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CFD ANALYSIS OF LOW GRADE PCM ON THERMAL ENERGY STORAGE

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*Abstract:*The current research investigates the heat storage capacity of Erythritol, paraffin wax and lauric acid on thermal energy storage unit using k epsilon turbulence model. The transient thermal analysis is conducted using techniques of Computational Fluid Dynamics and software used in ANSYS. The CAD model of thermal energy storage unit is developed using Creo design software. The temperature distribution and heat absorption capacity of different materials are determined and compared. Among all the materials investigated, the maximum heat is absorbed by erythritol during initial times of simulation. The two-variable k-epsilon turbulence model gives reasonably good predictions for the fluid flow behavior involving low turbulence. The maximum temperature of erythritol material obtained at the end of 500 seconds simulation is 341K. The energy storage capacity of erythritol is nearly 427 Watts higher than paraffin wax and 422 Watts higher than lauric acid material.

Key Words: PCM's, heat storage capacity, Temperature, IRW, CFD

1. INTRODUCTION

The thermal energy can be stored using latent heat, sensible heat and chemical method. The materials that store heat by changing its state are phase change materials (PCMs). The advantages of latent heat-based TES are high storage density and minimal temperature variation. The practical example of latent based TES is ice storage unit which requires nine times less volume against water storage unit for 10^0C temperature change. This makes it one of the futuristic technologies for energy conservation without any carbon emission. TES can rapidly release or store large amounts of heats because solar energy and heat are intermittent heat sources [1]. TES is an attractive technology because it is the most appropriate method to correct the gap between the demand and supply of energy [2].

2. LITERATURE REVIEW

Rezaeietal.[3]investigatedtheeffectofdifferentPCMs with different melting temperatures on energy and exergy efficiencies by considering the price of energy and exergy for each PCM type.

Li et al. [4] has investigated binaryeutecticLiNO_3–$NaNO_3$,LiCL–NaCL,andLi $_2CO_3$–Na_2CO_3 using analytical temperature model. This analytical temperature model is based on lumped parameter which is used to determine enthalpy difference function.

Izquierdo-Barrientos et al. [5] investigated the application of Phase Change Materials for building walls. The variables optimized during investigation were wall orientation, "PCM layer location" and ambient conditions. Out of these variables PCM layer and wall orientation had significant effect on energy storage capabilities.

Kuznik and Virgone [6] experimentally analyzed the comparative thermal performances of a PCM copolymer composite wallboard. The test room was "composed of two identical enclosures called Test Cells 1 and 2. The test cell had a volume of 3.10m×3.10m×2.50m and was bounded on five sides by air volumes regulated at a constant temperature" [6].

Chan [7] assessed PCM integrated external wall with respect to energy performance and thermal performance. The comparison is made from residential flat without PCM and analysis is done using computer simulation. The resultsshowedthatthe"livingroomofaresidential flat with a west-facing integrated external wall provides a comparatively significant decrease in interior surface temperature up to a maximum of 4.14%".

Zwanzig et al. [8] investigated the 1D transient heat equationviathemultilayeredbuildingenvelopetostudythe energy saving potential of PCM for residential homes. In thisstudy,a"PCMcompositewallboardincorporatedintothe wallsandroofofatypicalresidentialbuildingacrossvarious climate zones was examined. The simulation results showed

that the optimal location for PCM placement within the buildingenvelopedependsontheresistancevaluesbetween the PCM layer and the exterior boundary conditions" [8].

3. OBJECTIVE

The current research investigates the heat storage capacity of Erythritol, paraffin wax and lauric acid on thermal energy storage unit using shear stress transport turbulence model. The analysis is conducted using techniques of Computational Fluid Dynamics and software used in ANSYS and condition of analysis is transient.

4. METHODOLOGY

Initially CAD model of computational domain is developed in CREO design software which is sketch based, parametric 3d modelling software developed by PTC. The modelling procedure comprises of sketch, extrude and assembly and carried out in 2 steps. Three concentric circles are created with dimensions as shown in table 1 below.

