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Paper Authors

Santha kumar,Shaik Saleem, Dr. Bazani Shaik, Dr. M.Muralidhara Rao,P.Siddik Ali, B. Sudhakar Rao, P.Rajesh

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STUDY OF SENSIBLE HEAT AND LATENT HEAT STORAGE MODEL FOR CONCENTRATED SOLAR POWER PLANT

Santha kumar[1],Shaik Saleem[2], Dr. Bazani Shaik[3], Dr. M.Muralidhara Rao[4],P.Siddik Ali[5], B. Sudhakar Rao[6], P.Rajesh[7]
[1,2,5,6,7]Assistant Professor, Ramachandra College of Engineering, Andhra Pradesh, India.
[3, 4] Professor, Ramachandra College of Engineering, Andhra Pradesh, India.

***Abstract*—*Concentrating Solar Power (CSP) technologies use mirrors to concentrate (focus) the sun's light energy and convert it into heat to create steam to drive a turbine that generates electrical power. 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 (PCM) are used. Heat Storage by using phase change materials is called Latent Heat storage The properties possessed by these heat storing materials are high heat capacity, high storing time. So, heat which stores in these materials can be transferred to working fluid at night time. The detailed comparison between sensible heat and latent heat storage in both encapsulated and non-encapsulated models are mentioned. We are Studying heat transfer capacity and heat storing capabilities of the phase change material (PCM), the solar salt (Eutectic mixture of 70 wt% of NaNO3 and 30 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 Phase change material.*

1. INTRODUCTION

Concentrating Solar Power (CSP) technologies use mirrors to concentrate (focus) the sun's light energy and convert it into heat to create steam to drive a turbine that generates electrical power. Intermittence 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., [5] 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,[1]mentioned that packed bed generally represents the most suitable energy storage unit for such air based

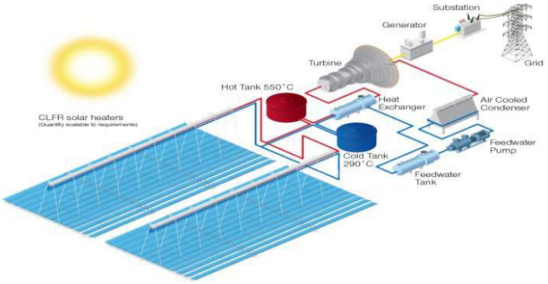

Fig. 1 : Concentrated Solar power plant

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. Barker et al,[3] have presented extensive literature review of research work reported since the work of Schumann,[6] 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,[7]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,[1]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,[9]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. 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.By studying all the authors presentations we have developed models of sensible heat , phase change materials and Encapsulated phase change materials.

2. MATHEMATICAL MODEL

By taking consideration of all the above experimental analysis , we are analyzing the heat storage capabilities and Heat Transfer capacities of the Phase Change Material (PCM) , Salt (*Eutectic mixture of 70 wt% of NaNO3 and 30 wt% KNO3) and related properties are mentioned in table 2 & 3 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

Table 1: Nomenclature and Acronyms of parameters used

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
Volume of packed bed	Vpb or b
Volume of Phase change material(PCM)	Vpcm or s

2.2. Materials

Heat transfer fluid :Air

Working fluid	:Water
PCM	: salt
PCM shell	: Aluminum
Packed bed wall	:Ceramic wall
Working fluid pipe	:Aluminium
Sensible heat storage	:Concrete

Table 2 : Properties of shell material.

PROPERTY	VALUE
Name	Aluminium
Melting Point (o C)	750
Heat of Fusion (KJ/K)	425
Density (g/mL)	3.12
Heat Capacity (J/mol. K)	25
Molar Weight (Kg/mol.)	14
Thermal Conductivity (WM-1K- 1)	249

Table 3 : Properties of Phase Change Material

PROPERTY	VALUE
Name	Salt (70wt% NaNO3 + 30wt% KNO3)
Melting Point (o C)	280
Boiling Point (o C)	654
Heat Capacity (Cp) (KJKg-1K-1)	1.45
Thermal conductivity (K) (WM- 1K-1)	0.53
Density (Kg/m3)	1987
Dynamic Viscosity (Pa. Sec.)	1.89
Prandtl Number (Pr)	4.85
Degradation Temperature (o C)	512.79
Heat of Fusion (KJ/Kg)	178
Volume change of fusion (%)	5.9
Stored Energy Density (KJ/Kg)	567

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.

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

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.

