

CFD Analysis On Thermal Energy Storage In Phase Change Materials Using High Temperature Solution

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ABSTRACT

Phase Change Materials (PCMs) are widely used to store solar energy as latent heat. These materials can also be used to store waste heat available from chimney, reboiler etc. A vertical concentric pipe regenerative type heat exchanger has been modelled where, Heat Transfer Fluid (HTF) is passing through the inner pipe and phase change material is inserted into the annulus. Simulation has been carried out to estimate the temperature profiles in solid and liquid domain of PCM along the length of the concentric pipe using CFX 12.0 version. In present study, High temperature solutions used as PCM. As most of the PCMs possess very low thermal conductivity, the temperature distributions become non uniform in the PCM. Due to this non uniform distribution of temperature, natural convection is taking place in liquid domain. Liquid-solid moving boundary in PCM can be predicted by the temperature profiles.

KEYWORDS: High Temperature Solution, Heat Transfer Fluid, Regenerative Type Heat Exchanger, CFD analysis, liquid-solid moving boundary.

Abbreviations-used:

PCM: Phase Change Material; HTF: Heat Transfer Fluid; HTS: High Temperature Solution.

1.Introduction

In most processes excess thermal energy is released to the atmosphere or a large body of Water to complete a cyclic process or prevent overheating of components or facilities. Although excess thermal energy is

impossible to completely eliminate, it has the potential to be harvested and used for applications that would otherwise require additional energy Input from other sources. The two most significant of these are that the industry or Utility that is producing the excess thermal energy is often not able to use it all at the time It is available, and that creating thermal energy from combustion of fossil fuels has Historically been inexpensive. An increase in overall system efficiency from excess thermal energy recovery would only be seen on a much larger scale in most instances, when the system Analyzed is a community or region and the energy inputs from all sources are considered.

The transfer of thermal energy as a commodity would minimize the traditional thermal energy generation requirements, including the use of electricity and the chemical energy in fossil fuels to supply the heating requirements of residential and industrial customers. Locating and quantifying the production and utilization of thermal energy on a regional scale would allow a more comprehensive energy system model to be developed in order to identify potential efficiency improvements in various communities. It would also allow for small and large thermal energy recovery systems to be used such that thermal storage and transport can be accomplished on all scales. Some of the technologies required to make this possible include thermal storage batteries and transport systems for thermal energy storage. some of the authors have investigated the thermal energy storage process for different purposes some of which are

Debojyoti Chakraborty et al [1] , carried out an experiment on paraffin wax and concluded that At the vicinity of the wall of the inner pipe through which heat is supplied to shell side (annulus), the temperature difference is very steep. The phase change near wall is noted by the formation of a flat plateau regime on temperature v/s . time plot . The radial variation of the temperature is noted in three different cases and also the natural convection was considered in liquid phase.

R. Ponechal [2] - This paper provides an outline of how we can simulate phase change materials (PCM) more accurately. Experiments were conducted in order to verify the phase change material model in the Esp-r simulation program. At first the component with the phase change material was evaluated in a climate chamber. The temperatures and the heat flow were measured on the surface of a polycarbonate slab within Rubitherm RT 20. Next an appropriate test room was chosen and the phase change material was applied to the construction of the ceiling. The indoor climate parameters of the room were monitored and measured as well as the outdoor parameters before the facade was added. The measured values were applied to refine the simple computation models.

Ya nan zang^{1,2}, en yong ding³- New kinds of solid-solid phase change materials have been prepared in our laboratory. In these materials, the rigid polymer chlorinated polypropylene is taken as skeletons and the flexible polymer polyethylene glycol 6000 and polyethylene glycol 10000 are taken as functional chains. Results show that chlorinated polypropylene grafted by polyethylene glycol 10000 has greater enthalpy than chlorinated polypropylene grafted by polyethylene glycol 6000.

