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SIMULATION AND ANALYSIS OF PHASE CHANGE MATERIALS(PCM) BASEDTHERMAL ENERGY STORAGE SYSTEM USING CFD

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ABSTRACT

A Computational Fluid Dynamics (CFD) modelfor thermal energy storage tank by keeping PhaseChange Material (PCM) in the capsules has been developed and validated with experimental results.The heat transfer fluid flow (HTF)in thermal energy storage tank was developed using PCM capsules in a single arrangement during the charging and discharging processes. A Two-Dimensional CFD model using Ansys code was developed and validated with experimental results. The inlet and outlet HTF temperatures in the PCM were compared with the CFD results. This paper gives details of the CFD model and compares results from the model and experiments.

Keywords:*Thermal energy storage tank, Phase Change Material, Thermal stratification, CFD.*

1. INTRODUCTION

Thermal energy storage is needed to improve the efficiency of solar thermal energy applications and to eliminate the mismatch between energy supply and energy demand [1]. Among the thermal energy storages, the latent heat thermal energy storage has gained much attention because of its high- energy densities per unit mass/volume at nearly constant temperatures [9,10]. Storage of latent heat using organic phase changematerials (PCMs) offers greater energy storage density over a marginal melting and freezing[5,8] temperaturedifference in comparison to inorganic materials. These favourablecharacteristics of organic PCMs makethem suitable in a wide range of applications [2].A CFD model has been developed for a thermal energy storagesystem usingAnsys16.0. Resultspredicted by the model were compared to experimental results.From this study, the CFD model can developed topredict the behaviour of the thermal energy storage system duringthe charging and discharging processes [3,4].The three-dimensional (3D) transient unsteady Computational Fluid Dynamics (CFD)simulations[7] to investigate the influence of several design and operating parameters during chargingoperation on the flow behaviour, thermal stratification and performance of a hot water storage tankinstalled in thermal energy storage systems[6,14].

2. EXPERIMENTAL EVALUATION

This consists of an insulated cylindrical TES tank, which contains PCM stored in cylindrical, spherical, and square capsules, flow meter and water storage tank. The stainless steel TES tank has 300mm diameter and 150mm height and containing 10 lits of water. A flow distributor is provided on the top of the tank to make uniform flow of HTF with 55° C to 60° C temperature. The storage tank is insulated with glass wool of 50 mm thick. The PCM capsules of different shapes are uniformly packed in the storage tank. The $Na_2S_2O_3$ $5H_2O$ is used as PCM that has a melting temperature of 48° C and latent heat of fusion of 210 kJ/kg. PCM temperature in Storage tank is maintained as room temperature. Water is used as both SHS material and HTF.

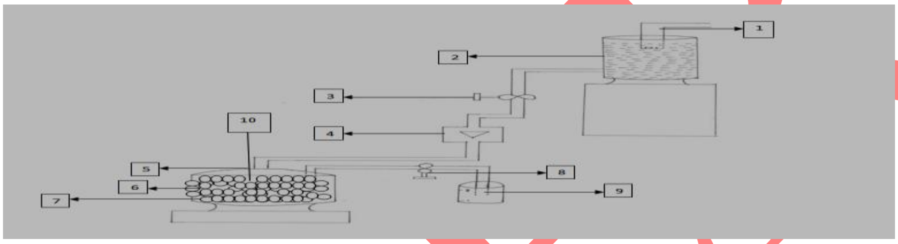


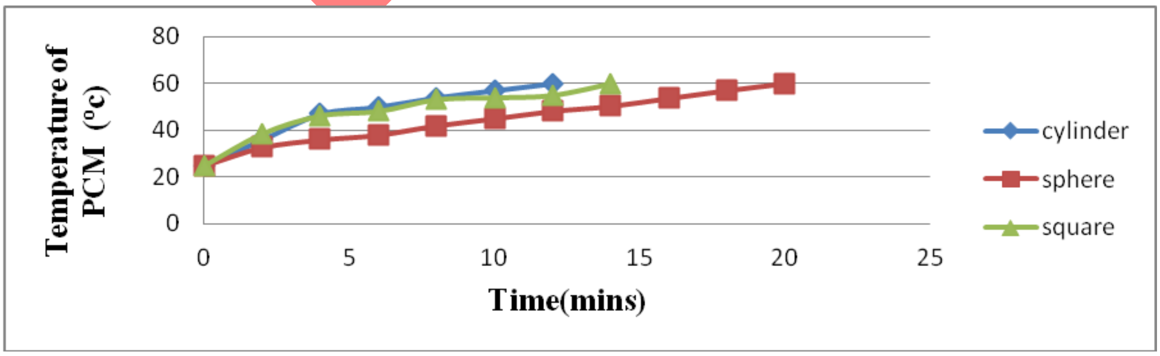
Fig.2.1 Schematic diagram of Experimental set-up

