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# Comparative Study of Sensible and Latent Heat Storage Model for Concentrated Solar Power Plant

**[1]M. Mohan Ram, K. Durga Prasad, G. Shankar Rao, K. Bulli Reddy,
Sk. Saleem, J. Someswara Rao and [2*]Birendra Kumar Barik**

*[1]B Tech students, Dept. of Mechanical Engg. RGU IIIT, Nuzvid-521202, Andhra Pradesh*
*[2]Dept. of Mechanical Engg. RGU IIIT Nuzvid-521202, Andhra Pradesh, India*
*E-mail: *biren.barik@gmail.com*

**Abstract—***Concentrated solar power plant (CSP) technology utilizes focused sunlight to heat working fluid of power plant in day time to produce electricity. To avoid intermittence of power production, heat storage systems were introduced in which extra heat absorbed by heat transferred fluid will be stored in any heat storing materials. In heat storage systems different heat storing materials like ceramics and phase change materials (latent heat storage model) are used. The properties that should be possessed by these heat storing materials are high heat capacity, high storing time. So, heat from these storages can betransferred to working fluid at night time. The comparison sensible and latent heat storage in both non-encapsulated and encapsulated models are also mentioned. In the paper We are characterizing heat transfer capacity and heat storing capability of the phase change material (PCM), the solar salt (Eutectic mixture of 60 wt% of NaNO3 and 40 wt% KNO3) by conducting comparative study with simulation in ANSYS FLUENT on Sensible heat storage model (block model), Phase change model (PCM model) and Encapsulated phase change model (EPCM).*

**Keywords***: CSP, storage system, phase change material, encapsulate*

## 1. INTRODUCTION

Intermittent nature of solar energy demands integration of energy storage system with the solar collectors in order to have uninterrupted supply of energy in the absence of availability of solar energy and to fulfil the peak load energy demands even in the presence of solar energy. In air based solar energy utilization systems, storage of hot air is not possible due to low density of air. Denser medium is required for storage of thermal energy. Mathur, R. Kasetty et al., [1] said that Storing thermal energy as latent heat of fusion in phase change material can improve the energy density by 50% while reducing the cost by 40%. However, to discharge stored energy from PCMs, which has low thermal conductivity requires a large heat transfer area. Salts encapsulated into small capsules can provide high specific surface area. So, to obtain this we voted for packed bed arrangement of encapsulated phase change materials to store energy. Cautier and Farber,[5]mentioned that packed bed generally represents the most suitable energy storage unit for such air based solar energy systems.Packed bed energy storage system consists of packed solid material in a storage tank through which the fluid is circulated. Hot air flows from solar collectors into a bed of solid particles from top to bottom, where thermal energy is transferred from hot air to solid material during the charging phase. For heat retrieval, cold air flows from bottom to top during discharging phase. Barker et al,[4]and Balakrishnan et al.,[3]have presented extensive literature review of research work reported since the work of Schumann,[12] Most of the investigators used small sized bed elements like gravel, rocksand pebbles to study the performance of packed bed solar energy storage system. Duffie and Beckman,[8]reported that generally recommended size of these particles is 0.01–0.03 m. Packing of small sized particles requires a large pressure drop for uniform flow of hot air through the bed, which causes a large amount of energy consumption to propel hot air through the bed. It reduces the overall benefit of the solar energy system. Cautier and Farber,[5]said that fan energy consumption must be compared to the maximum energy collected and it should not exceed 10% of the maximum energy available.Kulakowski and Schmidt,[11]also emphasized that size of the material elements and pressure drop through the bed are considered to be two parameters of primary importance in the design of the storage unit.Packing of large size storage material could be used to reduce the pressure drop. However, thermal performance of the system may deteriorate due to lesser area of contact available for heat transfer. Authors presented separate equations for evaluating heat transfer coefficient and pressure drop in the bed for each of the four different shapes of material elements investigated. Lo¨f and Hawley,[18]reported the correlation for heat transfer coefficient for bed of gravel under normal voids and mentioned that large variation of heat transfer coefficient may be expected with change of bed voids and shape of material elements. The element shape is a significant variable in gas–

liquid flooding in packed columns. Scmidt and Willmott,[13] mentioned that as the fluid flows Therefore effect of particle shape and bed porosity are required to be taken into account while calculating the heat transfer coefficient. Ranjit Singh & R P Singh et al.,[2] developed correlations for Nusselt's number and friction factor as function of Reynolds number, sphericity of material elements and void fraction of the bed. A good agreement has been found between the experimental and the values predicted by these correlations.

