CFD simulations on a phase change thermal energy storage integrated with conducting fins

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Abstract. Global warming has become a major problem that leads to an abnormal climate change crisis. For most countries around the world, there be would be a rise in the average daily temperature. Therefore, many research works have been conducted in order to overcome this problem. One of the most viable solutions is to store thermal energy for later use. This can be done by integrating phase change material (PCM) into thermal energy storage (TES) system. To counter the increasing temperature problem in the residential house, PCM can be implanted in the wall of the house, for instance. This way, PCM can go through freezing process during the night and countering the heat through the wall by melting process during day time. However, due to the thermal resistance within these systems, the inadequate heat transfer problem had always become the problem of low thermal conductivity. Therefore, the integration of conducting fins is proposed to the system to increase the overall thermal conductivity.

1. Introduction

Phase change material (PCM) has a large latent heat-storage capacity that makes them the best storage medium for thermal energy system (TES). The utilization of PCM as a storage medium is one of the great choices especially for refrigeration system [1]. PCM works by absorbing or releasing thermal energy on the surrounding during the process of melting and solidifying. During melting process, PCM absorbs a large amount of heat from surrounding and vice versa during solidification process.

In a TES, the rate of the PCM volume per total system volume is characterized as the compactness ratio [2]. The obstacle in designing PCM encapsulation is to have a greater compactness ratio so that the greatest amount of latent energy can be utilized. Much of the time, the PCM should be encapsulated in order to maintain liquid phase PCM and also to prevent impurities enter from surrounding.

In any case, most PCM endure low thermal conductivity, which brings about a danger temperature for the electronic parts [3, 4]. To manage it, the fins are taken into the PCM to improve the thermal conduction [5, 6]. Some conducting related work has introduced composites for options [7, 8].
Packed bed of spheres has been used as thermal energy storage (TES) to enlighten the availability in space especially within the system incorporated with phase change material (PCM), nevertheless, due to the thermal resistance within these systems, the inadequate heat transfer problem had always become the problem of low thermal conductivity. Therefore, the integration of conducting fins is proposed to the system to increase the overall thermal conductivity. The main objective of this project is to study the effect of multiple physical design of the PCM in TES system towards the thermal performance of TES system.

2. Design Configuration
Three 3D models are developed using Solidwork software as shown in Figure 1.

![Figure 1. Assembly design of TES tank (a) for no fin [9, 10], integrated with (b) 2 fins and (c) 4 fins, tilted at different angles within a PCM sphere.](image)

These models are then imported into Ansys CFX in .IGES format as preparation for simulation works. The different tilted angle positions are to be named as Orientation 1 (facing Inlet) and Orientation 2 (facing tank wall).

3. Simulation set up
The first step is to set boundary conditions that the wall of the tank is no slip type and adiabatic, sphere is thin Medium Density Poly Ethylene, heat transfer fluid is air at -20°C with velocity of 1 ms⁻¹, and the PCM is PCM0 (ice-water), and copper fin/s. There are four domains in total for the simulation which is the PCM and the HTF, encapsulation and the fin. Simulations are transient with total time of 5 minutes of freezing process, with optimised time steps to satisfy the convergence criteria of 10 x 10⁻⁴, as has been found sufficient for most of the heat exchanger simulations [11].
4. Results and discussions
Result of the temperature distributions against the time steps (from CFX Solver) for phase change time (PCT) visualisation and the temperature distribution on the mid plane of PCM in sphere (from CFX Post) are shown in Figures 2 to 6.

**Figure 2.** (a) PCT for PCM sphere with no fin, and temperatures contour for (b) 5%, (c) 25%, (d) 50%, & (e) 75% frozen mass fraction.

**Figure 3.** (a) PCT for PCM sphere with 2 fins at Orientation 1, and temperatures contour for (b) 5%, (c) 25%, (d) 50%, & (e) 75% frozen mass fraction.
Figure 4. (a) PCT for PCM sphere with 2 fins at Orientation 2, and temperatures contour for (b) 5%, (c) 25%, (d) 50% & (e) 75% frozen mass fraction.

Figure 5. (a) PCT for PCM sphere with 4 fins at Orientation 1, and temperatures contour for (b) 5%, (c) 25%, (d) 50% & (e) 75% frozen mass fraction.

Figure 6. (a) PCT for PCM sphere with 4 fins at Orientation 2, and temperatures contour for (b) 5%, (c) 25%, (d) 50% & (e) 75% frozen mass fraction.
The PCT can be calculated based on the time step interval as shown in Table 1. It is shown that the phase change time are different based on the number of fin used and the orientation of the fin inside the PCM sphere.

| Design of PCM sphere | Initial Time Steps | Final Time Steps | Time Step Interval |
|----------------------|--------------------|------------------|-------------------|
| No fin               | 255                | 3414             | 3159              |
| 2 fins at Orientation 1 | 209                | 2510             | 2301              |
| 2 fins at Orientation 2 | 193                | 2376             | 2183              |
| 4 fins at Orientation 1 | 188                | 2519             | 2331              |
| 4 fins at Orientation 2 | 184                | 2492             | 2308              |

The shortest PCT is depicted from the PCM sphere with 2 fins at Orientation 1. While the longest time taken for phase change is by PCM sphere with no fin. Surprisingly, the PCT for 2 fins are shorter than the 4 fins in general. This is due to the large fin area perpendicular to the inlet of the tank. Comparing PCM sphere with fins at different orientations, it is found that the change in the HTF angle of attack (or the orientation) can result to as high as 5% different on the phase change time.

5. Conclusion

In summary, the best design configuration tested in this simulation project is the PCM sphere with 2 fins at Orientation 1. It is due to its shortest PCT or in other word, the highest thermal performance. This finding is contradicted with the hypothesis that the more high-conducting material (fins) used in the PCM sphere, the higher the thermal performance of the TES. The other consideration must be taken on the largest area exposed to the HTF angle of attack. The result also indicated that the correct orientation does affect thermal performance of the TES. Whereas in general, it is concluded that the use of high conducting material in PCM sphere shown a tremendous improvement in phase change time compared to no fin design.

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