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Performance Analysis of Latent Heat Thermal Energy Storage using Phase Changing Material in a Circular Orientation.

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***Abstract:** The enormous consumption of energy has led to the fact of saving it at large. To negate the loss of energy, the present work commences research in the field of Thermal Energy Storage in its latent form incorporating Phase Changing Material (PCM) in circular oriented copper Ball Structure. Heating of PCM (by an electric heater) inferred in these copper balls continues till 85˚C(well beyond the melting point of selected PCM), and then when disconnected, PCM discharges gradually giving off the heat accumulated within. Considering 30litres of water in Latent Heat Thermal Energy Storage Tank(LHTES), for a family of four, the research intends to investigate the prolonged duration of time required to keep the water warm. The consequence presents that the time required to charge(heat) water is 4.6 hours(270minutes) and discharge(heat is given off) is 29hours(1740 minutes). Thus proving significant potential in keeping water warm for better performance in a circular orientation.*

***Keywords:** Phase Changing Material, Latent Heat Thermal Energy Storage, Charging, Discharging.*

Acronyms:

CFD- computational fluid dynamics
HTF- heat transfer fluid
PCM -phase change material
TES -Thermal energy storage
LHTES-Latent heat Thermal Energy storage
UR-Upper Ring
LR-Lower Ring
PW-Paraffin Wax
ECBC-Energy Conservation Building Code
H-Enthalpy/kg K
k -thermal conductivity, W m−1 K−1
S- Source term
t- Time, seconds
T-Temperature $^{\circ}C$
S - Source Term
ρ -density, kg m^3

I. INTRODUCTION

In the current Era, the exhaustive nature of energy has embarked on its presence abundantly. In the said Channel, there exists an urge to modify energy sources into cleaner sources from mother nature. This reminds of solar energy, but it comes with the detriment of its infrequent nature.LHTES, on the other hand, serves to be a popular storage system due to its advantageous history of high storage density [1].

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Also, there occurs to be huge merchandise for PCM in the minds of researchers due to the need for investing in energy[1,2].

Studies deduce that TES charging with the help of air conditioning and discharging by electric heater benefits greater performance[3,4]. Also, the spherical shape of capsules offers maximum thermal conductivity with the largest energy density[5].

Solidification rates are depicted to give more amount of periodic time when compared with charging[6]. Though this scenario prevails, PCM poses a threat of low thermal conductivity. Not to compromise with thermal conductivity, the PCM can be incorporated into structures having higher thermal conductivity[7,8-10] like copper material, heat pipes, etc. some materials are posing better results than PCM like myristic acid[11], but cost limitation demands to choose PCM over any other. Various research regarding storing thermal energy in PCM is initiated mostly in the domestic domain of temperature between 0-60˚C[5], hence present study too, concentrates on the domestic application.

From the above characterization, current research work attains a spotlight on storing thermal energy in PCM for domestic application of trapping heat for long hours in other household purposes until it prevails to be warm, hoping to get the water warm for an entire day. for the said purpose, according to the survey, spherical capsules serve a better solution for incorporating PCM to negate the loss of low thermal conductivity.

1.1 Novelty in Research

Acquiring the observations from the current survey, though spherical capsules prove out best to incorporate PCM, the study is deprived of the way the spherical capsules of PCM are to be placed in the LHTES tank. The placing/orientation of PCM inside the LHTES tank has not been quantified. Circular orientation has been selected for investigating the performance of PCM in the LHTES tank.

II. METHODOLOGY

According to a study by K.nithyanandam et.al[16], two resistances, surface convective and internal conduction resistance needs to be propagated in LHTES.

1. The Setup created for the experimental work consists of two hot water tanks which are insulated with Glasswool of 30mm thickness. The tank can store 30litres of water.
2. The Experiment is carried out in two stages-charging(melting) and discharging(solidification). Two tanks viz.hot water tank and LHTES tank are taken into consideration. The circular orientation in LHTES tank is shown in Fig.no.1(b)

3. This orientation consists of two rings -the upper and lower ring. Both the rings are separated with a 150mm distance. The PCM incorporated inside copper balls are placed in these orientations for measuring the charging and discharging traits.

4. A hot water tank contains a heater that is used for heating of water up to 85˚C. A thermostat is placed for automatic regulation of temperature in the LHTES tank. The flow control valve is used in between the tanks to regulate hot water flow from Hot water tank to LHTES tank.