## 2. MATHEMATICAL MODELING

On the basis of the above experimental conclusions, we are characterizing heat transfer capacity and heat storing capability of the phasechange material (PCM), Solar salt (Eutectic mixture of 60 wt% of $NaNO_3$ and 40 wt% $KNO_3$) and corresponding material properties are mentioned in Table 2,3,4&5 respectively. To prove the effectiveness of encapsulated solar salt we are conduction comparative study with simulation in ANSYS Fluent on,

1. Sensible heat storage(block) model
2. Phase change model (PCM model)
3. Encapsulated PCM model

### 2.1. Nomenclature

Parameters used in paper and their symbols are tabulated below Table 1.

**Table 1; Nomenclature and Acronyms of parameters used in this paper**

| Parameter | Symbol |
|---|---|
| Packed bed diameter | dpb |
| Sphere diameter | ds |
| Pipe diameter | dp |
| Void fraction | E |
| Renold's number | Re |
| Nusselt's number | Nu |
| Bed heat transfer coefficient | hpb |
| Pipe heat transfer coefficient | hp |
| HTF mass flow rate | mhtf |
| WF mass flow rate | mwf |
| Specific heat capacity of HTF | cphtf |
| Specific heat capacity of WF | cpwf |
| Boiling point of WF | Tbwf |
| Sphere-city | $\psi$ |
| Volume of packed bed | Vpb or b |
| Volume of Phase change material(PCM) | Vpcm or s |
| Acronyms: | |
| HFT | Heat transfer fluid |
| WF | Working Fluid |
| PCM | Phase Change Material |
| EPCM | Encapsulated PCM |

### 2.2. Materials

| | |
|---|---|
| Heat transfer fluid | Air |
| Working fluid | Water |
| PCM | Solar salt |
| PCM shell | Aluminium |
| Packed bed wall | Ceramic wall |
| Working fluid pipe | Aluminium |
| Sensible heat storage | Concrete |

**Table 2: Properties of Phase Change Material**

| PROPERTY | VALUE |
|---|---|
| Name | Solar Salt (60 wt% NaNO3 + 40 wt% KNO3) |
| Melting Point (o C) | 220 |
| Boiling Point (o C) | 600 |
| Heat Capacity (Cp) (KJKg-1K-1) | 1.52 |
| Thermal conductivity (K) (WM-1K-1) | 0.53 |
| Density (Kg/m3) | 1804 |
| Dynamic Viscosity (Pa. Sec.) | 1.69 |
| Prandtl Number (Pr) | 4.85 |
| Degradation Temperature (o C) | 511.77 |
| Heat of Fusion (KJ/Kg) | 161 |
| Volume change of fusion (%) | 4.6 |
| Stored Energy Density (KJ/Kg) | 456 |

**Table 3: Properties of shell material.**

| PROPERTY | VALUE |
|---|---|
| Name | Aluminium |
| Melting Point (o C) | 660 |
| Heat of Fusion (KJ/K) | 321 |
| Density (g/mL) | 2.719 |
| Heat Capacity (J/mol. K) | 24.2 |
| Molar Weight (Kg/mol.) | 13 |
| Thermal Conductivity (WM-1K-1) | 231 |

**Table 4: Properties of working fluid.**

| PROPERTY | VALUE |
|---|---|
| Name | Water |
| Density (g/m3) | 1000 |
| Specific heat of water vapour (KJ/Kg. K) | 1.996 |
| Specific heat of water (KJ/Kg. K) | 4.187 |
| Latent heat of evaporation (KJ/Kg. K) | 2270 |
| Boiling temperature at 1 atm. (o C) | 100 |
| Mean Pressure (bars) | 16.83 |
| Mean Temperature (o C) | 187.5 |
| Density (Kg/m3) | 879.21 |
| Dynamic Viscosity (Pa. Sec.) | 0.000144 |
| Thermal Conductivity (WM-1K-1) | 0.6704 |
| Specific heat capacity (KJ/Kg. K) | 4.4335 |
| Latent Heat (KJ/Kg) | 796.664 |
| Prandtl Number (Pr) | 0.952 |

**Table 5: Properties ofHeat Transfer Fluid.**

| PROPERTY | VALUE |
|---|---|
| Name | Air |
| Heat Capacity (KJ/Kg. K) | 1.0141 |

| | |
|---|---|
| Thermal Conductivity (WM-1K-1) | 0.033019 |
| Density (Kg/m3) | 0.88401 |
| Dynamic viscosity (Kg/m.sec.) | 2.2892*10-5 |
| Prandtl Number | 0.70305 |

### 2.3. Parameters calculation:

The important parameters for packed bed design are bed diameter, particle diameter and void fraction of packed bed.

