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AN INVESTIGATION ON LATENT THERMAL ENERGY STORAGE USING PHASE CHANGE MATERIALS

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Abstract

The major energy demand is in the form of electrical energy for domestic as well as industrial sectors, a large part of which are the heating and cooling requirements. Appropriate utilization of thermal energy storage can effectively aid in reducing the electrical demand by storage and release of this thermal energy during peak hours. Thermal Energy Storage using Phase Change Materials (PCMs) is an attractive method of energy storage, with a wide variety of potential applications. Several configurations have been tested by researchers to develop energy storage devices with PCMs. The cycling of melting and solidification of PCMs results in storage and release of heat at a relatively small temperature difference. Design and deployment of these storage systems have certain challenges and considerations associated to them for instance, when used in buildings, PCMs should be non-toxic, non-corrosive, and others.

Keywords: *phase change material, PCM, ANSYS.*

1. Introduction

Electricity generation can release a large amount of heat that can be stored and utilized further for cooling, heating, and other applications, which would require efficient method of TES. As in case of the Combined Heat and Power (CHP) Plants, the heat released can be extracted using heat recovery units. This process is also known as cogeneration. Heat recovery units are utilized to extract heat from the hot exhaust gases, released from combustion of fuel to run turbines or engines. This heat can then be used for heating or cooling purposes in buildings or facilities. The CHP process flow can be seen in Figure 1 below. The heat released from the cogeneration process can be stored using various modes or methods of Thermal Energy Storage (TES). The principle of all TES applications is the same, i.e. thermal energy is supplied to storage media for periodic usage and heat extraction. The main difference arises in the scale and method of storage media .TES refers to storage of energy for certain period and its subsequent usage.Applications for this technology can be found in diverse disciplines like cogeneration, Solar Power, HVAC systems, and others. With the appropriate TES system, diurnal or seasonal storage and utilization of energy is possible. This means that, in areas where heating in winter or cooling in summer is required,

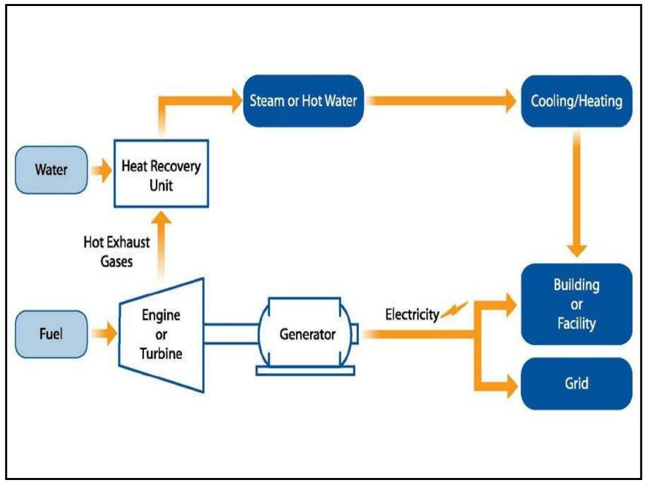

Figure 1: CHP Process Flow Diagram

TES provides several advantages like,

• Application in active and passive systems (allowing usage of waste energy)
• Peak load shifting strategies
•Rational use of thermal energy
•Increase overall efficiency and better reliability
•Reduction in investment and running costs
•Reduction in CO2 emissions and pollution of the environment

1.2 Methods of Thermal Energy Storage (TES)

Thermal energy can be stored using several media which focus on various methods of storage. TES is mainly classified into sensible, latent, and chemical energy storage, some of which have been discussed here.

1.2.1 Sensible Heat Storage

Sensible Heat is the energy released by a material as its temperature is reduced, or absorbed by a material as its temperature is increased, and this method of TES is called the Sensible Heat Storage. The effectiveness of Sensible Heat Storage depends on the specific heat of the storage material and, if volume is important, on its density. Sensible storage systems commonly use materials like rocks, ground, or water as the storage medium, and the thermal energy is stored by increasing the storage-medium temperature . Following are certain examples of Sensible Heat Storage, The four main types of large-scale Sensible Storage systems are Aquifer thermal energy storages (ATES), Borehole thermal energy storages (BTES), Tank thermal energy storages (TTES), and Pit thermal energy storages (PTES),