Table 1: Dimensions of shell and tube

Item	Symbol	Value
tube length	L	3000mm
internal radius of the interior tube	r_i	26mm
external radius of the interior tube	ro	30mm
internal radius of the exterior shell	r_0	45mm

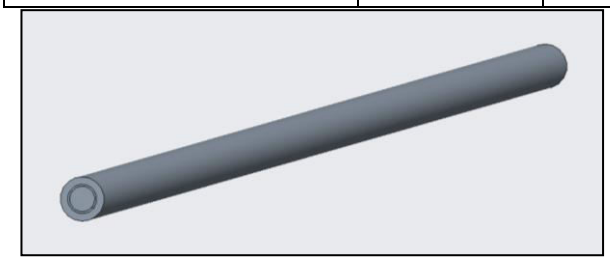

Figure 1: CAD modelling of computational domain in Creo design software

The CAD model of computational domain of IRW is shown in figure 1 above. The model comprises of inner tube (for hot IRW), annulus (copper) and outer annulus for phase change material. The CAD model is developed using sketch and extrude tool of Creo parametric.

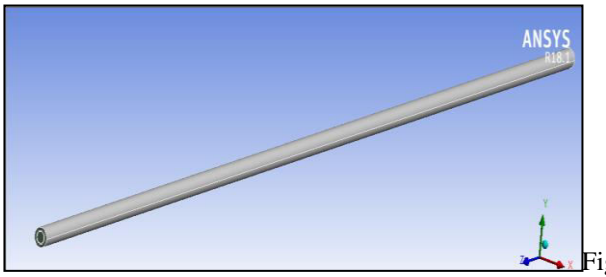

Figure 2: Imported CAD model of computational domain

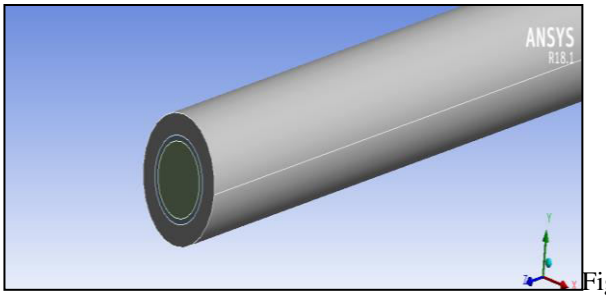

Figure 3: Enlarged view of CAD model of computational domain

The CAD model developed in Creo is converted in .iges file and imported in ANSYS design modeler as shown in figure 3 above, The model is checked for any geometric errors like hard edges, spikes, curvature defects etc. The model is meshed using brick elements as shown in figure 4.5 below with given parameters and appropriate mesh density.The mesh size is set to fine and inflation to normal with relevance set to 100. Transition is set to slow and smoothing medium and span angle fine.

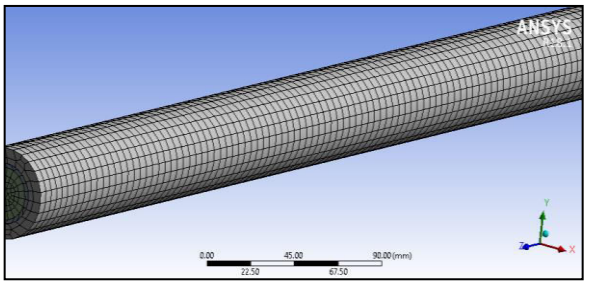

Fig. 5: Enlarged view of meshing (brick shape element)

The brick shape element has eight nodes and has quadratic interpolation function. The number of elements generated is 87949 and number of nodes generated is 120390. This stage involves generation of domain, material definition, fluid flow velocity, generation of interfaces, definition of

morphology, pressure conditions. Figure 6 below shows domain definition for copper which is defined as solid domain and geometry is highlighted in green colour. As heat transfer takes place the energy model is set to thermal energy.

