Freezing characteristics in finned LDPE spherical capsule

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ABSTRACT: The current research examines the findings of the freezing features of PCM in an LDPE spherical capsule fitted with and without fins. De-ionized water is used as phase change material to store energy in form of latent heat. Four fins of length 14mm are inserted in LDPE spherical capsule of same dimension. The effect of fins on the freezing time has been analyzed at various heat transfer fluid temperatures. The experimental results indicated that 50% of the mass of PCM has frozen in 21% and 16% of freezing time with the help of fins when compared to LDPE spherical capsule without fins at -6°C and -9°C bath temperatures. There is not a significant reduction in total freezing time for LDPE spherical capsule with inclusion of fins at all the bath temperatures. A marginal increase in surface heat flux value is observed in case of LDPE finned spherical capsule. Along with heat transfer enhancers, the container material's thermal conductivity is critical in increasing the freezing rate of PCM.

Keywords: Latent heat thermal energy storage, LDPE spherical capsule, PCM, Solidification, Pin fins

1. Introduction

Energy storage technologies are critical for ensuring a sustainable energy supply in the coming years. Latent heat storage is a reliable approach for energy storage where PCM stores power during loading and releases the required energy at peak time demand. During charging and discharging it undergoes through isothermal process which is an inherent property of latent heat storage system.

Literary surveys demonstrate that a significant number of investigations employing water as a medium for phase transition have been carried out utilising different approaches for heat transfer improvement[1,2]. PCM with low thermal conductivity is the most significant drawback encountered in CTES systems. As a result, by using a high conductivity PCM and a good heat transfer augmentation approach, the performance of latent heat systems may be improved. The various augmentation techniques used are high thermal conductivity additives, dispersion of nanoparticles, inclusion of fins etc. Water is the most reliable choice for cold storage applications due to its high latent heat, affordability, and thermal conductivity. Water, despite its benefits, suffers from the subcooling issue. The performance of refrigeration unit used in CTES systems is greatly harmed by this subcooling. Researchers employed various techniques to improve the heat transfer rate in the PCM and it is discussed in the following
An experimental research was conducted in a spherical capsule that used water as PCM by spreading CuO nanoparticles and a nucleating agent in base PCM. The findings showed that the use of nanoparticles shortened the total solidification time and removed the subcooling [3]. An experimental examination was carried out in a spherical capsule to explore the impact of different fill volumes of PCM and determined that a greater fill volume of PCM results in an increase in heat flux [4]. Experimental research in a spherical capsule in stainless steel of various diameters has been conducted and subcooling has been completely removed as the capsule diameter increases [5]. Hisham Ettouney et al. [6] examined a single spherical shell in a heat/cold air stream packed with wax and metal beads. It was revealed that the increase in the amount and diameter of the metal beads resulted in a 15% reduction in the duration of charging and discharging times. Using multiwall carbon nanotubes as the nanomaterial and pseudomonas as the nucleating agent, experimental investigation were carried out in a spherical container [7]. The experimental findings showed that the subcooling phenomena is totally alleviated in the PCM when the nucleating agent is used, and the freezing time is reduced by 25% because to the increased heat transmission properties caused by the addition of MWCNT. Similar results were reported by Ponrajan et al. [8] and Sathish Kumar et al. [9] using different additive agents. Xuejiao Jia et al. [10] performed a spherical capsule inquiry into the use of PCM Composite Material with circular fins, and found that inserting six fins into the capsule shortened the duration of solidification by over 50% compared to that without fins. Kumaresan et al. [11, 12] observed that the inclusion of a multiwall carbon nanotube increased heat transfer properties of the PCM and resulting in a substantial decrease in subcooling. The NFPCMs are expected to save roughly 6-9 percent of energy in the CTES systems. The features of freezing of the PCM in a stainless steel spherical capsule equipped with rectangular fins were examined by Premnath et al. [13] The freezing period was down by 87-90% when 50% of the PCM weight was taken into account at various heat transfer fluid temperatures. Premnath et al. [14] employed experimental design of Box-Benkehn to create mathematical models for forecasting the period of solidification with fin length effects using surface regression. In comparison with a capsule without a fin under identical circumstances the period of solidification was improved between 17 percent and 21 percent by the combinations anticipated by the desired strategy. Charging phase features of the PCM in spherical and cylindrical finned systems using were examined by Kalaiselvam et al. [15]. With the integration of fins for various configurations, the total time for solidification was lowered by 65-72% and the numerical results was in excellent accord with the experimental findings. Fewer amounts of studies have been shown in case of LDPE spherical capsule with fins. Hence in this investigation the freezing characteristics have been studied in a LDPE spherical capsule fitted with the copper fin material.

