CFD analysis on heat transfer in a building wall using Phase Change Materials (PCM)

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Abstract. Environmental conditioning is now a critical factor for modern day keeping the temperature inside the buildings in a safe state using the air-conditioner. Phase change materials promise innovative materials that are used inside the building to build wall for cooling. The current work is aimed at managing the thermal transfer in buildings using PCM materials and controlling the transfer of heat from various states to store the energy and use it later. A PCM storage medium filled with a variety of PCM panels was developed and tested using the ANSYS Fluent simulation of computational fluid dynamics. In this paper the PCM is purposely designed between the roof and concrete wall layer for energy gains in thermal systems to storing solar energy in buildings. The experiment was conducted using 3D model designed per mass unit within a small temperature range using CFD analysis. Numerical model displayed effective similarity with experiment; hence the model can be used as energy storage unit under different configurations for performance evaluation of the building system. The specific heat, viscosity, heat conductivity, temperature and total energy has been evaluated using the linear method available using CFD Fluent. Majorly the result considering depends on the thickness, inlet cooling temperature and mass flow rates.

Keywords: Phase change materials, Sodium Hydrogen Phosphate, Building wall & CFD

1. Introduction:
A Phase Change Material (PCM) is a substance with a high heat of fusion which, melting and solidifying at certain temperatures, is capable of storing or releasing large amounts of energy. The goal of this study was to provide an effective and important database for low temperature Thermal Energy Storage (TES) applications for phase change materials (PCMs). Thermal Energy Storage (TES) with Phase Change Materials (PCMs) provides a smart solution, cheap method, and accurate energy storage capable of improving energy system performance and filling the gap between energy supply and energy demand; allowing for energy conservation. Phase change materials promise innovative materials that are used inside the building to build wall for cooling. PCM using computational fluid dynamics (CFD) is reported, in line with the current trend of CFD to become increasingly popular. Numerical experiments on solidification and melting procedure use a variety of substance to explain the natural phenomenon associated with these processes, in particular the latent heat and the transition velocity of the liquid and the solid phase [1]. The superior thermal characteristics of such a structural system are studied using CFD numerical simulation in five climate regions. The ideal phase temperature dependence for each climate region is evaluated by comparing these with...
roof without PCM. The analysis shows that the PCM’s phase-transition temperature in the roof increases gradually as the median open-air type solar temperature increases [2]. The primary use of the PCMs is in the design of structures, where it is used in many ways to either retain a stable temperature within the structure or to preserve a significant volume of sun energy as a stored thermal energy in it [3]. The research strategy on the heat conductivity and removal capability of PCM is being used to manage energy consumed inside a vehicle cabin thermal stratification [4]. Showings of two dissimilar metals such has water and phase change material were analyzed thermal energy for passive building design and experimental were carried under numerical simulation methods were used in the research setting for double glazed window samples [5]. The PCM heat exchanger is specifically designed with spiral-wired tubes and is embedded into the explicit solar-assisted heat exchanger test procedure. While this spiral-wired tube still hasn’t been introduced to the PCM heat exchanger, it is found to fully improve the heat conduction and thermal energy performance of the PCM [6]. Transferring thermal energy as a medium of exchange will reduce thermal renewable energy demands, and use of electricity and heat reactions in energy production to meet the energy demand of both residential and industrial users [7]. A PCM storage system involving a number of PCM panels has indeed been implemented and tested using computational fluid dynamics modeling. The impact of the system parameters on performance and reliability has been discussed by analyzing the solidification and melting procedure evaluation of the PCM [8]. CFD study is conducted to analyze and disclose the impact of fin inclination on heat transfer performance of the paraffin PCM in the directly finned spherical capsule [9].

The suggestion from the existing literature is that many strategies are being implemented to enhance heat transfer in PCM-based storage devices. It is understood the Sodium Hydrogen Phosphate PCM is not implemented in building roof system. The main aim of this present work to analyse the heat transfer in the buildings using phase change materials and control the heat transfer from various states to store the energy and use it later. Phase change materials promise innovative materials that are used inside the building to build wall for cooling. The experiment was conducted using 3D model designed per mass unit within a small temperature range using CFD analysis. Numerical model displayed effective similarity and hence the model can be used as energy storage unit under different configurations for performance evaluation of the building system.