5. The Hot water transferred to the LHTES tank gives heat steadily to Copper balls and further it is transferred to PCM which is the charging cycle of the PCM and later after the significant temperature difference is created reverse cycle begins which is noted as Discharging cycle of the PCM. The below figures show the circular orientation and Schematic Setup Diagram implemented.

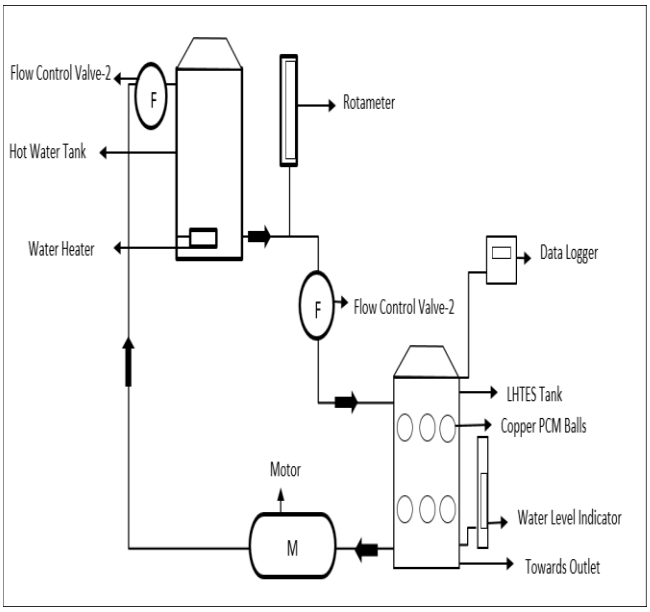

Fig.No 1(a) Schematic Diagram of Set-up

Fig. No 1(b) Circular orienation in LHTES tank

PCM selected is n-tetracosane having melting point as 48-50˚C.

Thermocouples are inserted vertically inside each Spherical Copper Balls. When PCM is in charging condition it starts melting and reaches its temperature up to 85˚C, where it is partially in the vapor state. At this point, it stores latent heat and it stays in this condition for a long duration of time. Again it starts discharging when it gives its heat back to the water surrounding it.

III. GOVERNING EQUATIONS

The Model for investigating the performance of LHTES encompasses the use of 10 Spherical balls in circular orientation (five, on the upper ring and remaining five on the lower ring) in the LHTES tank.

The assumptions made for CFD analysis are stated as under:

○ The density ρ, specific heat capacity C_p and thermal conductivity K are constant throughout for the PCM.

○ Copper material properties are used for copper Balls and Stainless Steel for the LHTES Tank.

○ Conductive Heat Transfer rules over Convective Heat transfer Phenomenon.

Designing of Model on CATIA Software (CAD Model), its Transient Analysis on CFD is pursued by Pre-Processing (Setting up the model), counting Engineering Data (Adding the material Properties of the model), Meshing (Discretizing the given continuum into the finite elemental system), applying the Boundary Conditions. (Natural, Geometric and Thermal), Solving the Continuum to obtain the unknown parameters(solver) and Post-Processing.

Tool Used in the process is Ansys Design Modeler for de-featuring cad models &Ansys Fluent 16.0 is used to interpret time, temperature variations by performing CFD analysis.

The mathematical energy equation (Eq. 1) that governs the physical phenomenon of phase
Change problem is as under:

$$\frac{\partial}{\partial t}(\rho H) + \nabla.\rho\vartheta H = \nabla\cdot(K\ \nabla T) + S \quad \text{.......Eq 1}$$

In the present analysis, due to the absence of convection ($\nabla.\rho\vartheta H$) and source term(S), the governing equation is modified as in Eq. (2)

$$\frac{\partial}{\partial t}(\rho H) = \nabla\cdot(K\ \nabla T) \text{...Eq 2}$$

The properties of selected PCM and Boundary Conditions are stated in Table no 01 and 02.