1. Electric heater 2. Constant temperature bath (water storage tank)
3&8. Flow control valves 4. Flow meter 5.Distributer 6. TES Tank
7.PCM capsules 9. Outlet tank 10. Digital thermometer

2.1Charging Process

The energy is stored inside the capsules as sensible heat and latent heat. As the charging process proceeds, energy storage increases until it reaches the equilibrium position (i.e., HTF temperature = PCM temperature). Temperature of PCM (T_{PCM}) and HTF (T_{HTF}) in the TES tank is recorded at an interval of 2 minutes. The charging process is continued until the PCM temperature comes in equilibrium with the temperature of HTF in the TES tank.

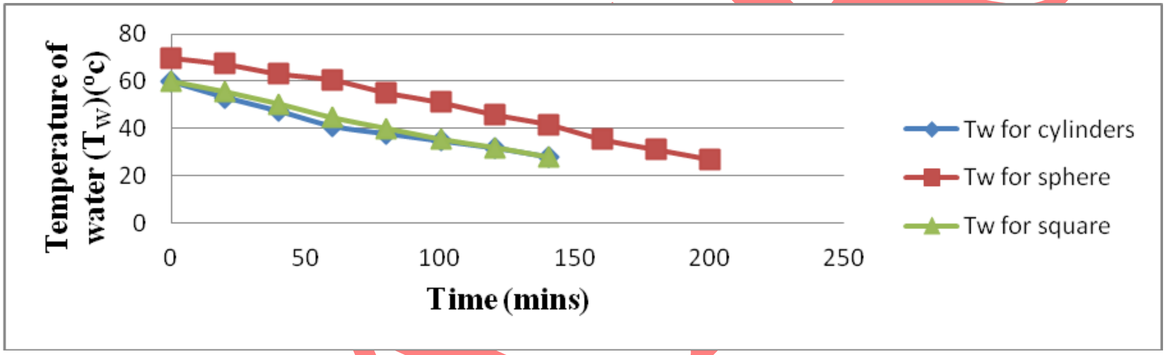
The variation of HTF and PCM temperature during charging process (Heat recovery) is reported. A comparative study is also made between the conventional SHS system and combined storage system.



2.2 Discharging Process

The discharging process starts after the completion of charging process. Batch wise discharging experiments are carried out as explained below. In this method 4 litres of hot water is discharged from the thermal energy storage (TES) tank and the same quantity of cold water at 25°C is fed into TES tank in each batch. The average temperature of the collected discharge water in the bucket is measured using a digital thermometer. The time difference between the consequent discharges is 20 min. The batch wise withdrawing of hot water is continued till the temperature of the outlet water reaches room Temperature.

The variation of HTF and PCM temperature during discharging process (Heat recovery) is reported. A comparative study is also made between the conventional SHS system and combined storage system.



2.3 Experimental Results

- The effect of mass flow rate of heat transfer fluid at 4 lit/min and heat transfer fluid inlet temperature at 60°C is more on charging time when compared to other. Hence, it is concluded that higher flow rates and higher inlet temperatures of heat transfer fluid are recommended.
- From the results, it is observed that the total energy stored and energy retrieval time are high in combined Sensible heat storage (SHS) and Latent heat storage (LHS) system than conventional sensible heat storage system (SHS). Hence, combined SHS and LHS are recommended for thermal energy storage systems.
- The charging time, surface area to volume ratio and energy retrieval time is more for Spherical PCM capsule shape compared to others. Hence, Spherical PCM capsule is recommended for filling PCM.
- After the experimental results ,Spherical shape capsule are used in CFD Simulation process.

