CHAPTER 5

CONCLUSION

In an air conditioning / industrial refrigeration system when the chiller is integrated with latent cool thermal energy storage system for any applications, there are lots of advantages like capacity and electricity demand reduction and operating the chiller, during the off peak hours to achieve tariff benefit, always with full load to attain better motor efficiency and during the night hours due to lower condensing temperature that lower the SEC. However chiller has to be operated with a higher temperature driving potential than the system without storage to achieve the required heat transfer. This will reduce the energy efficiency and nullify all the above said advantages in the energy consumption though economic benefit is achieved due to tariff difference and demand side management. Hence the storage temperature that in turn decides the freezing temperature of the selected PCM though depends on the process-cooling requirement should be as high as possible to achieve higher COP or lower SEC. Thus it is construed that the temperature at which the chiller is operated and the efficient heat transfer mechanism play a vital role in determining the energy efficiency of the cool thermal storage system.

Considering the pressing need to develop an energy efficient CTES system through enhanced heat transfer rate as well as to achieve higher operational storage temperature, the objectives of the present research work were devised to explore the possibility of enhancing the effective thermal conductivity of the phase change material and to reduce the sub cooling effect in the PCM during solidification with the latest concepts of adding different nano particles with the base PCM along with other nucleating agents. Further, the effect of percentage of fill volume of the PCM in the container and the size of PCM container are also studied in detail for optimization.
The following conclusions are arrived from the present experimental investigation on the solidification behavior of water based PCMs.

### 5.1 NFPCMs

The developments in the field of nanotechnology make the CTES more energy efficient, in addition to its effective thermal energy management in various industrial sectors.

- As the temperature potential increases, the freezing duration is significantly reduced and the onset of solidification occurs at a faster rate with a reduction in the subcooling effect.
- The presence of pseudomonas plays a major role in eliminating the subcooling of the PCM and the NFPCMs significantly reduce the freezing duration compared to that of pure water PCM.
- Various nanoparticles produce different effects on the reduction of subcooling behavior and in enhancement of heat transfer. Among the nanoparticles, Iron(II) oxide nanoparticle eliminates the subcooling. Thermal conductivity of the nano material has not shown direct influence in heat transfer enhancement.
- The enhanced thermal transport properties of the NFPCM along with the elimination of subcooling will facilitate the CTES system to operate at the highest possible temperature of the secondary refrigerant.
- A uniform rate of charging is achieved during the first 25 % of the freezing time during which 50 % of the mass is frozen. Hence, the major problem of non-uniform charging and discharging encountered in the CTES system can be alleviated by considering only 50 % of the PCM for the applications that demand the large uniform supply of heat energy.
It is predicted that there is a considerable energy saving potential of 18% to 28% in the chiller with CTES system due to possible increase in the operating temperature of the evaporator by 6 to 7 °C by using the enhanced heat transfer characteristics of the NFPCM during the solidification.

5.2 SIZES OF CAPSULES

A series of experiments were performed to study the dynamics of solidification characteristics of water as PCM filled in a spherical capsule of various sizes at different surrounding bath temperatures and the following conclusions are made based on the experimental results.

- The sub cooling effect decreases with the increase in the size of the capsule when the surrounding bath is maintained at -6 °C. However, the sub cooling is totally eliminated for all the sizes of capsules when the surrounding bath is maintained at -9 °C and -12 °C.

- The solidification front moves faster in the larger capsule than the smaller one till the solidification of 75% of PCM mass and this effect is more pronounced with increased temperature driving potential. This is due to the domination of the nucleation rate till the solidification of 75% of the PCM mass and the domination of conduction resistance thereafter.

- The ratio of the time averaged heat flux till 75% mass solidification to 100% mass solidified is higher with the 100 mm capsule compared to the 74 mm capsule and this ratio increases further with increase in temperature driving potential.

- Accounting of the energy available in 75% PCM in a larger size capsule while designing with appropriate temperature driving potential is the most optimal way to increase the energy efficiency of a CTES system along with rapid charging and discharging.
5.3 **FILL VOLUMES**

Based on the series of experiments performed and its interpolated results on solidification characteristics of water as PCM filled with different volumes in a spherical capsule, the following conclusions are made.

- The major problem of subcooling that exists in a CTES system with water as the PCM is completely eliminated by filling the PCM up to 95% of its full volume. The onset of solidification is significantly advanced due to the elimination of subcooling along with the reduced solidification duration.

- The maximum accelerated charging prevails during the solidification of 50% mass of PCM with the capsule filled up to 95% of its full volume at any HTF temperature.

- The ratio of maximum heat flux to average heat flux is several folds higher with increased temperature driving potential while considering 50% of PCM mass.

- The increased contact area and reduced thermal contact resistance are to be the contributing factors for the enhanced performance.

- This accelerated mode of charging without subcooling, with water as the PCM paves the way to select pure water as a potential candidate for a CTES system to alleviate the major problem of non uniform charging / discharging encountered in the CTES system for various applications that demand large heat flux within a short duration.
5.4 SCOPE FOR FUTURE WORK

The following works are proposed for furthering the research work in the field of PCM based thermal energy storage using the nanofluids.

- In the present work, different nanoparticles are used for the enhancement in the thermal transport properties of the PCM. The integration of the high conductive nanoparticles in the HTF fluid needs to be analyzed for exploring the maximum enhancement of heat transfer in a CTES system.

- The performance of the storage based chiller unit need to be evaluated to quantify the improvement in the performance with the presence of NFPCMs and the HTF based nanofluids.

- The development of mathematical modeling to predict the dynamics of solidification/melting for NFPCMs.

- The correlations to predict the dynamics of solidification/melting of NFPCMs