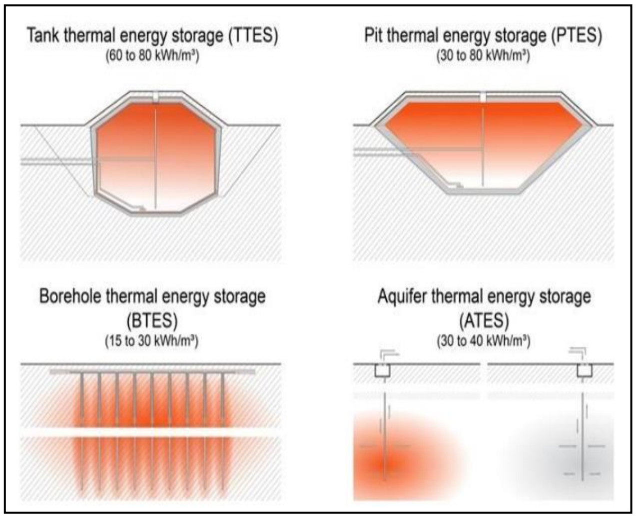

Figure 2: Types of Large-Scale Sensible thermal storage systems

2. Literature review

[1] Ritvij M Dixit, (2020). The Thermal Energy Storage (TES) research in the past 20 years has focused on two main aspects which have been discussed below.Materials Research includes experimentation with the thermal storage of material, compatibility, thermophysical properties of material for energy storage, long and short-term behavior, and others. The second main aspect is the development of Heat Exchangers, which includes sizing and selection of the exchanger type and parameters, design and simulation of conditions for thermal analysis, prototyping for use based on applications, testing on the field, cost analysis, and others.

[2] Kyung Eum Min (2019).PCMs are classified based on several criterion, including type of phase change, thermophysical properties, chemical properties, and others. The energy storage with PCMs, occurs from solid-solid, liquid-solid, solid-liquid, solid-gas, and liquid-gas phase changes. Even though liquid-gas phase changes have a higher heat of transformation than their solid-liquid counterparts, they prove to be impractical for thermal storage since, large volumes or high pressure are required to store materials in their gas phase. Solid- solid phase changes have relatively low heat of transformation and are slow processes. Thus, solid-liquid and liquid-solid are more practical for TES. A flowchart below shows the classification of materials as provided.

[3] V.A Lebedev and A.E Amer, (2019) Hygroscopic Materials mean absorb and release water with change in temperature. Several construction materials are naturally hygroscopic such as, clay, wool insulation, and others. The water evaporates when phase transformation occurs from liquid to gaseous state. This process releases a limited amount of heat, but when considered over large surfaces in buildings, the heat transfer can be significant and can reduce temperatures. The process can be segregated as well.

[4] Tianyu Yang and William P.King, (2021). Organic materials are typically derived from bio-based compounds, Paraffin waxes (C_nH_{2n+2}), carbohydrates, lipid derived compounds, and others. A significant number of authors have based their work on organic materials such as alkanes, waxes, or paraffin’s. Within organic materials, there is a class called MCPAM (Phase change materials made up of molecular alloys), formed by alkane-based alloys which have the advantage of being thermo-adjustable, which means they allow alterations to the phase change temperature through their composition. Inorganic materials primarily consist of salt hydrates and eutectic mixtures. These materials are noted for their multiple applications in Solar Energy Storage. Following are some of the advantages and disadvantages of Organic and Inorganic materials. For the purpose of this project, literature with PCMs having melting temperatures or temperature intervals between 100 to 210oC (212 to 410oF), has been reviewed. This is due to the considered application of storing by-product heat at moderate temperatures, i.e. (100 to 200oC), produced during power generation by CHPs. Following table includes a list of these materials with their thermophysical properties.