Atul Sharma , V.V. Tyagi,C.R. Chen, D. Buddhi [4]- The use of a latent heat storage system using phase change materials (PCMs) is an effective way of storing thermal energy and has the advantages of high-energy storage density and the isothermal nature of the storage process. PCMs have been widely used in latent heat thermal storage systems for heat pumps, solar engineering, and spacecraft thermal control applications.

The objective of the present work is to carry out the simulation process using High Temperature Solution as Phase change material and study the Temperature profile and compare the Heat carrying capacity of High temperature solution (H500) with Paraffin wax.

2. Methodology

CFD techniques consist of numerical solutions of mass, Momentum and energy conservation with other equations like species transport. Two main stages comprise the solution of CFD problems. First, PCM regime has been divided into small control volumes known as mesh. In present system, In this case, unsteady energy balance equation has been solved in solid phase and unsteady momentum and energy balance equation have been solved simultaneously in liquid phase for each control volume.

Step 1: Grid Generation

The first step in the finite volume method is to divide the domain into discrete control volumes. Let us place a number of nodal points in the space between A and B. The boundaries (or faces) of control volumes are positioned mid-way between adjacent nodes. Thus each node is surrounded by a control volume or cell. It is common practice to set up control volumes near the edge of the domain in such a way that the physical boundaries coincide with the control volume boundaries.

The usual convention of CFD methods is shown in Figure. 2. A general nodal point is identified by P and its neighbours in a one-dimensional geometry, the nodes to the west and east, are identified by W and E respectively. The west side face of the control volume is referred to by 'w' and the east side control volume face by V. The distances between the nodes W and P, and between nodes P and E, are identified by δx_{WP} and δx_{PE} respectively.

Similarly the distances between face w and point P and between P and face e are denoted by δx_{wp} and δx_{PE} respectively. Figure. 2 shows that the control volume width is $\Delta x = \delta x_{we}$

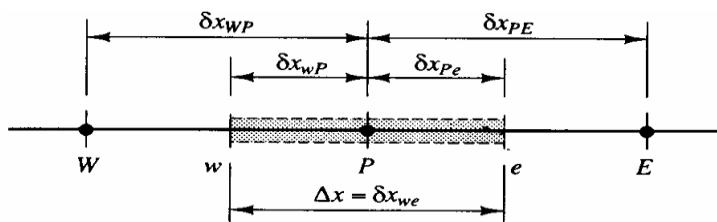


Fig 2.1 Grid generation

Step 2: Discretization

The key step of the finite volume method is the integration of the governing equation (or equations) over a control volume to yield a discretised equation at its nodal point P. For the control volume defined above this gives

$$\int_{\Delta V} \frac{d}{dx} \left(\Gamma \frac{d\phi}{dx} \right) dV + \int_{\Delta V} S dV = 0$$

$$\left(\Gamma A \frac{d\phi}{dx} \right)_e - \left(\Gamma A \frac{d\phi}{dx} \right)_w + \bar{S} \Delta V = 0 \quad (2.1)$$

Here A is cross section area of the control volume; $V\Delta$ volume S is average values of source S over control volume. If we evaluate the derivative $\frac{d\phi}{dx}$ in equation (2.1) from the piecewise profile the results equation will be

$$\Gamma_e A_e \left(\frac{\phi_E - \phi_P}{\delta x_{PE}} \right) - \Gamma_w A_w \left(\frac{\phi_P - \phi_W}{\delta x_{WP}} \right) + (S_u + S_p \phi_P) = 0 \quad (2.2)$$

Equation (2.2) can be re-arrange as $a_P \phi_P = a_E \phi_E + a_W \phi_W + S_u$ (2.3)

where $a_E = \frac{\Gamma_e A_e}{\delta x_{PE}}$ (2.4a)

$$a_W = \frac{\Gamma_w A_w}{\delta x_{WP}} \quad (2.4b)$$

$$a_P = a_E + a_W - S_p \quad (2.4c)$$

Here, Γ_e , Γ_w are interface diffusive coefficients. We can take these coefficients by harmonic mean and arithmetic mean.