Table no 01: Properties of PCM[13]

Property	values
Material Used	n-Tetracosane
Molecular formula	$C_{24}H_{50}$
Specific Heat capacity	730.9 J/K mol
Boiling Point	391.4˚Cat 760mm Hg
Latent Temperature	48˚C
Specific Heat (liquid)	772.50 J/milk at 57.63˚C
Specific Heat (gas)	1087.48 J/milk at 475.52˚C

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Table no 02: Boundary Conditions

No. of steps	01
Step End Time	72000Secs
Initial Time Step	720Secs
Minimum Timestep	72Secs
Maximum Timestep	7200Secs
Solver Type	Programme Controlled

IV. RESULTS AND DISCUSSION

No.of trials are considered to investigate the performance of PCM for circular orientation.charging and discharging cycle is employed and the results indicated in CFD are as under:

4.1Charging for circular orientation

Fig. no. 2,3,4 depicts the temperature versus time graph in CFD for 3600,7200,12600 seconds of charging for circular orientation.

The temperature plots can be seen as 42.024°C as lowest temperature in LHTES tank and 41.348°C as highest temperature in LHTES tank at about 3600seconds; 56.371°C as lowest temperature in LHTES tank and 57.047°C as highest temperature in LHTES tank at 7200seconds,and78.907°C as lowest temperature in LHTES tank and 79.583°C as highest temperature in LHTES tank at 12600 seconds having temperature gradient of 0.67°C, which means approximately 30 mins more will be required (approx) to reach the temperature of 85°C(which is to be attained for charging). The total time to charge circular orientation is 4 hours.

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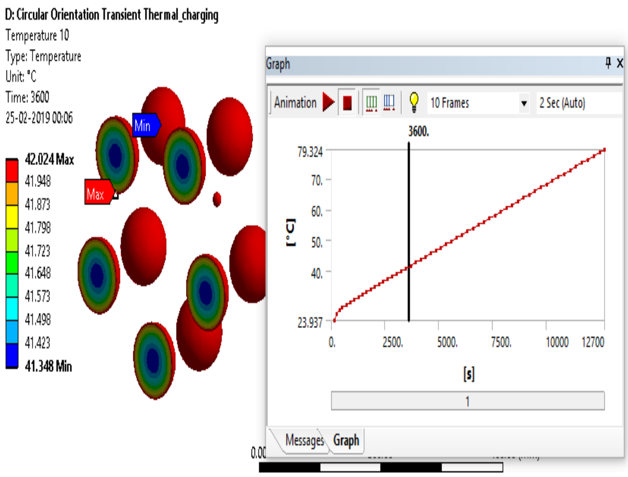

Figure no 2: Charging for Circular Orientation-PCM (3600sec)

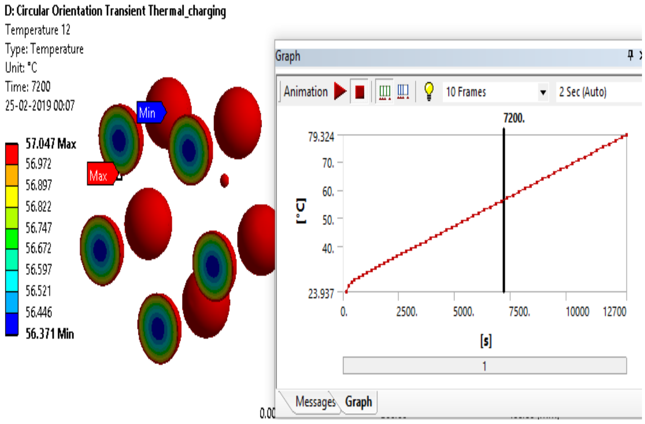

Figure no 3: Charging for Circular Orientation-PCM (7200sec)

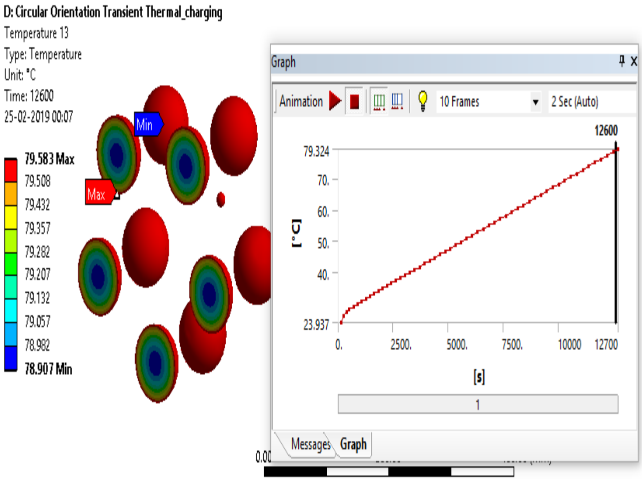

Figure no 4: Charging for Circular Orientation-PCM (12600sec)