3. SIMULATION MODEL AND ANALYSIS

A 3-D CFD model was developedto analyse the transient heat transfer during the PCM in thermal energy storage tank using ANSYS16.0 is illustrated inFig. 1.

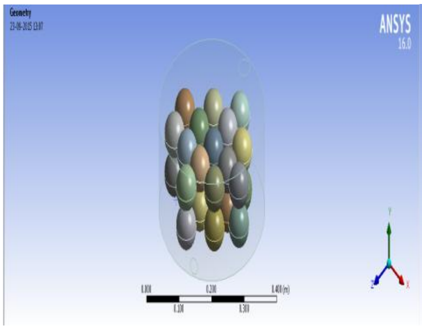


Fig.3.1: Storage Tank geometry

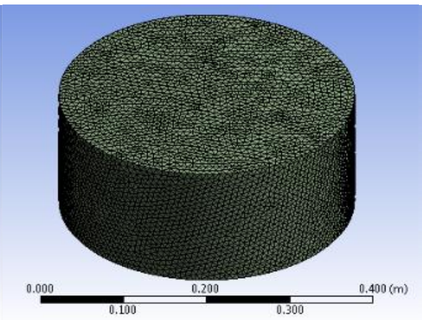


Fig.3.2: Grid for Storage tank

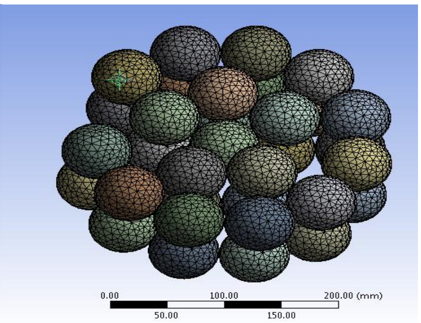
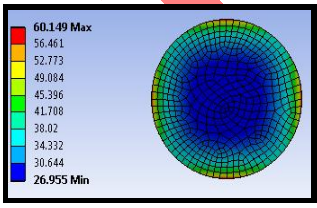


Fig.3.3:grid for spherical capsules

The developed methodology is the same as for TES without PCM. Above 3-D model of the TES system is simulated by keeping PCM in to tank in varying shapes of cylindrical, spherical andsquare concentration. The geometry is modelled in the FLUENT as shown in fig.1. Meshing of the geometry is done in same way as for TES is shown in fig.2. While the PCM Spheres are meshed with Tet element shown in Fig.3.PCM used in spherical shape62 mm diameter and 2mm thickness capsules asSodium thiosulfate pentahydrate whose properties are shown in table3.1. All conditions are given same as required for analysis of thermal energy storage system except solidification and Melting model.

3.1 Charging Contour

The CFD Simulation with mass flow rate of heat transfer fluid 4 lit/min and HTF inlet temperature at 60 °C in charging process. Temperature stratification inside the storage tank is affected by different factors such as tank dimensions (height and diameter), inlet and outlet ports location and type of fluid. Therefore, the flowing section illustrates effect of aspect ratio at different tank heights and diameter as well as the inlet and exit port location on the temperature distribution inside the PCM tank at different time history.



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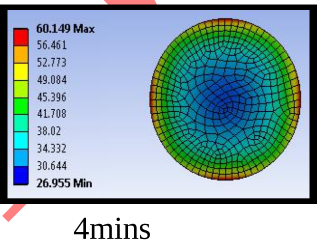

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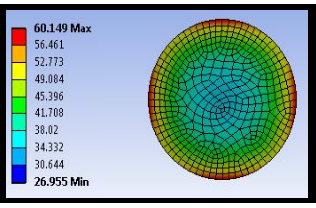

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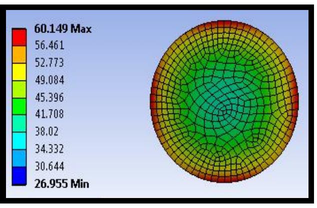

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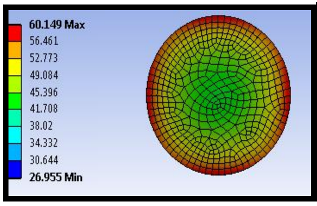