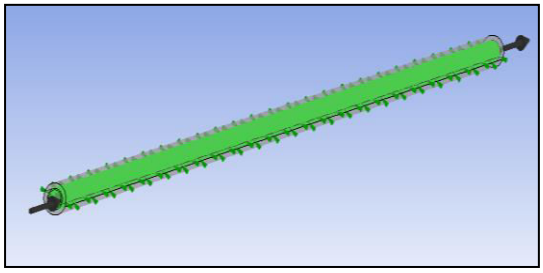

Fig. 6: Domain definition of copper

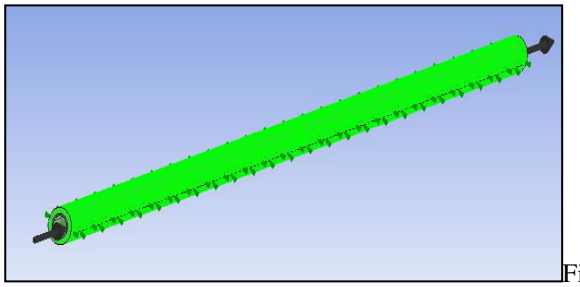

Fig. 7: Domain definition of paraffin

Figure 7 above shows domain definition for paraffin which is defined as solid domain and geometry is highlighted in green colour. As heat transfer takes place the energy model is set to thermal energy.

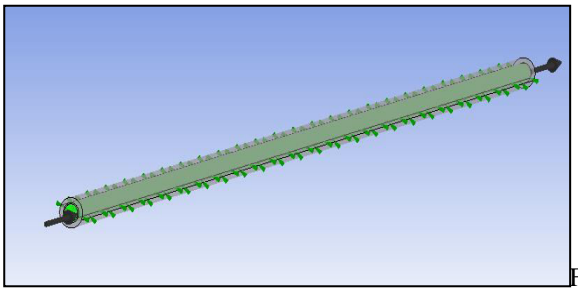

Fig. 8: Domain definition of water

Figure 8 above shows domain definition for water which is defined as fluid domain and geometry is highlighted in green colour. As heat transfer takes place the energy model is set to thermal energy. The reference pressure is set to 1atm and turbulence model is set to k-epsilon. The inlet mass flow rate is defined as .278Kg/s and temperature is defined at 70^0 C. The k-ε is 2 variable turbulence model given by equation below:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[(\mu + \frac{\mu_t}{\sigma_k})\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\epsilon - Y_M + S_k \quad (1)$$

The k-ε turbulence model comprises of turbulence kinetic energy (k) and eddy dissipation rate (ε) which are obtained from transport equation as shown in equation 1.

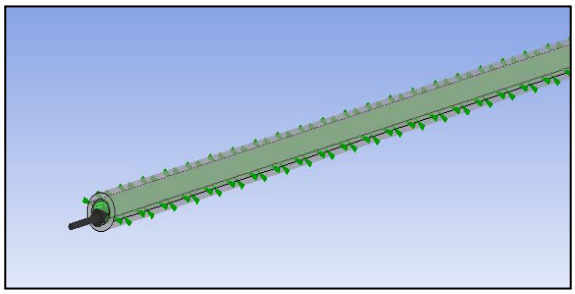

Fig. 9: Fluid solid interface

The fluid solid interface is generated between copper and water domain. The heat transfer is set to conservative interface flux as shown in figure 9 above.

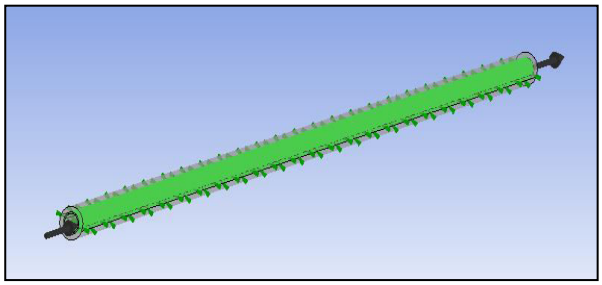

Fig. 10: Solid solid interface

The fluid solid interface is generated between copper and paraffin domain. The heat transfer is set to conservative interface flux as shown in figure 10 above. The transient thermal analysis simulation is set to run for 500secs. The RMS residual values is set to .0001 and loop iterations are set to 10. The solver report is generated as shown below.

5. RESULTS AND DISCUSSION

The transient thermal CFD analysis is conducted using paraffin wax material and temperature plots are generated for different time intervals (after each 25 counter seconds). The heat flux absorbed is also evaluated from CFD analysis.