4.3Discharging of Circular Orientation

The temperature plots can be seen as 77.5°C as lowest temperature in LHTES tank and 77.567°C as highest temperature in LHTES tank at about 18000seconds; 70°C as lowest temperature in LHTES tank and 70.067°C as highest temperature in LHTES tank at 36000seconds,and40°C as lowest temperature in LHTES tank and 40.067°C as highest temperature in LHTES tank at 108000 seconds. Total time taken for discharging till 40°C is about 30 hours.

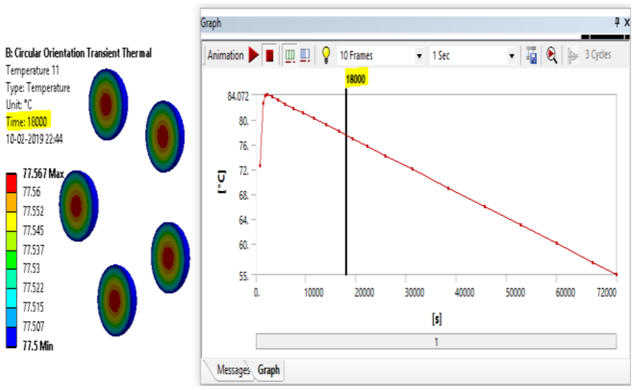

Fig. no 5: Discharging of Circular Orientation-PCM (18000sec)

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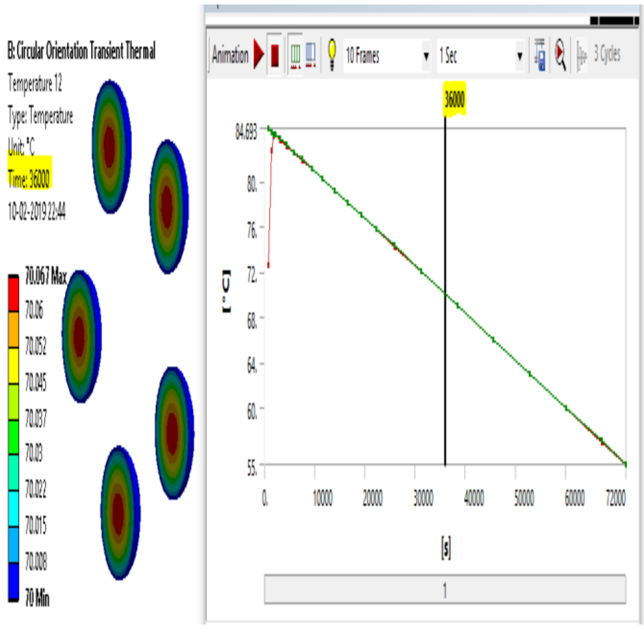

Fig.no 6: Discharging of Circular Orientation-PCM (36000sec)

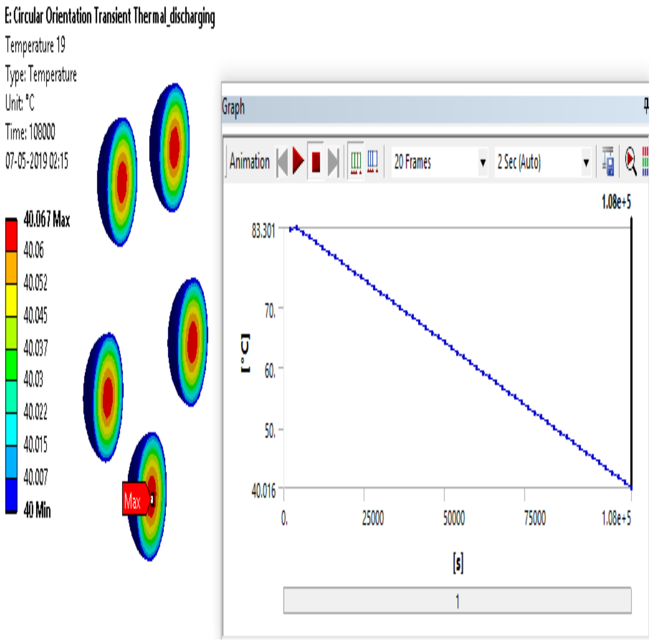

Fig. no 7: Discharging of Circular Orientation-PCM (108000sec)

V. VALIDATION OF CFD WITH EXPERIMENTATION RESULTS

An experimental study is done by charging the PCM up to 85˚C (by an electric heater, which can be replaced by the solar heater)and then observing the discharging cycle till ambient temperature. The period attained for these cycles is noted down.