$$\varepsilon = \frac{V_b - V_s}{V_b} \quad \text{(Nsofor and George, 2001)}$$

Each parameter has their own effect on over all heat transfer coefficient. We had considered random values of backed bed diameter, spheres and void fractions for 2 kg of phase change material in optimal range mentioned inRanjit Singh et al.,[2] and remaining parameter values were mentioned in Table 6. The follow regime was considered as turbulent flow with mass flow inlet of 1 kg/sec. To calculate heat transfer coefficient of packed bed ($h_{bed}$), we first calculated the Reynold's number (Re) by considering the void fraction of packed bed as 0.5 with randomly arranged spheres.

$$Re_p = \frac{D_p V_s \rho}{(1-\varepsilon)\mu}$$

For the obtained value of Reynold's number, obtained the correlation for Nusselt's number to calculate heat transfer coefficient between fluid and particles of packed bed from literature.

$$Nu = 0.437(Re)^{0.75}(\psi)^{3.35}(\varepsilon)^{-1.62}[\exp\{29.03(\log\psi)^2\}]$$

$$\text{Nusselt's Number} = \frac{\text{h x character length}}{\text{k}}$$

As the heat transfer fluid (fluid runs in between solar field and packed bed) is air there is no need consider the phase change effect of air while giving up heat to PCM but this not true in the case of working fluid water (fluid runs in between packed bed and power generation unit.). Since water under goes phase change from water to vapour while gaining heat from sphere we had to consider the heat transfer phenomenon with phase change in pipe flow.

**Table 6: Calculated design parameters**

| Parameter | Value |
|---|---|
| Vs | 4.4x10-3 m3 |
| Vb | 8.8x10-3m3 |
| Packed bed column height | 0.5 m |
| Volume of each sphere | 1.413x10-3 m3 |
| Void fraction | 0.5 |
| Mass flow rate of fluid | 1 kg/s |
| Nusselt's number | 386.55 |

### 2.4.Assumptions

- Heat transfer model is in steady state condition.
- Each particle in packed bed are contactless.
- Each particle contains two layers i.e. shell and PCM.
- Coefficient of thermal expancity is considered to be negligible for PCM.
- Specific heat capacities of al materials are invariant throughout the process.
- Solidification of PCM takes place on shell only by forming a second layer in sphere.
- Solidus and liquidus temperatures and specific heat capacities of al materials are invariant throughout the process.

## 3. DESIGN AND SIMULATION

Software tool used for designing the model is Gambit 2.3.2 and analysis is ANSYS FLUENT 14.0. For obtained geometric and flow parameters model was designed in gambit by setting spheres for which $\psi$ is unity in unstructured order for encapsulated PCM model. For sensible and non-encapsulated PCM model a block of cylinder shape was created for heat storage models were given in below Fig. 1, 2&3.