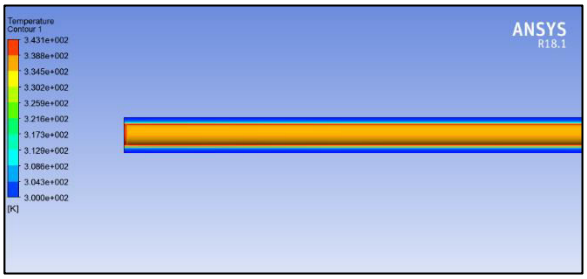

Figure 11: Temperature plot at 25 seconds

The temperature plot at 25 seconds shows very high temperature between copper paraffin wax interface and temperature is nearly 308K as shown by light blue colour and most of the paraffin wax region has temperature below 304K.

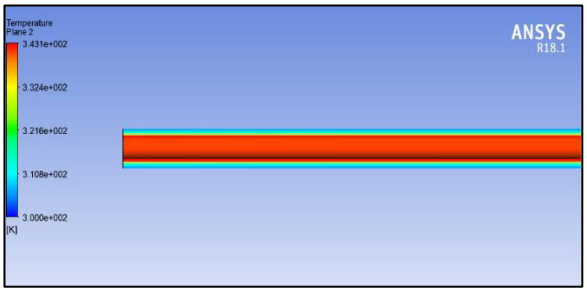

Figure 12: Temperature plot at 100 seconds

The temperature plot at 100 seconds shows very high temperature between copper paraffin wax interface and temperature is nearly 330K as shown by light green colour and most of the outer regions of paraffin wax has temperature below 304K.

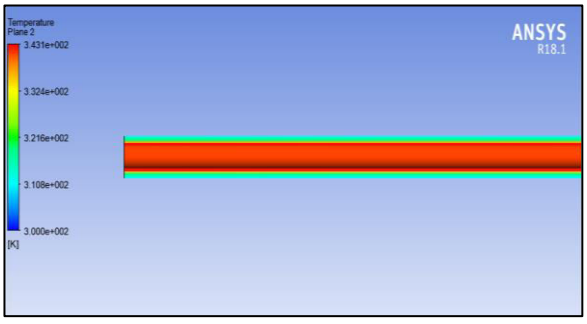

Figure 13: Temperature plot at 150 seconds

The temperature plot at 150 seconds shows very high temperature between copper paraffin wax interface and temperature is nearly 334K as shown by yellow green colour and most of the outer regions of paraffin wax has temperature below 308K.

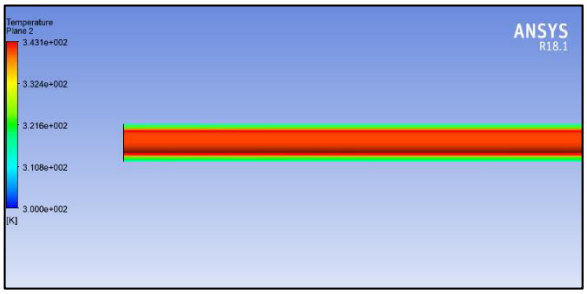

Figure 14: Temperature plot at 200 seconds

The temperature plot at 200 seconds shows very high temperature between copper paraffin wax interface and temperature is nearly 337K as shown by yellow green colour and most of the outer regions of paraffin wax has temperature nearly 312K.

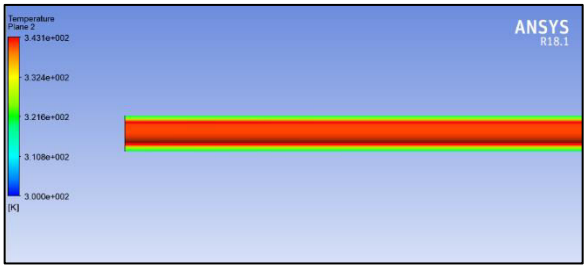

Figure 15: Temperature plot at 250 seconds

The transient thermal CFD analysis is conducted using erythritol material and temperature plots are generated for different time intervals (after each 25 counter seconds). The heat flux absorbed is also evaluated from CFD analysis.

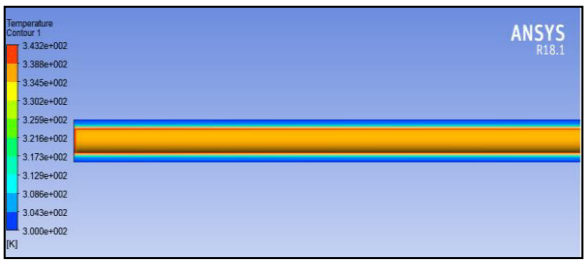

Figure 16: Temperature plot at 25 seconds

The temperature plot at 25 seconds shows very high temperature between copper erythritol wax interface and temperature is nearly 321K as shown by light blue colour and most of the paraffin wax region has temperature below 304K.