[5] AMY Fleischer, (2015). Several experiments have been carried out by researchers across the world to select the appropriate materials by testing their thermophysical properties appropriate for TES. In 2015, at the Nelson Mandela Institution of Science and Technology, John G. et at conducted bulk thermal cycling tests with Galactitol, a phase change material, with melting temperature 187oC (368.6 oF). Galactitol was identified as a possible PCM for medium temperature latent heat storage of solar cookers. The PCM samples were repeatedly heated and cooled in an experimental setup. The effects of changing the upper temperature Top, for the hotplate used to heat the samples kept in a closed container, defined as the average of cycle temperatures with the standard deviations for each cycle, were observed and documented. It was concluded that

Galactitol is thermally stable at temperatures up to 200oC. In addition, the upper cycle temperature of bulk galactitol with repeated heating and cooling cycles has a great influence on the rate of structural change. Figures 7 and 8 depict the experimental setup and influence of varying upper cycle temperatures on galactitol

[6]A. Sørensen and T. Schmidt, (2018) Solid-Solid Phase Change Materials Solid-solid PCMs (SSPCMs) absorb and release heat by reversible phase transitions between a (solid) crystalline or semi-crystalline phase, and another (solid) amorphous, semi-crystalline, or crystalline phase. Different from solid-liquid-PCMs, SSPCMs retain their bulk solid properties within certain temperature ranges and are therefore also referred to as "solid-state" PCMs . Following schematic shows change in crystalline structure of a Perovskite type SSPCM . The SSPCMs can change crystalline structure from one lattice to another with change in temperature. These materials have comparable latent heat capacity to the solid-liquid PCMs. Problems associated with handling liquids like containment, potential leaks, and others, are not applicable to the SSPCMs.

3. NUMERICAL SIMULATION

3.1 Melting in a Vertical Cylindrical Tube

Conducted numerical and experimental analysis of a PCM in a vertical cylindrical tube. They also investigated effect of mushy zone constant 'C', on melting in a vertical cylindrical tube, using the solidification/melting model of the commercial CFD software Fluent. Vertical cylindrical tubes of 3 cm and 4 cm in diameter, with the wall temperatures of 10 and 30oC above mean melting temperature of the PCM, were considered for their experimental and numerical investigation. Following figure shows the interface of PCM exposed to air at 17 cm from the base, the total height of the tube being 20 cm.

3.1.1 Numerical Model

For the numerical model, properties of PCM are based on a commercially available PCM, Rubitherm GmBH (RT27), with a melting temperature interval of 299.15–301.15oK (26-28oC), with the entire system being at an initial temperature of 295.15 oK (22oC). It is assumed that both solid and liquid phases are homogeneous and isotropic, and the melting process is axisymmetric. The molten PCM and the air are incompressible Newtonian fluids, and laminar flow is assumed in both. A temperature dependent expression is used to describe the density of air given as,

$$\rho = 1.2 \times 10^{-5}T^2 - 0.001134T + 3.4978 \qquad (3.1)$$

3.1.2 Simulations with Variation in Mushy Zone Constant

The results for the model configuration with tube diameter of 4 cm, height of phase change material in the tube being 17 cm, and the wall temperature 10oK above the mean melting temperature of the PCM, have been studied for the purpose of this project. The effect of varying 'C' on the melting of PCM, between 105 and 1010, was investigated to obtain comparable results to the experimental results, as can be seen in the figure below,

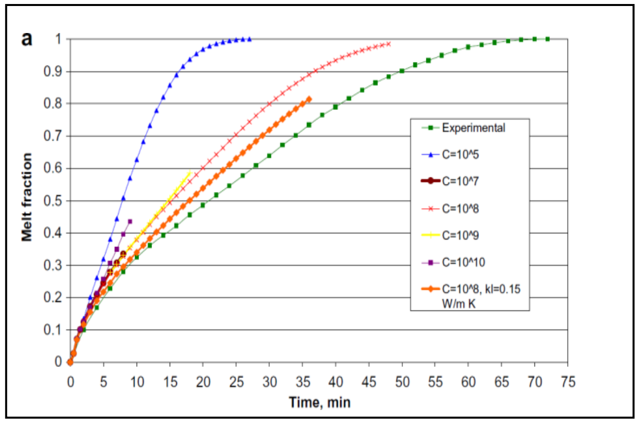

Figure 3: Melt Fraction Vs Time (min) for various values

3.1.3 Modeling Schemes and Discretization

Three models are available for Multiphase modeling in Fluent for pressure-based solvers namely, Volume of Fluid (VOF), Mixture, and Eulerian models. The VOF model uses an Eulerian approach to model multi-phase flows. The boundary conditions for the momentum equation are no-slip and no penetration at all solid boundaries [18]. A pressure-outlet boundary condition is used at the upper boundary, which is open to the atmosphere, with the ambient temperature of 300.15oK at this boundary. At the PCM-air interface, the interior boundary condition is used. The outer tube wall is maintained at a constant temperature of 10oK above the mean melting temperature of the PCM. An adiabatic wall condition is used for the bottom wall of the tube. The edges parallel to the X-axis are assigned the axis boundary conditions. Comparing with the experimental results, the value of (C = 106), yields the most accurate results, as shown below.

