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Applying Magnetic Field to Control the Melt Motion in a PCM Thermal Battery

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Abstract

Thermal batteries using different types of heat sources and sinks have recently attracted interest as a cost-effective energy storage technology, which can be used in a variety of industries, including in concentrating solar power (CSP) plants. Using renewable electricity as a heat source and phase change material (PCM) as a heat storage material, this study investigates the thermal performance of a shell and tube type PCM storage system in a horizontal configuration. The thermal behaviour of PCM in the charging process is studied, while the focus is on enhancing convection of liquid PCM. During the early stages of the melting process, the buoyancy driven convection is weak due to low temperature/density gradients. It has been suggested that an external time dependent magnetic field can induce a Lorentz force in electrically conductive media and drive small scale turbulence, eddy currents and convection of liquid mass [1].

Time dependent magnetic field for directional solidification of silicon in glass melting and the photovoltaic industry has been well studied and implemented [2, 3]. In a different approach, a rotating magnetic field has been proposed to suppress the temperature gradients driven by buoyancy in semiconductor production [4]. Modelling of the melting of gallium as a low-melting-point and low-Prandtl-number metal under a travelling magnetic field has been reported [5].

Thermal Battery Storage System

A horizontal shell and tube system with a length and diameter of 70 cm has been selected for this study. Electrical elements are placed inside the shell as the heat source for charging purposes. Horizontal tubes are distributed so that they are separated with a distance of 6 cm centre-to-centre. The heat transfer fluid flows in the tubes during a discharging process. Here, the discharging process is not investigated, however, its consideration is necessary as a boundary condition during the melting process. At the outer surface of the shell, electrical heating tape is considered. In the real application, the heating tape is used during the warm up process or during the normal operating condition to reduce thermal stresses and heat loss. A sketch of a section of the shell is shown in Figure 1a. The PCM selected for this study is PCM569 with a melting temperature of 569 °C and a low electrical conductivity of 218 siemens per meter (S/m). However, a small induced Lorentz force is required to stir the melt at the early stages of the melting process. At the higher rate of melt fraction and density/temperature gradient, buoyancy provides the higher rate of convection.

Methodology

Numerical modelling has been conducted, using Fluent [6], to study the impact of a varying alternating (AC) electrical heat source in a thermal battery during the charging/melting process. Switching on and off all of the electrical heaters at specific time intervals provides two effects. Firstly, the on and off electrical heaters disturbs the temperature field, driving convection. Secondly, it induces magnetic field in the SS316 shell and less pronounced in the PCM due to its lower electrical conductivity. The numerical model developed in Fluent has been verified with a previous work on the melting process of gallium [5].

Considering symmetry, a geometry and grid of half of the cross-section of the cylindrical thermal battery system has been generated (Figure 1a). At the top, a zone of argon provides space for the PCM volume expansion. The tubes where the heat transfer fluid passes during a discharging process, have been included as an insulating boundary condition. The electrical elements at the bottom of the shell are included as fixed heat flux sources. The outer surface of the shell has been considered as a fixed heat flux boundary condition to mimic the electrical tapes/heaters. Using the Magnetohydrodynamic (MHD) model provided in Fluent [6], an alternating magnetic field is applied on the shell and PCM569 domains. Different magnetic field intensity and phase differences are examined to control flow pattern and intensity of mass convection in the PCM domain at the early stages of the melting process.

The preliminary results of applying an external field with B0_X=B0_Y=0.1 Tesla (T) show the induction of a magnetic field (B-x, B-y). The induced field in the shell and PCM569 resulted in a Lorentz force distribution (F-x and F-y), and the eddy currents in the melted PCM. Figures 1(b) through to 1(f), show the fields at 100 seconds from the start of the melting process where melt fraction is just 0.4%. Figure 1(f) shows the eddy currents formed close to the interior side of shell and around electrical heaters.