2. Methodology

CFD methods consist of computational energy saving solutions; heat exchanger, solidification and melting with other calculations such as species transport are used. There are two main stages to solve CFD problems. First, the PCM system was divided into small nodes of element known as mesh. In this case, unstable energy balance equation has been solved in solid phase and unstable momentum and energy balance equation for each control volume has been solved simultaneously in liquid phase.

![Basic Steps to Solving each Problem in ANSYS](image)

Fig 1: Basic Steps to Solving each Problem in ANSYS

Fig 1: The generic steps involved in ansys it's consists of three principle steps [10]. Preprocessing: Geometry model of building with concrete wall covered with PCM material...
(Sodium Hydrogen Phosphate), the materials properties are selected in material library for concrete: 32.5°C melting temperature, 180 KJ/Kg heat fusion, 0.6 W/mk Thermal conductivity and 1600 Kg/m$^3$ Density assigned for phase change materials. Analysis: The data which prepared from the preprocessing used as input with ansys code, which solve the heat transfer systems with solidification method to Concrete and PCM with algebraic equation. Post processing: It is easy to analysis the graphical displays to assist the results, from the simulation result to hot spot the varying forms. The specific heat, viscosity, heat conductivity, temperature and total energy has been evaluated using the linear method available using CFD Fluent [11]. Majorly the result considering depends on the thickness, inlet cooling temperature and mass flow rates.

Fig 2 Cross Sectional View of the Roof without PCM Panel.

Fig 3 Cross Sectional View of the Roof with single layer PCM Panel.

The simulation of the exterior environment in order to measure the rate of heat flow and the solar loading on the surfaces was a complicated method and so a simplified way was taken. For this process, the heat flux obtained from the experimental results was given as input to the top surface of the roof slab. The Heat flux variation for a span of 8 hours was the roof and concrete slab were modelled as 200x200x100 mm and 200x200x120mm (Fig 2).This was considered as the domain for analysis. Similarly the single layer PCM was designed as 200x200x100 mm for roof and 200x200x120 mm for concrete and 200x200x25 mm for single layer PCM (Fig 3) domain as considered for analysis with same input temperature vs time.

Table 1: Material Properties

| NAME                  | Material Type | Density (kg/m$^3$) | CP (Specific Heat –j/kg-k) | Thermal conductivity (w/m-k) |
|-----------------------|---------------|--------------------|-----------------------------|-------------------------------|
| Concrete              | Solid         | 2300               | 880                         | 1.37                          |
| Roof top slab         | Solid         | 2100               | 800                         | 1.45                          |
| Sodium Hydrogen Phosphate (PCM) | Solid – liquid | 1562 (liquid, 32ºC) | 1440                         | 0.540 (liquid, 38.7ºC) |
|                        | Liquid –      | 1802 (solid, 24ºC) |                             | 1.088 (solid, 23ºC)          |
|                        | Solid         | 1710 (solid, 25ºC) |                             |                               |

Structured mesh has been created and the number of elements found to be 440. For the transient case study, Table 1: shows the density of the roof slab was assumed to be 2300 kg / m$^3$ and the density of the concrete slab was assumed to be 2100 kg / m$^3$. Likewise, the actual heat was estimated to be 880 j / kg-k and 800 j / kg-k respectively for the roof slab and the concrete slab [12]. Thermal conductivity of 1.37 and 1.73 w / m-k was found for roofing slab and concrete slab respectively. The boundary conditions for the study were calculated as transient heat fluxes taken for every 15 minutes for 8 hours from 9:00am to 5:00pm Convective heat transfer was considered at the base surface of the concrete slab. Convective heat transfer was considered at the bottom surface of the concrete slab. The heat transfer coefficient was given as 1 W/m2K and 4 W/m2K. The free stream temperature was assumed to be 300K. For the transient case a step size of 60 seconds was taken and the analysis was done for 35000 seconds.
3. **Result and Discussion:**

**Fig 4:** Temperature Dependent – Specific Heat

In Fig 4: Storage of a PCM's thermal energy is compared to other materials used in buildings for TES. Specifically, compared to the theoretical sensitive heat storage capacity of concrete and PCM, the latent heat storage capacity of sodium hydrogen phosphate as a PCM that melts at 32.5°C with a fusion heat of 180.5 kJ/kg. By using the CFD Fluent, the Specific heat capacity of the liquid and solid phases can be taken directly from the min and maximum linear method. The basic concrete and PCM heat efficiency was estimated at 0.07260 kJ/(Kg. K) and 1.143 kJ/(Kg. K), respectively.