5.1Charging results for circular orientation

Fig. no 8 shows the charging cycle readings. It took 4.6 hours to reach a temperature of 85°C. This indicates the similarity in CFD and experimental readings; wherein CFD results displayed 4.5 hours of expectation which is almost fulfilled by experimentation.

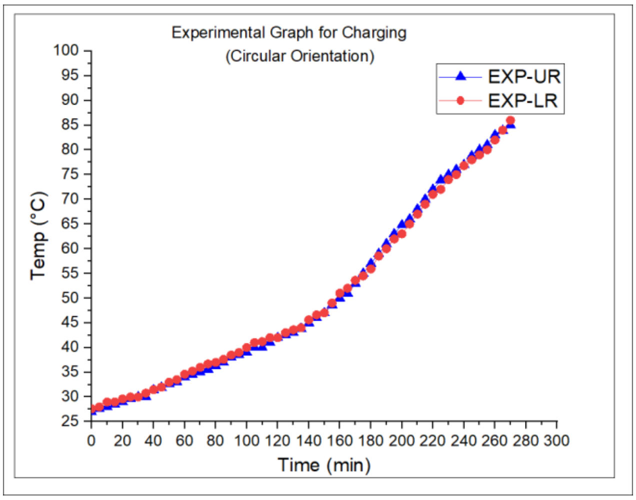

Fig no 8: Experimental Charging Results -Circular Orientation

5.2Discharging results for circular orientation

Fig. no 9 shows the total discharging cycle readings. It took 29 hours for PCM to reach an ambient temperature which is less by 1 hour than the CFD readings obtained for the discharging cycle. This 60 minutes time variation may be due to manual errors while experimenting.

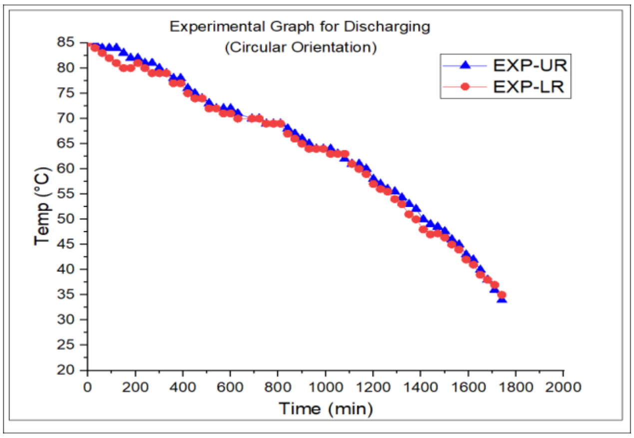

Fig no 9: Experimental Discharging Results -Circular Orientation

Table no.03 Summary of Results

Summary of Results			
CFD Charging Time	**CFD Discharging Time**	**Experimental Charging Time**	**Experimental Discharging Time**
240 mins i.e 4 hours	1800 mins i.e 30 hours	270 mins i.e 4.5 hours	1740 mins i.e 29 hours

VI. CONCLUSION

An investigation on the performance of PCM in circularly placed Copper Balls is effectuated.

- Temperature divergence on the behavior of circular oriented PCM balls gives fairly good appearance between the presented CFD and experimental results.
- 4.5 hours of charging(heating) and 20 hours of discharging(giving off heat) is the time taken to integrate the process of storing energy in water.
- circular orientation postulates avancement in storing heat for a longer duration of time but minor temperature fluctuations across the LHTES tank occur.
- These fluctuations may have occurred due to the absence of a PCM ball in the middle of the orientation, making the water of midway reaching to a different temperature.
- Hence, once charged, hot water continues to stay warm to about 29 hours which is more than a single day expectation without consuming much energy.
- The utilisation is thus signified upon the use of PCM material in selected copper Balls in the said orientation.

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