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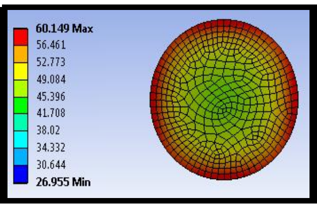

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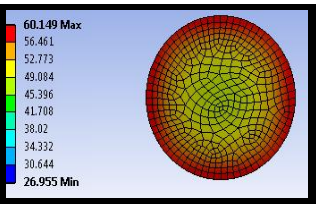

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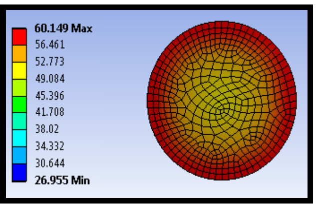

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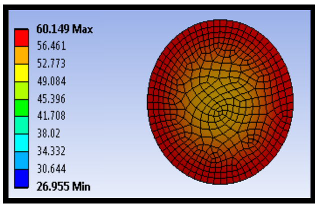

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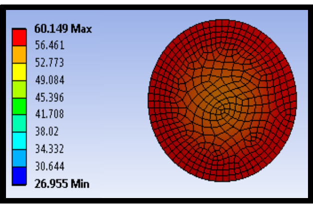

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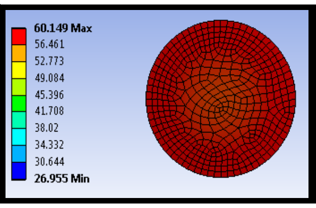

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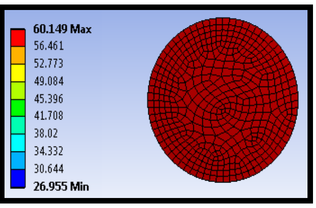

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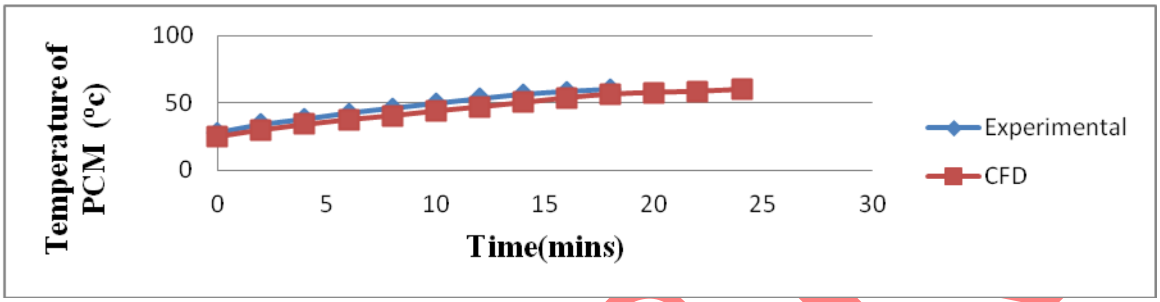
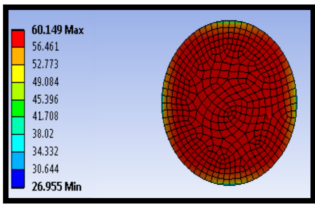


Graph 3.1: Comparision between Experimental and CFD results while charging

3.2 DischargingContour :



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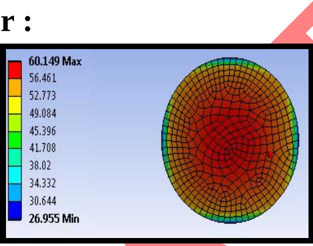

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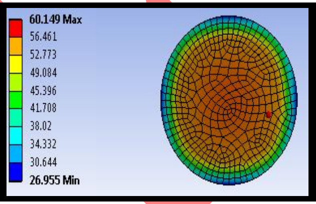

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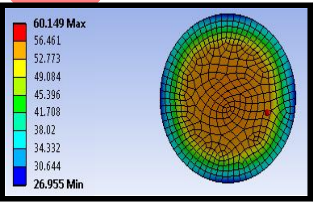

