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3D simulation of the Melting of PCM within a Horizontal Shell and Tube Heat Exchanger

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Extended Abstract

Phase Change Materials (PCM) are capable of absorbing and releasing a substantial amount of heat at a near-constant temperature during the phase change. This makes PCM particularly useful in the case where a system that releases or absorbs heat needs to be kept at a constant temperature. However, PCM have a relatively low thermal conductivity, leading to low melting rates, so that the energy absorption takes a long time. As such, the main application point of PCM has been in HVAC systems, as the melting and solidification process can be designed over the cycle of a day. To limit the operation cost of the HVAC systems, the PCM heat exchanger is designed so that the pressure drop of the heat transfer fluid (HTF) over the length of the heat exchanger is limited. This has led to simple designs of PCM heat exchangers, such as shell and tube geometries, where the HTF is circulated within a centred tube, and the PCM is encapsulated within the shell.

The melting of PCM is characterised by complex phenomena that need to be properly captured to accurately predict the energy absorption rate of the material when modelling the PCM. Due to the temperature difference between the solid PCM and the HTF, the melted pool of the PCM will start to convect, so that the buoyancy will need to be taken into account. As the phase change happens over a range of temperatures, a mushy layer will form where the PCM is in a mid-phase between solid and liquid, leading to smaller velocities of the PCM in that region. These aspects can be modelled by using the enthalpy-porosity model [1], which has previously been shown to compare well with experimental results in shell and tube geometries [2], [3].

Numerical models of PCM heat exchangers presented in the literature usually consist of 2D simulations, as this leads to smaller meshes in simulations which are highly computationally demanding, due to small time step requirements compared to the long melting time. Previous studies have shown that the melting behaviour of the PCM was mostly dependent on the temperature of the fluid. As the temperature of the HTF drops over the length of the heat exchanger, it is expected that this will have a significant effect on the melting of the PCM, so that relying on 2D simulations could lead to an over- or under-prediction of the heat exchanger performance. Hosseini et al. [1] have provided results for 3D simulations within a horizontal cylinder, but these do not highlight the complex melting behaviour over the length of the cylinder. In fact, the effect of the temperature drop of the HTF over the length of the heat exchanger has mostly been uncovered in the literature.

In this work, a conjugate heat transfer model based on the enthalpy-porosity model has been developed in OpenFOAM v9 to capture the coupling between the drop in temperature and the melting of the PCM. This will be based on a section of the geometry and the materials used in Hosseini et al. [2]. This will then be compared to a 2D model in which the temperature was kept constant at the tube wall.

References

[1] A. D. Brent, V. R. Voller, and K. J. Reid, "Enthalpy-Porosity Technique for Modeling Convection-Diffusion Phase Change: Application to the Melting of a Pure Metal," *Numer. Heat Transf.*, vol. 13, no. 3, pp. 297–318, Apr. 1988, doi: 10.1080/10407788808913615.

[2] M. J. Hosseini, A. A. Ranjbar, K. Sedighi, and M. Rahimi, "A combined experimental and computational study on the melting behavior of a medium temperature phase change storage material inside shell and tube heat exchanger," *Int. Commun. Heat Mass Transf.*, vol. 39, no. 9, pp. 1416–1424, Nov. 2012, doi: 10.1016/j.icheatmasstransfer.2012.07.028.

[3] S. Mat, A. A. Al-Abidi, K. Sopian, M. Y. Sulaiman, and A. T. Mohammad, "Enhance heat transfer for PCM melting in triplex tube with internal–external fins," *Energy Convers. Manag.*, vol. 74, pp. 223–236, Oct. 2013, doi: 10.1016/j.enconman.2013.05.003.