2. Experimentation

Figure 1 illustrates experimental installations, which comprises a refrigerator unit, a temperature bath with a thermal insulation, a spherical capsule, PDTC and data logger (Agilent 34972A) and necessary measurement sensors. The temperature controller range is -50°C to 50°C. The Keysight 34972A data acquisition system records the temperature of the PCM for every 30 seconds. Stainless steel cylindrical container is insulated with polyurethane foam material (volume -0.015 m³). A 70 percent water/30 percent ethylene glycol by volume is used in the cylindrical bath. This HTF (Heat Transfer Fluid) acts as heat transport medium to transfer heat from encapsulated Phase change Material to the surrounding bath. The PDTC with 0.15°C stability was employed through the use of a 3kW cooling unit and a 3kW power heating coil to maintain the ideal bath temperature. The PDTC adjusts the heating coil output according on the temperature of the surrounding heat transmission fluid, which is measured by an RTD consistently. Owing to its large latent heat, convenient accessibility, minimal corrosiveness and inexpensive cost, deionized water is utilised as a PCM. A stirrer is used to keep the temperature consistent throughout the bath. Spherical shell made of low density polyethylene (LDPE) with an outer diameter of 66mm is used for experimentation. The spherical LDPE capsule contains four RTD and is located at radial points in bottom part of the capsule which represent 50% (T1), 75% (T2), 90% (T3), and 100%
(T4) of the total volume from the inner surface of the sphere. The fill volume of the PCM in the container is taken as 90%. The spherical capsule must be lowered into the HTF-filled constant temperature bath and for every 30 seconds the temperature at four locations using RTDs in the capsule were recorded in data acquisition system. The experimental trails were duplicated three times to confirm the reproducibility and accuracy of the measured data. The tests were conducted at three distinct temperatures: -6°C, -9°C, and -12°C.

Figure.1. Schematic diagram of the experimental setup

Figure. 2. LDPE capsule with four fins

Figure. 3. Thermocouple locations
3. Results and Discussion

3.1 Total solidification time at the centre of the container:

Figure 4 shows the time needed for the PCM to freeze in the centre of the container fitted with and without fins. From the above figure, it is inferred that total solidification time difference of the PCM between LDPE capsule without fins and fitted with fins is 9 minutes, 4.5 minutes and 1.5 minutes at T bath = -6°C, -9°C and -12°C (T bath = Bath temperature). It is inferred that there is a marginal drop in the total solidification time at -6°C bath temperature when compared with the other bath temperatures of -9°C and -12°C. Thus a slight decrease of 6% in the overall solidification time at bath temperature of -6 °C is noticed with the use of fins.

![Figure 4. Temperature Time history of PCM at the centre of the capsule](image)

3.2 Fraction mass freezed:

From the figures 5-7 it is observed that the time taken for the 50% PCM mass to freeze in unfinned and finned capsules are 34 and 27 minutes, 22 and 18.5 minutes, 15 and 14 minutes at T bath = -6°C, -9°C and -12°C. Similarly the time taken for 75% and 90% of PCM mass to be freezed in unfinned capsules are 61.5 and 76 minutes, 37.5 and 46.5 minutes, 26 and 33 minutes at T bath = -6°C, -9°C and -12°C. Similarly, the duration of the PCM to be freezed at the same bath temperature in finned capsules is also 50 and 66 minutes, 33 and 42, 24.5 and 31.5 minutes. From the above values it is noticed that the 50% of PCM mass freezes fastly than the other mass fractions. The PCM mass nearer to the container wall and the fins
provided inside the capsule helps in aiding the quicker heat transfer rate in the 50% PCM mass region. Later as the freezing front progresses towards 75%, 90% and 100% PCM mass region the heat transfer rate decreases due to the formation of solid ice layers. An enhancement of 21%, 16% and 7% is observed for 50% PCM mass at $T_{\text{bath}} = -6^\circ\text{C}, -9^\circ\text{C}$ and -12°C. Thus the provision of fins aids in increasing the freezing rate in 50% PCM mass region.

Figure 5. Freezing duration-Frozen mass history at bath temperature of -6°C

Figure 6. Freezing duration-Frozen mass history at bath temperature of -9°C
3.3 Heat flux Vs Frozen mass fraction

Figures 8 and 9 shows the surface heat flux variation with respect to the solidified mass fractions at bath temperatures of -6 °C and -9 °C. The time-averaged surface heat flow is computed using the relationship proposed by the author in his previous study [14]. At $T_{\text{bath}} = -6 \, ^\circ\text{C}$, the surface heat flux fluctuates between 773 and 559 W/m$^2$ for the capsule without fin, and 965 to 589 W/m$^2$ for the finned capsule. Similarly at $T_{\text{bath}} = -9 \, ^\circ\text{C}$, for the capsule without fin the surface heat flux values varies between 1194 to 956 W/m$^2$ and for finned capsule the heat flux values ranges between 1408 to 1002 W/m$^2$. A marginal surface heat flux increase is observed at bath temperature of -6 °C with the provision of fins in the capsule. The ratio of heat flux of finned capsule with respect to the unfinned capsule is 1.3, 1.2 and 1.1 at $T_{\text{bath}} = -6 \, ^\circ\text{C}$, -9 °C and -12 °C respectively. With the help of fins provided in the capsule, the surface heat flux increased marginally at higher bath temperature of -6 °C. However, there is no great improvement in heat flux at lower bath temperatures. Also, the fraction wise 50% PCM mass freezed comparatively better than the other mass fractions. Thus, with the help of fins the heat transfer rate is increased marginally at higher bath temperature of -6 °C.
4. Conclusion

The findings of the research on the freezing features of PCM enclosed in an LDPE spherical capsule with and without copper pin fins are mentioned below.

1. The use of fins provided in the capsule reduces total solidification time by 6% at -6°C.
2. Considering 50% PCM mass, enhancement of 21%, 16% and 7% is observed at bath temperatures of -6 °C, -9 °C and -12 °C with the provision of fins.
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