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

Nusselt's Number =(h x character length)/ 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	3.5x10-3 m^3
Vb	9x10-3m^3
Packed bed column height	0.75 m

Volume of each sphere	1.528×10^{-3} m^3
Void fraction	0.7
Mass flow rate of fluid	1.5 kg/s
Nusselt's number	465.55

2.4.Assumptions

- Each particle in packed bed are contactless
- Heat transfer model is in steady state condition.
- Specific heat capacities of al materials are invariant throughout the process.
- Coefficient of thermal expancity is considered to be negligible for PCM.
- Solidus and liquidus temperatures and specific heat capacities of al materials are invariant throughout the process

3.DESIGN AND ANALYSIS

Gambit 2.3.2 is used for designing the model and ANSYS FLUENT 14.0 is used for Analysis.For obtained geometric and flow parameters model was designed in gambit by setting spheres for whichSphere-city is unity in unstructured order for encapsulated PCM model.For sensible, non-encapsulated PCM model and EPCM a block of cylinder shape was created for heat storage models were given in below Fig. 2, 3&4

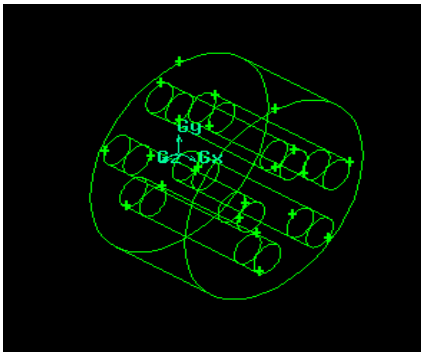

Fig. 2: Sensible Heat storage model

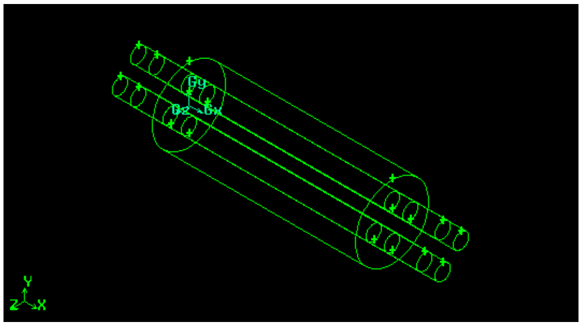

Fig.3 : Wire Frame model of Non-EPCM

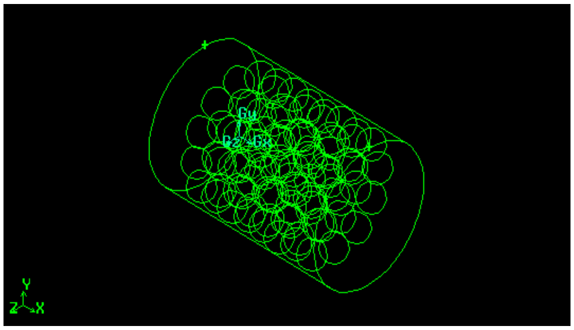

Fig.4 : Wire Frame model of Non-EPCM

After completion of model making in Gambit 2.3.2 Software we have to do meshing . The following figure 5 shows the complete meshing for designed model.

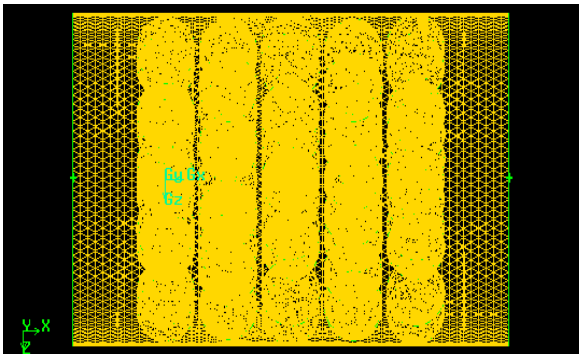

Fig. 5 : Meshing of EPCM wire frame in Gambit

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 and colour bodies were given in below figures.