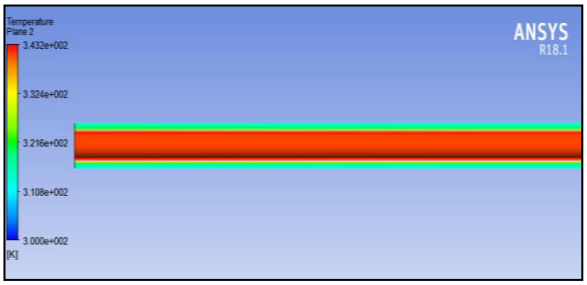

Figure 17: Temperature plot at 100 seconds

The temperature plot at 100 seconds shows very high temperature between copper erythritol wax interface and temperature is nearly 321K as shown by light blue colour and most of the paraffin wax region has temperature below 312K.

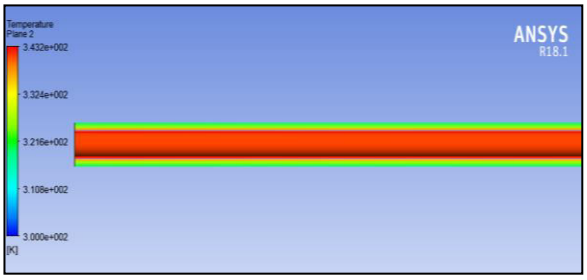

Figure 18: Temperature plot at 150 seconds

The temperature plot at 150 seconds shows very high temperature between copper erythritol wax interface and temperature is nearly 324K as shown by light green colour and most of the paraffin wax region has temperature below 318K.

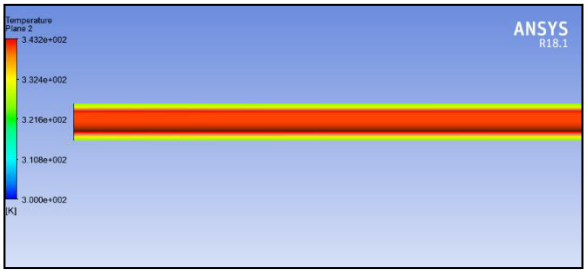

Figure 19: Temperature plot at 200 seconds

The temperature plot at 200 seconds shows very high temperature between copper erythritol wax interface and temperature is nearly 325K as shown by light green colour and most of the paraffin wax region has temperature below 322K.

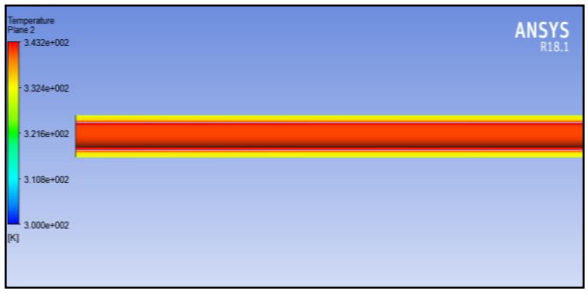

Figure 20: Temperature plot at 250 seconds

The temperature plot at 250 seconds shows very high temperature between copper erythritol wax interface and temperature is nearly 326K as shown by light green colour and most of the paraffin wax region has temperature below 322K. The transient thermal CFD analysis is conducted using lauric acid material and temperature plots are generated for different time intervals (after each 25 counter seconds). The heat flux absorbed is also evaluated from CFD analysis.

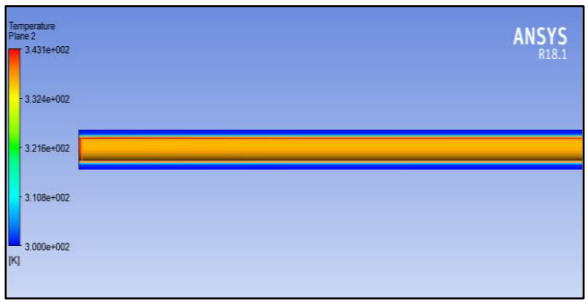

Figure 21: Temperature plot at 25 seconds

The temperature plot at 25 seconds shows very high temperature between copper-lauric acid interface and temperature is nearly 318K as shown by light blue colour and most of the paraffin wax region has temperature below 304K.