2.2 Model geometry and boundary conditions

2.2.1 Geometric model

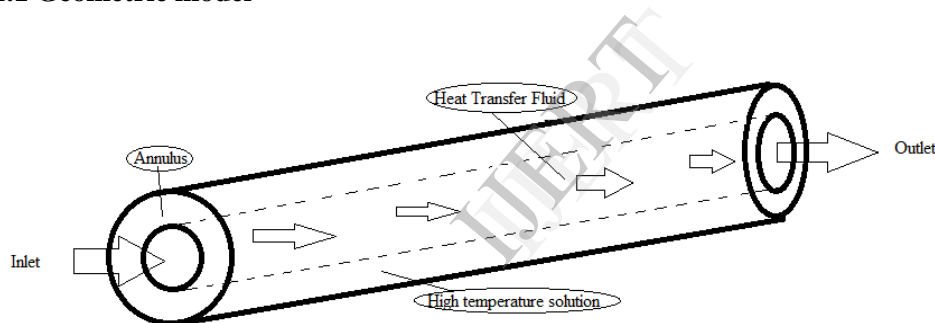


Fig 2.2 Geometric model

for the simulation of the present case the geometric model required is as shown above fig2.2

in which vertical concentric pipe regenerative type heat exchanger has been modelled where, Heat Transfer Fluid (HTF) is passing through the inner pipe and phase change material is inserted into the annulus and simulation is carried out.

2.2.2 Boundary Conditions

Boundary conditions are the set of conditions specified for the behaviour of the solution to a set of differential equations at the boundary of its domain. Boundary conditions are important in determining the mathematical solutions to many physical problems. These conditions specify the flow and thermal variables on the boundaries of a physical model. They are, therefore, a critical component of simulation and it is important that they are specified appropriately. The boundary conditions are defined on cell faces and they do not have a finite thickness and they provide a means of introducing a step change in flow properties.

The following boundary conditions at the walls are used with the equations of motion

- No slip conditions, (At fluid wall interface, there must be no slip)

- Temperature field

The principle different types of boundary conditions are as follows:

- Dirichlet boundary condition (first type)
- Neumann boundary condition (second type)
- Robbins boundary condition (third type).

2.3 Parameters required for the CFD simulation

Table 2.1 Physical parameters required for CFD model.

| HTS Type | Phase Change Temperature (°C) | Density (kg/m ³) | Latent Heat Capacity (kJ/kg) | Volumetric Heat Capacity (MJ/m ³) | Specific Heat Capacity (kJ/kg K) | Thermal Conductivity (W/m K) | Max Operating Temp (°C) |
|----------|-------------------------------|------------------------------|------------------------------|---|----------------------------------|------------------------------|-------------------------|
| H500 | 500 | 2,220 | 300 | 666 | 1.550 | 0.569 | 800 |

Table 2.2: Inlet and outlet temperatures for different cases.

| Different cases | T in in degree Celcius | Tout in degree Celcius |
|-----------------|------------------------|------------------------|
| Case 1 | 65 | 47 |
| Case 1 | 70 | 50 |
| Case 1 | 80 | 50 |

2.4 Simulation scheme

The CFD software Ansys CFX 12.0 was used in the simulation of High temperature solution at three different cases. Second order upwind differencing scheme was chosen as the solution of the momentum equations. The speed of the flowing fluid is chosen 0.0009m/s. in all the case of the simulations. The Heat transfer fluid is passed through annulus from inlet to outlet. The simulation process is carried out in unsteady conditions and amount of heat absorbed by the high temperature solution (H500) is calculated.

3.0 Result and Discussion

The transient temperature profiles in annulus along the length have been obtained by solving unsteady energy balance equation using CFX 12.0 version. The temperatures profiles have been estimated for Different cases As the natural convection was considered in liquid phase therefore, unsteady momentum and energy balance equation have been solved simultaneously in liquid phase.