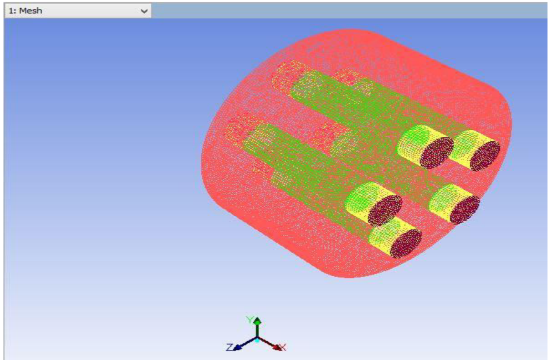

Fig. 6 Block & PCM domain with color by ID mode in Fluent

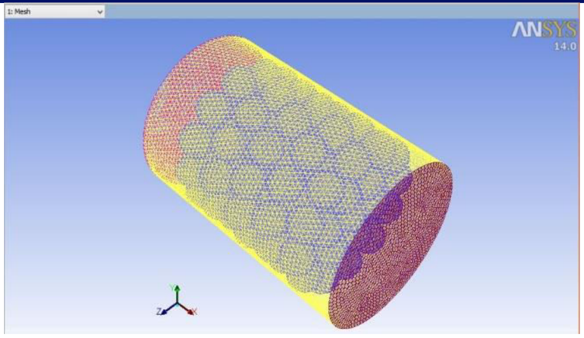

Fig. 7 EPCM domain with color by ID mode in Fluent

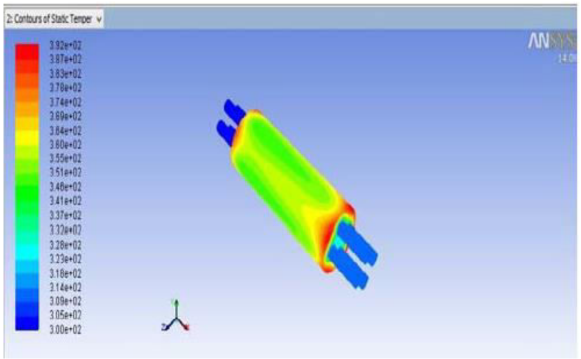

Fig. 8 Sample simulation for PCM Model

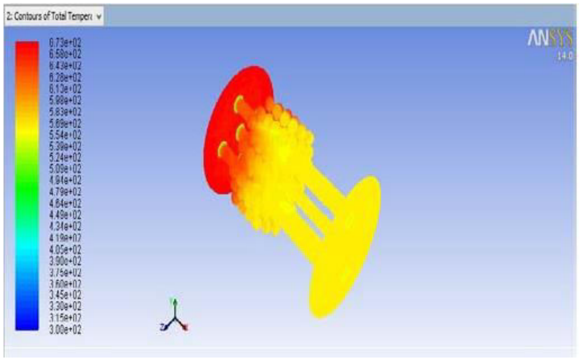

Fig. 9 Sample simulation of heat transfer in EPCM mode

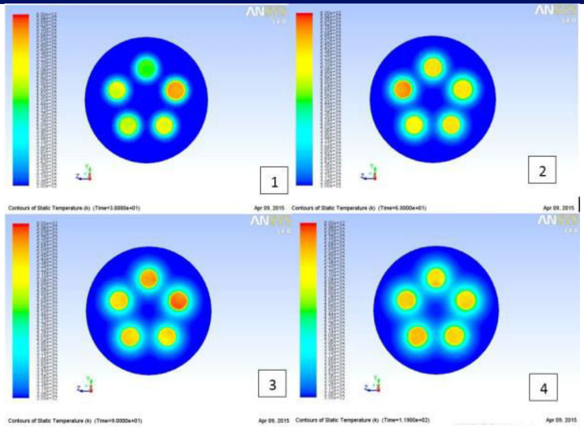

Fig. 10 Simulation of Block model

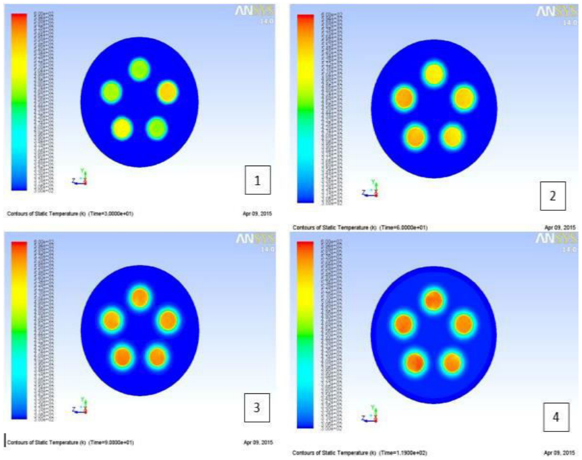

Fig. 11 Simulation of PCM model

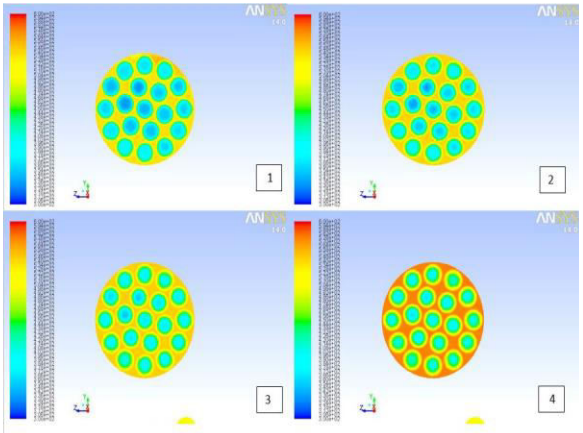

Fig. 12. Simulation of EPCM model

4. RESULT

The following Heat transfer rate(Watts) and Heat density (MJ/m^3) were obtained for Block , PCM and EPCM Models for charging mode .

Model	Heat transfer rate(Watts)	Hear Density(MJ/m^3)
Block model	257.89	74.8
PCM Model	261.4	39.4
EPCM Model	5014.98	988.5

5. 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.Heat storage density of EPCM is comparatively larger than other three models.The comparison of transient run of three models for 120 times steps shows, rise in temperatures of interior are 332 K, 314K and 498 K in Block, PCM and EPCM models respectively.While discharging the storage models, the working fluid outlet temperature from graphs of three models are 322K, 310K and 508.5 K in each three models. That shows heat transfer in EPCM model is quite larger.

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