to absorb the heat losses to the ambient. The PCM paraffin can retain some of the heat losses and discharge back the heat absorbs to the water tank during solidification. The stratified storage water tank temperature thermal performance can be enhanced by integrating PCM as thermal energy storage. Encapsulation of the PCM to serve as thermal insulator to the stratified storage water tank reduce heat losses and the same time heat recovery system.

Estimated 8oC water temperature is retained by the PCM stratified hot water storage tank from time difference of 12 hours, morning till night period.

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