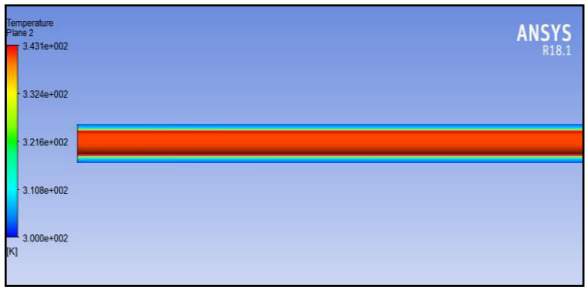

Figure 22: Temperature plot at 100 seconds

The temperature plot at 100 seconds shows very high temperature between copper lauric acid interface and

temperature is nearly 321K as shown by light blue colour and most of the paraffin wax region has temperature nearly 307K.

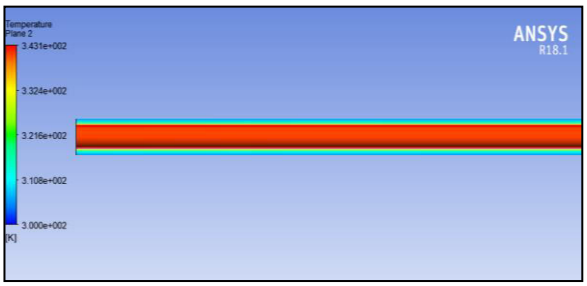

Figure 23: Temperature plot at 150 seconds

The temperature plot at 150 seconds shows very high temperature between copper lauric acid interface and temperature is nearly 328K as shown by light yellow colour and most of the paraffin wax region has temperature nearly 309K.

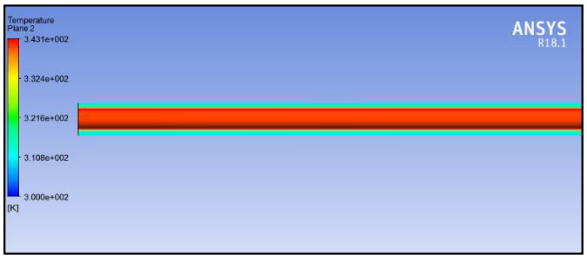

Figure 24: Temperature plot at 200 seconds

The temperature plot at 200 seconds shows very high temperature between copper lauric acid interface and temperature is nearly 330K as shown by light yellow colour and most of the paraffin wax region has temperature nearly 309K.

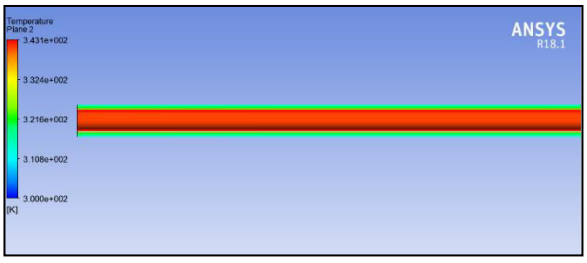

Figure 25: Temperature plot at 250 seconds

The temperature plot at 250 seconds shows very high temperature between copper lauric acid interface and temperature is nearly 332K as shown by yellow colour and most of the lauric acid region has temperature nearly 309K.