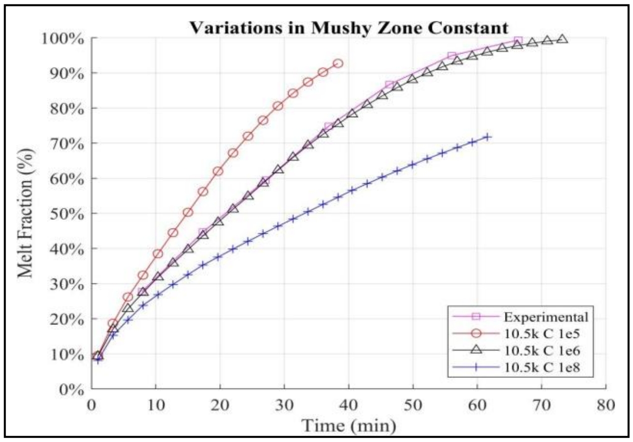

Figure 4: Melt Fraction Vs Time (min)

3.1.4 Time and Mesh Sensitivity Analysis

Implicit volume fraction formulation was used for the VOF modeling. The implicit formulation is iterative and can be used with either the Steady or Transient solver. It is well-suited to steady-state applications as the solution information propagates much faster compared to the explicit formulation. However, with a transient case where results are dependent upon initial flow conditions, a larger time-step size is more suitable which is available with Implicit formulation. The time step sizing was done based on the Courant-Friedrichs-Lewy (CFL) condition. For a case with 'n' dimensions, the general CFL condition is given by the equation,

$C = \Delta t \sum xi / \Delta xi \leq Cmax(3.7)$
i=1

where, Δxi is the length of the first node of each spatial variable for which (i =1,2,…..,n) (dimension being length), ux is the magnitude of velocity (dimension being length/time), Δt is the time step (dimension being time), and C is the dimensionless Courant number for which (Cmax ≥ 1).The time step sizes chosen for time sensitivity analysis range from 0.005s to 0.05s. Along with this, spatial length variations were also considered in the X direction for mesh refinement. The results for the time and mesh sensitivity can be seen in Figure15. Case proves to be insensitive to time and mesh variations, with small variations intotal time taken for melting, when compared to the experimental results provided

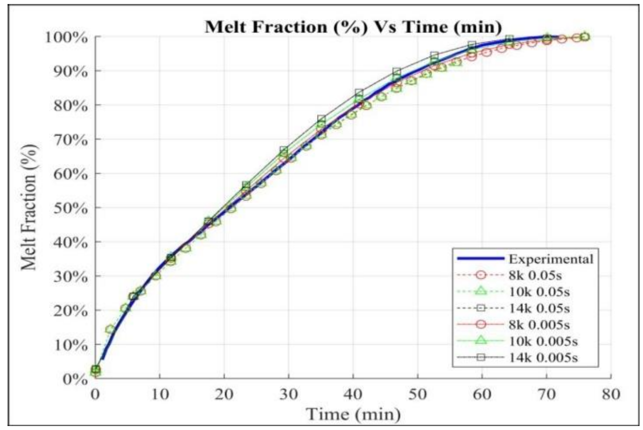

Figure 15: Mesh and Time sensitivity for C = 106 from 0.05s to 0.005s

4. Conclusions

The parameters for which simulations are carried out over the defined range of laminar natural convection and laminar heat transfer fluid flow, are restricted to '(Do)pcm', 'Ti', and 'Vi'. The other properties of the material were kept constant to have a conclusive analysis of melting/solidification with regards to current parameters. These properties like the thermal conductivity and latent heat capacity, along with the inner tube diameter, length of device, injection of the HTF, and others, can be considered to further analyze their respective effects on the Latent energy storage. Along with this, a correlation can also be developed considering multiple PCMs to further understand the phenomena involved in melting/solidification
The better your paper looks, the better the Journal looks. Thanks for your cooperation and contribution.

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