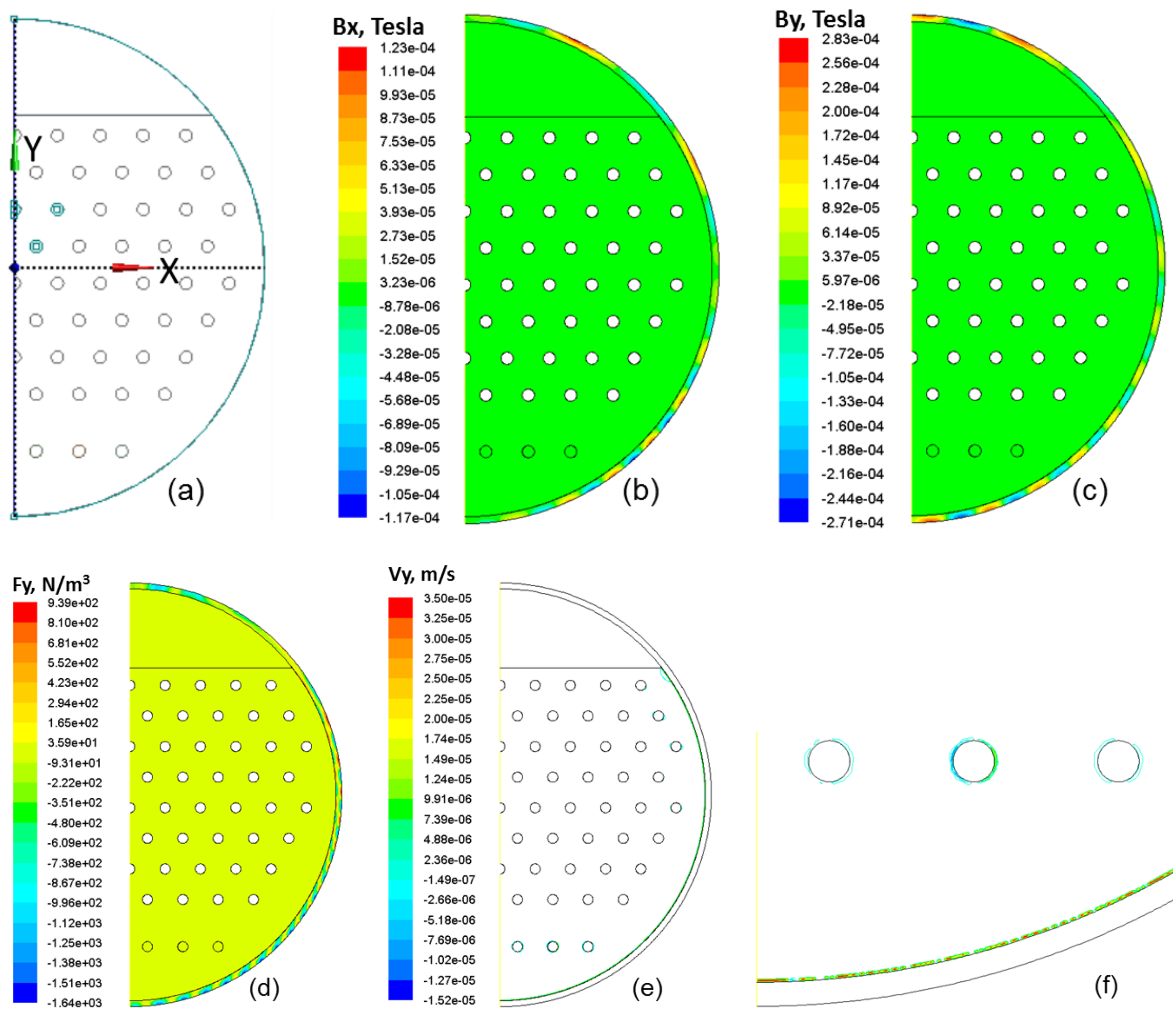

Figure1- (a) Schematic of the grid, (b) Induced Magnetic field in X direction, and (c) in Y direction, (d) Induced Lorentz force in Y direction, (e) Velocity in melted PCM in Y direction, (f) Zoom view of V_y showing eddy current in melt region close to shell and electrical heater surfaces

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