**Fig 5:** Temperature Dependent – Molecular Velocity

To minimize temperature change and energy consumption, the suggested PCM sodium hydrogen phosphate mixture may be integrated into structural construction of buildings. In addition, the PCM combination is supposed to provide multiple advantages by avoiding leakage, PCM and concrete which required to structural strength. In addition, PCM is supposed to boost stability over several periods, the Fig: 5 its estimated that the PCM materials which helps to increase the viscosity to 0.0172 Kg / m-s: An effort has been made to achieve this balance in order to improve structural strength, increase viscosity, provide a homogeneous
mixture when PCMs, PCMs are added so that the contribution of a sensible heat process to total energy storage becomes more significant.

**Fig 6:** Temperature Dependent – Thermal Conductivity

The investigation of the Thermal conductivity of design model was done using CFD Fluent as appeared in Fig 6. To ensure accuracy and repeatability, the reported values were the average of at least run through the calculation with 500 iteration from room temperature and increase the temperature to 32°C for a sample, or until an uncertainty the value which observed 0.0045 W/m.k minimum thermal conductivity was achieved and its reached the maximum value observed 0.05 W/m.k.

**Fig 7:** Temperature Dependent – Total Energy

Fig 7: Due to the latent heat during phase transitions, the largest contribution in total energy storage is phase change materials. However, it’s observed the min energy at room temperature is 5350 KJ/KG. The maximum energy at 32°C is observed at 68675 KJ/KG. The contribution of sensible heat also depends on the specific heat of the PCM. PCM sodium hydrogen phosphate mixture included to compare sensible heat storage materials with latent heat storage materials (PCMs). The design model for the specific heat capacity ($C_p$) and the total energy storage density of PCMs through a temperature range of about room temperature around the melting temperature (TES).
Fig 8: Temperature Distribution without PCM

Fig 9: Temperature Distribution with PCM

Fig 8 and Fig 9: The inner and outer surface temperatures distribution of the roof top are determined by CFD method. While some variations are found during the time interval, several specific conclusions can be drawn about the different thermal behaviour of the materials. The most significant result is that the highest and lowest temperatures (inner and outer) are simply damped on the PCM concrete building. Optimum values are increased and decreased by about 5 °C in the PCM walls, respectively. Some other significant variation found in the inner surface temperature data is that, during cooling, the PCM behaves until the temperature of the phase change is achieved, reducing the level of the inner temperature variance. It is because the PCM solidifies and absorbs the energy accumulated as heat energy as the temperature stays unchanged.

4. Conclusion:

A building wall and PCM generative type energy storage as been modelled, Thermal energy storage through the phase change materials storage purpose is accommodated into the model using computational fluid dynamics simulation is carried out.

With regards to the ansys fluent: computational fluid dynamics simulation in present study the following conclusions has drawn:

- The Specific heat capacity of the liquid and solid phases can be taken directly from the min and maximum linear method. The basic concrete and PCM heat efficiency was estimated at 0.077260 kJ/(Kg. K) and 1.143 kJ/(Kg. K), respectively.
- The PCM materials which help to increase the viscosity to 0.0172 Kg / m-s: An effort has been made to achieve this balance in order to improve structural strength, increase viscosity.
- The temperature to 32°C for a sample, or until an uncertainty the value which observed 0.0045 W/m.k minimum thermal conductivity was achieved and its reached the maximum value observed 0.05 W/m.k.
- The total energy storage is phase change materials. However, it’s observed the min energy at room temperature is 5350 KJ/KG. The maximum energy at 32°C is observed at 68675 KJ/KG.
- Optimum values are decreased by about 5 °C in the PCM walls, respectively.

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