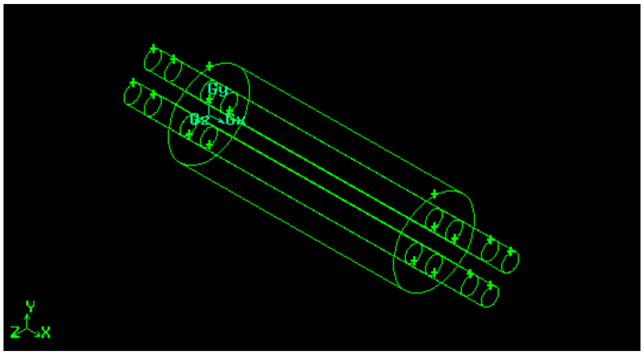

**Fig. 2: Non-encapsulated heat storage system**

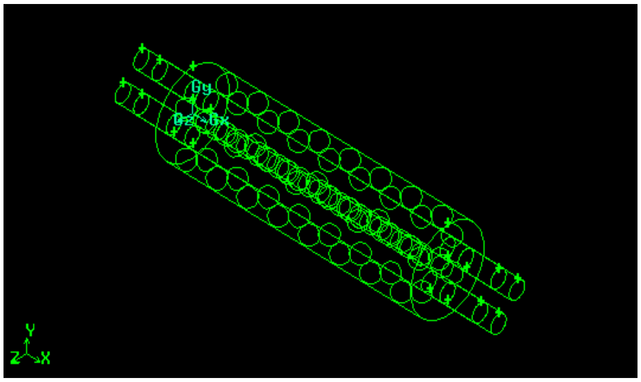

**Fig. 3 Model of encapsulated PCM storage system**

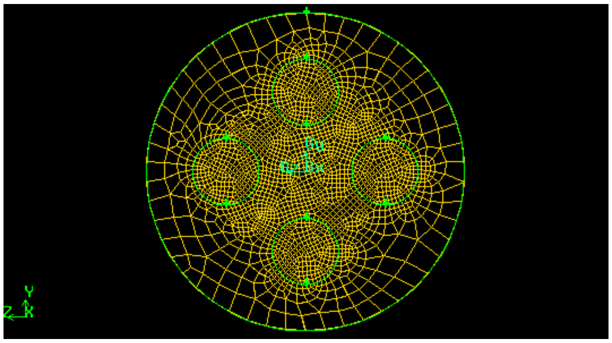

**Fig. 1: Model meshing in Gambit**

Simulation ran in ANSYS FLUENT 14.0. The simulation parameters were, the flow is in turbulent regime with k-ε model, steady state heat transfer condition. For solidification and melting of PCM we considered mushy zone value to be 100000 and multiphase system for water flowboiling in pipes. Partial execution of simulation results were given in below Fig. 4, 5&6.

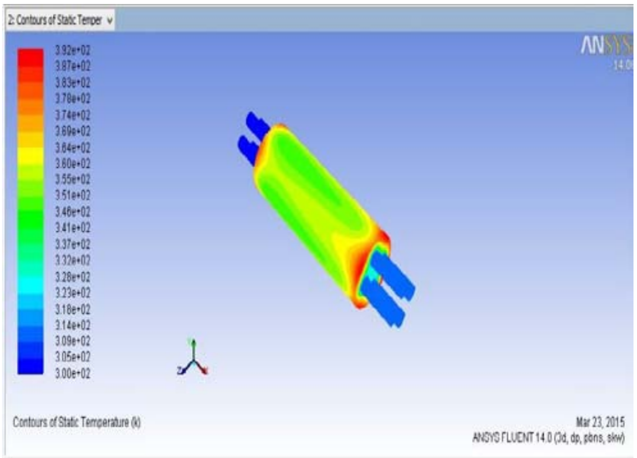

**Fig. 4: Sample simulation for PCM Model**

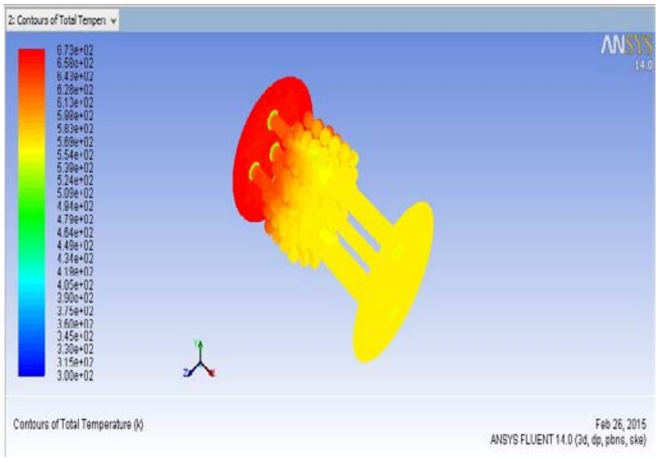

**Fig. 5: Sample simulation of heat transfer in EPCM mode**

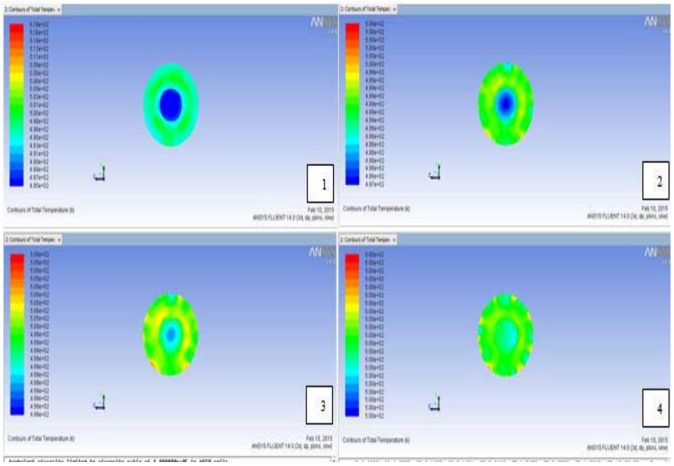

**Fig. 6: Heat flow in encapsulated PCM sphere from domain.**

## 4. CONCLUSION

The parameters for the simulation of heat transfer in sensible heat storage and latent heat storage were calculated and model was designed in gambit. The simulation of heat transfer in changing and discharging cases for sensible and latent heat storage systems were modelled. Partial execution of models has given satisfactory results for encapsulated and non-encapsulated latent heat storage systems.

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