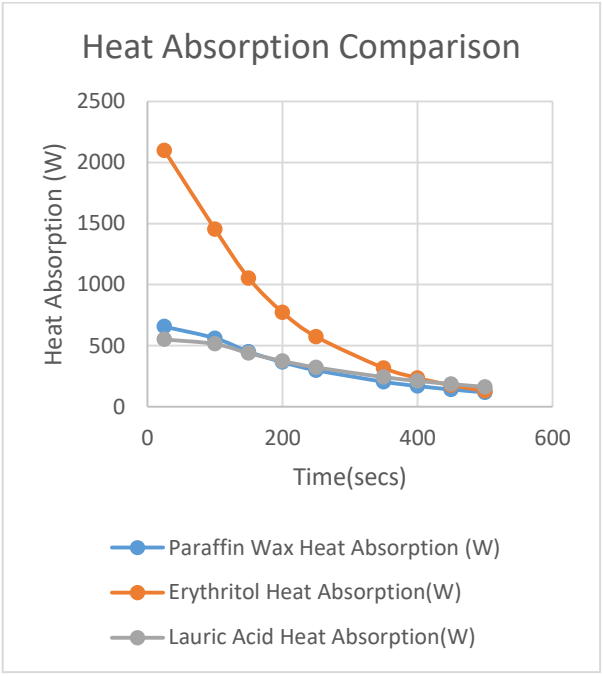

Figure 26: Heat absorption comparison of different materials

The heat absorption comparison curve shown in figure 5.36 above shows higher heat absorption capacity for erythritol and lowest heat absorption capacity for paraffin wax. Although the heat absorption capacity varies with time due to change in temperature gradient.

6. CONCLUSION

The Computational Fluid Dynamics is a viable tool in investigating heat transfer characteristics of different phase change materials (i.e. erythritol, paraffin, lauric acid) and use of computer simulation leads to reduced time and cost. The computer simulation package also facilitates Multiphysics conditions with varying loads and boundary conditions. The transient thermal profile along the length of annulus is obtained by solving unsteady energy balance equation using ANSYS CFX and the time of analysis was 500counter seconds. The detailed findings are as:

1. At initial time, the higher temperature difference between hot industrial water and phase change material resulted in higher heat transfer (high heat flux) which subsequently decreased with time.

2. The maximum temperature of paraffin wax material obtained at the end of simulation is 336K

and minimum temperature at starting of simulation is 300K.

3. The maximum temperature of erythritol material obtained at the end of simulation is 341K and minimum temperature at starting of simulation is 300K.

4. The maximum temperature of lauric acid material obtained at the end of simulation is 332K and minimum temperature at starting of simulation is 300K.

5. The maximum heat is absorbed by erythritol during initial 200 seconds of simulation. The maximum heat absorption is observed at commencement of simulation and decreases with time.

6. The two variable k-epsilon turbulence model gives reasonably good predictions for the fluid flow behaviour involving low turbulence.

7. The energy storage capacity of erythritol is nearly 427W higher than paraffin wax and 422W higher than lauric acid material.

REFERENCES

[1] T. Nomura, M. Tsubota, T. Oya, N. Okinaka, and T. Akiyama, "Heat storage in direct-contact heat exchanger with phase changematerial"AppliedThermalEngineering,vol.50,no.1,pp. 26–34,2013.

[2]E.Or´o,A.deGracia,A.Castell,M.M.Farid,andL.F.Cabeza, "Review on phase change materials (PCMs) for cold thermal energy storage applications," Applied Energy, vol. 99, pp. 513– 533,2012.

[3] M.Rezaei,M.R.Anisur,M.H.Mahfuz,M.A.Kibria,R.Saidur, and I. H. S. C. Metselaar, "Performance and cost analysis of phase change materials with different melting temperatures in heatingsystems,"Energy,vol.53,pp.173–178,2013.

[4] Y.Li,Y.Zhang,M.Li,andD.Zhang,"Testingmethodofphase change temperature and heat of inorganic high temperature phase change materials," Experimental Thermal and Fluid Science,vol.44,pp.697–707,2013.

[5] M. A. Izquierdo-Barrientos, J. F. Belmonte, D. Rodr´ıguezS´anchez,A.E.Molina,andJ.A.Almendros-Ib ´ a˜ nez,"Anumerical study of external building walls containing phase change materials(PCM),"AppliedThermalEngineering,vol.47,pp.73– 85,2012.

[6] F.KuznikandJ.Virgone,"Experimentalassessmentofaphase changematerialforwallbuildinguse,"AppliedEnergy,vol.86, no.10,pp.2038–2046,2009.

[7] A. L. S. Chan, "Energy and environmental performance of building fac¸ades integrated with phase change material in subtropical Hong Kong," Energy and Buildings, vol. 43, no. 10, pp.2947–2955,2011.

[8] S.D.Zwanzig,Y.Lian,andE.G.Brehob,"Numericalsimulation of phase change material composite wallboard in a multilayered building envelope," Energy Conversion and Management,vol.69,pp.27–40,2013.