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Numerical Investigation of Phase Change Materials (PCM) Solidification in a Finned Rectangular Heat Exchanger

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Abstract : Because of the rise in energy costs, thermal storage systems designed for the heating and cooling of buildings are becoming increasingly important. Energy storage can not only reduce the time or rate mismatch between energy supply and demand but also plays an important role in energy conservation. One of the most preferable storage techniques is the Latent Heat Thermal Energy Storage (LHTES) by Phase Change Materials (PCM) due to its important energy storage density and isothermal storage process. This paper presents a numerical study of the solidification of a PCM (paraffin RT27) in a rectangular thermal storage exchanger for air conditioning systems taking into account the presence of natural convection. Resolution of continuity, momentum and thermal energy equations are treated by the finite volume method. The main objective of this numerical approach is to study the effect of natural convection on the PCM solidification time and the impact of fins number on heat transfer enhancement. It also aims at investigating the temporal evolution of PCM solidification, as well as the longitudinal profiles of the HTF circling in the duct. The present research undertakes the study of two cases: the first one treats the solidification of PCM in a PCM-air heat exchanger without fins, while the second focuses on the solidification of PCM in a heat exchanger of the same type with the addition of fins (3 fins, 5 fins, and 9 fins). Without fins, the stratification of the PCM from colder to hotter during the heat transfer process has been noted. This behavior prevents the formation of thermo-convective cells in PCM area and then makes transferring almost conductive. In the presence of fins, energy extraction from PCM to airflow occurs at a faster rate, which contributes to the reduction of the discharging time and the increase of the outlet air temperature (HTF). However, for a great number of fins (9 fins), the enhancement of the solidification process is not significant because of the effect of confinement of PCM liquid spaces for the development of thermo-convective flow. Hence, it can be concluded that the effect of natural convection is not very significant for a high number of fins. In the optimum case, using 3 fins, the increasing temperature of the HTF exceeds approximately 10°C during the first 30 minutes. When solidification progresses from the surfaces of the PCM-container and propagates to the central liquid phase, an insulating layer will be created in the vicinity of the container surfaces and the fins, causing a low heat exchange rate between PCM and air. As the solid PCM layer gets thicker, a progressive regression of the field of movements is induced in the liquid phase, thus leading to the inhibition of heat extraction process. After about 2 hours, 68% of the PCM became solid, and heat transfer was almost dominated by conduction mechanism.

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