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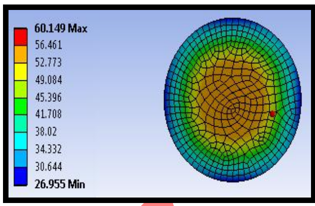

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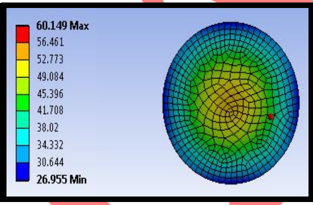

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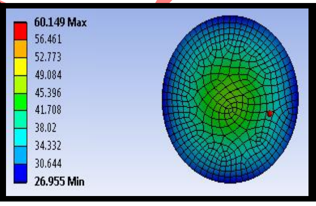

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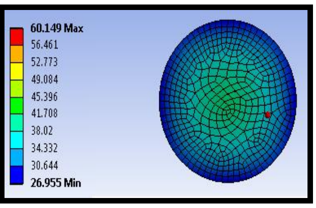

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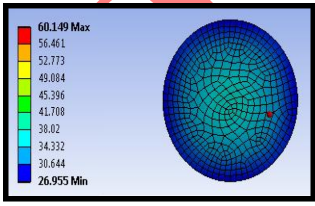

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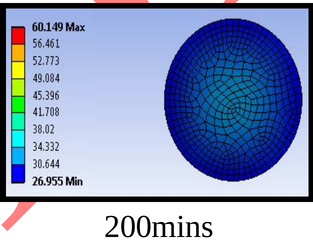

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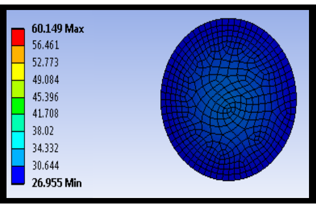

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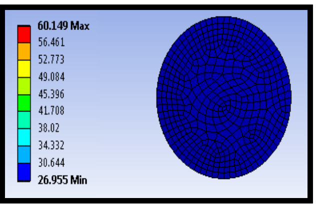

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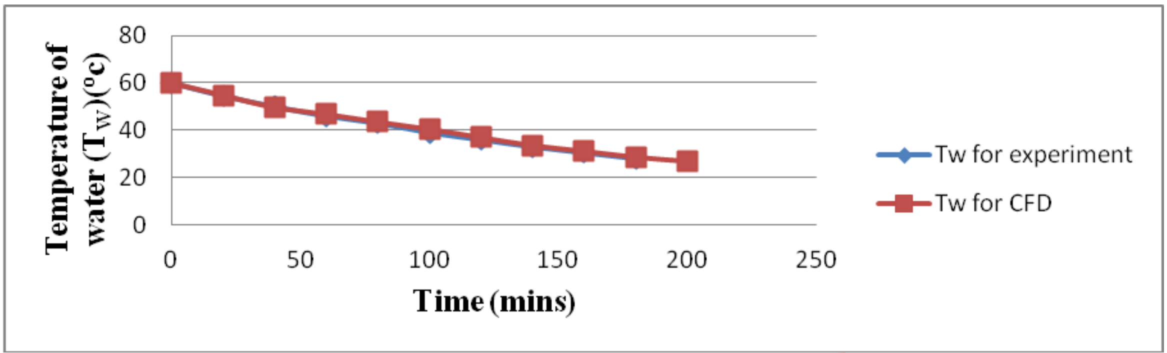

Graph 3.2: Comparison between Experimental and CFD results while discharging

4.RESULTS AND CONCLUSION

A CFD model has been developed for a thermal energy storage system with spherical shape PCM filled inside the cylindrical tank. Results predicted by the model were compared to experimental results. From this study, it was found that the CFD model developed can accurately predict the behaviour of the thermal storage system during the charging and discharging processes. This model has been created ignoring the effect of natural convection. It was observedthat without the effect of natural convection,the thermal behaviour of the freezing and melting processes of the PCM are different compared to the experimental results. The phase change process starts at the top and bottom of the tank and ends at the middle of the tank. The phase change duration between the CFD model and the experimentalresultswerealsocompared.It wasfoundthat theCFDmelting model's phase change duration is generally longer than the experimental results. This change of behaviour as well as the increase in time did not affect the average effectiveness predicted by the CFD model.

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