Solidification characteristics in a spherical capsule integrated with pin fins and rectangular fins - a comparative study

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Abstract: This study aims at investigating the solidification characteristics in a spherical capsule with pin fins and rectangular fins of same length and volume immersed in a constant temperature bath (-6°C, -9°C, -12°C). The fins are made of copper and are attached to the inner surface of the spherical capsule. The fin lengths correspond to the annulus fill volume margin of 75% taken on the inside wall of the spherical container. The findings showed that the overall solidification period of the capsules with rectangular fins was reduced. Also, the subcooling phenomena is completely eliminated at bath temperature of -6°C. Results also indicated that 50% PCM mass is reduced effectively with the provision of fins. Thus, with the employment of rectangular fins better potential energy savings can be attained when operated at partial charging mode at higher bath temperature.

Keywords: Latent heat thermal energy storage, Stainless steel spherical capsule, PCM, Solidification, Pin and rectangular fins

1. Introduction:

CTES (Cool Thermal Energy Storage) systems are devices that are nowadays mainly used in air conditioning for buildings, Industrial applications, etc [1,2]. Due to the great increase in the energy consumption many of researchers are focusing their attention to CTES systems [3-6]. Researchers are finding effects of coolant that surrounds the container [7]. From the different types of encapsulation, the spherical capsule was preferred due to its high heat transfer area [8,9]. Chen et al [10] their results indicated that both low and high inlet HTF flow rate resulted in higher storage tank efficiency. Water is used as the PCM due its properties like high thermal conductivity, high latent heat availability, etc. However, it has a disadvantage of supercooling phenomena as reported by Cheralathan et al. [11]. Researchers [12] studied freezing characteristics of spherical capsule with water as PCM of different sizes. They found that big capsules with 75 percent PCM mass may be employed for the effective design of the CTES system with the proper temperature differential. Researchers [13] investigated the freezing features of spherical containers filled with
water at various fill volumes and discovered that the CTES performance increased with the suitable volume and temperature. Researchers et al. [14] reported that by the addition of nanofluids at varying fraction resulted in reduction in the solidification time and subcooling phenomena. Govindaraj et al. [15] reported that orthogonal fin configuration is better than the circumferential fin configuration. Xuejiao et al [16] indicated that the thermal performance can be improved by optimizing length L and diameter D of pin fins. Premnath et al. [17] indicated that a 9-12 percent reduction in partial loading technique may be accomplished by adopting rectangular fins in the CTES system.

It can be observed that from the above literature that nanofluids show improved performance in CTES systems but the problem being faced is that these particles settle at the bottom of the encapsulation over a period of time. Researchers have reported that using fins also improved the performance of these systems [18]. Few researchers have implemented using pin fins and rectangular fins in their encapsulation for their tests. So, an attempt to compare the solidification characteristics of pin finned and rectangular finned capsule with water based PCM at different bath temperatures is carried out.

2. Experimentation

Figure 1 depicts an experimental arrangement consisting of a refrigeration unit, thermal insulation bath, spherical capsule, PDTC and data logger (Agilent 34972A) and the measuring sensors required. The constant temperature bath is made of stainless-steel material. The heat transfer fluid employed in this temperature bath is 70% water and 30% ethylene glycol. An electric motor and submersible pump are used to keep the constant temperature of the fluid in the bath. The spherical capsules used here are made of stainless steel with diameter of 75mm. The pin fins and rectangular fins are made of same length (13.5mm). The fins are welded on the inner surface of the capsule at radial directions that have an inclusive angle of 90°. The spherical capsule is filled with deionized water up to 90%. The four RTD’s used are placed at positions that relate to 100%, 90%, 75% and 50% of the annulus volume of spherical capsule. These are the frozen masses when the freezing front reaches at their locations.

The two spherical capsules with pin fins and rectangular fins respectively are immersed in the bath at three constant temperatures $T_{\text{bath}} = -6^\circ\text{C}, -9^\circ\text{C}$ and $-12^\circ\text{C}$. The temperature fluctuations of the PCM in the spherical capsule are monitored using a data logger. Also, the depth at which the spherical capsules are kept is the same. The experiment is executed till the set constant bath temperature is reached at the core.

**Figure 1.** Schematic of Experimental Setup

**Figure 2.** Experimental Setup
3. **Results and Discussion:**

3.1 **Temperature fluctuations of the PCM at capsule centre:**

*Figure 3.* Temperature fluctuations of PCM with pin fins, rectangular fins and without fins at three different bath temperature, \(T_{bath}\) a) -6°C, b) -9°C, c) -12°C
From the plots it is observed that the onset time of solidification of the container with pin fins was 18 mins, and for the capsule with rectangular fins, it was 14.5 mins at -6°C bath temperature. Similarly, there was a reduction seen in the onset of solidification at $T_{bath} = -9°C$ and -12°C.

The solidification time difference of without fins capsule with Pin fins and rectangular fins capsule at -6°C are 30mins and 30.5mins, at -9°C are 8mins and 14.5mins and at -12°C are 5mins and 5.5mins respectively. From this we were able to infer that there is a significant decrease in the time of solidification at -6°C bath temperature when compared with at -9°C and -12°C. Therefore, rectangular fins are better by a small margin than pin fins.

3.2 Solidified Mass Fraction

*Freezing duration vs Frozen mass fraction:*
It was observed that at 50% frozen mass fraction the freezing duration for pin fins decreases by 53% and for rectangular fins decreases by 75% at -6°C, the freezing duration for pin fins decreases by 10% and for rectangular fins by 44% at-9°C and the freezing duration for pin fins decreases by 7.1% and for rectangular fins decreases by 14% with respect to the capsule without fins. There was similar relationship seen at 75% and 90% frozen mass fraction. Also, these results were better than the results obtained by Premnath et al. [18] with SS fins. There was a significant decrease in the solidification time of rectangular fins when compared with pin fins.

3.3 Heat flux vs Frozen fraction:

The heat flow is determined in accordance with the relationship used in the research article[19].
From the plots we were able to infer that at 50% frozen mass fraction the heat flux for pin fins increases by 52.8% and for rectangular fins increases by 73% at -6°C, the heat flux for pin fins increases by 14.2% and for rectangular fins increases by 40% at -9°C and the heat flux pin fins increases by 6.5% and for rectangular fins increases by 13% at -12°C with respect to the spherical capsule without fins.

4. Conclusion

By the experimental tests the following points are concluded:

- The heat flux for pin fins increases by 6.5% and for rectangular fins increases by 13% with respect to the ball without fins.
- There is significant decrease in the solidification time at -6°C bath temperature by 53% and 75% for pin fins and rectangular fins respectively whereas at -9°C and -12°C bath
temperature the decrease is by (10%, 44%) and (7,14%) at 50 % frozen fraction and continues to increase for further frozen fractions.

- Heat flux increases greatly at -6°C bath temperature by 52.8% and 73% for pin fins and rectangular fins respectively whereas at T_{bath} = -9°C and -12°C the increase is by 14.2%,43%) and (6.5%,13%) at 50% frozen fraction and continues to decrease for further frozen fractions.
- Maximum enhancement in the solidification characteristics is seen in rectangular fins with 50% frozen fraction constraint at -6°C bath temperature.
- Therefore, from the above results it is clear that rectangular fins have better solidification characteristics than pin fins.

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