3.1 Temperature profile of high temperature solution (H500) at different temperature conditions

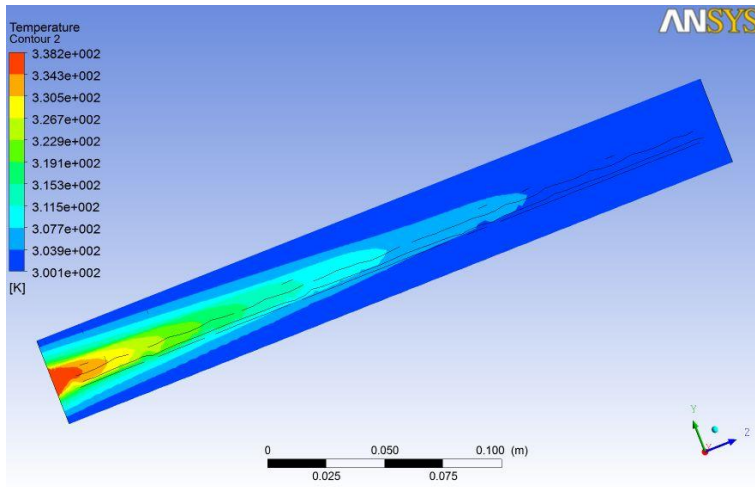


fig 3.1 Temperature profile of H500 at 65°C

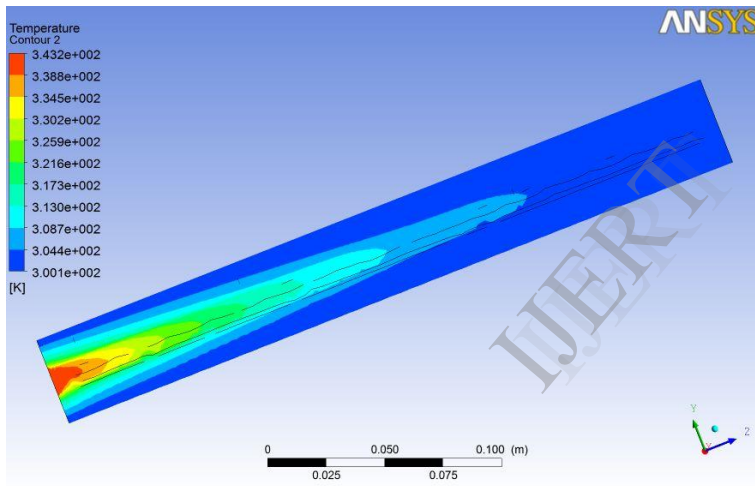


fig 3.2 Temperature profile of H500 at 70°C

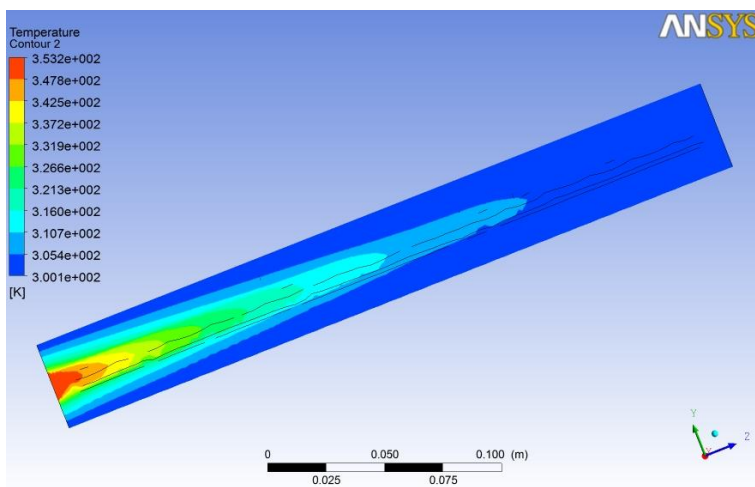
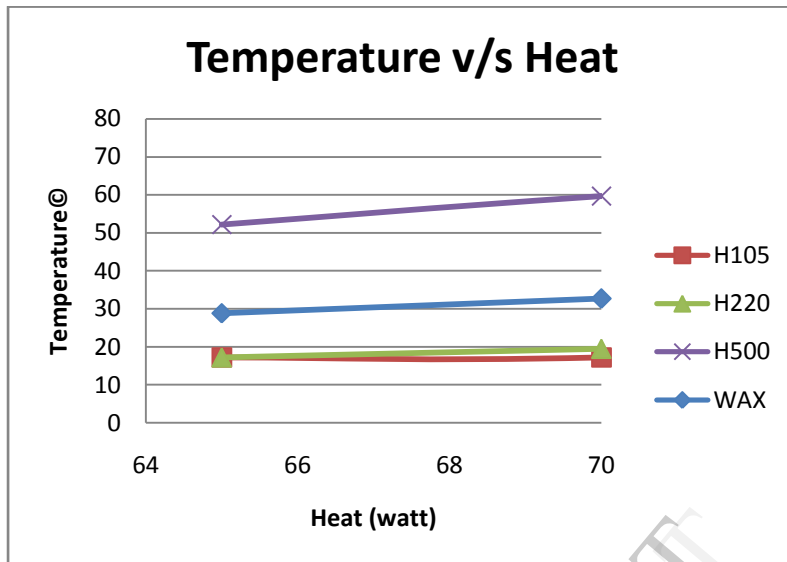


fig 3.3 Temperature profile of H500 at 80°C

3.2 Graphical representation of the heat absorbed by the high temperature solution at different temperatures conditions



3.2 Heat absorbed by the different materials at different temperatures

Table 3.1 Heat absorbed by the different materials at different temperatures

| Material | Inlet Temp | Outlet Temp | Heat Flux | Area | Heat Absorbed By The Material |
|----------|-------------|--------------|---------------------|--------------------|-------------------------------|
| | T_{in} °C | T_{out} °C | (q)W/m ² | (A) m ² | Q=q*A. (W) |
| Wax | 65 | 44.80 | 793.85 | 0.0364 | 28.88 |
| | 70 | 47.00 | 898.30 | 0.0364 | 32.69 |
| | 80 | 51.70 | 1107.2 | 0.0364 | 40.29 |
| H105 | 65 | 28.65 | 473.35 | 0.0364 | 17.23 |
| | 70 | 28.65 | 473.35 | 0.0364 | 17.23 |
| | 80 | 29.24 | 660.20 | 0.0364 | 24.03 |
| H220 | 65 | 28.62 | 473.72 | 0.0364 | 17.24 |
| | 70 | 28.81 | 536.06 | 0.0364 | 19.51 |
| | 80 | 29.20 | 660.72 | 0.0364 | 24.05 |
| H500 | 65 | 28.55 | 1434.21 | 0.0364 | 52.20 |
| | 70 | 28.70 | 1622.92 | 0.0364 | 59.70 |
| | 80 | 29.70 | 2000.34 | 0.0364 | 72.80 |

4.0. Conclusions:

A vertical concentric pipe regenerative type heat exchanger has been modelled where, Heat Transfer Fluid (HTF) is passing through the inner pipe and phase change material that is High temperature solutions (H105,H220,H500) is accommodated into the annulus .using computational fluid dynamics simulation is carried out.

With regards to the computational simulation in the present study the following conclusions can be drawn:

- H500 stores more thermal energy than wax.
- Temperature distribution along the length of the pipe is clearly appreciable.
- Thermal energy storage in High temperature solution increases with temperature.
- from the temperature profile for different temperature values high temperature solutions absorbs more thermal energy than wax.
- wax can be replaced with High temperature solution for thermal energy storage applications and also for increasing the efficiency of double pipe heat exchanger using waste heat recovery.

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