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Numerical analysis and design optimization of multi-coil units for latent heat cold storage

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Abstract—The use of latent heat cold storage systems in commercial food storage industry has experienced a notable growth over the past few decades due to their advantages in terms of high energy storage efficiency, relatively low production and maintenance costs. This technology is a proven way to match efficiently energy supply with fluctuating demand. It has certainly a great potential impact on energy savings at world level. Among the various cold storage techniques, approaches involving the coil tubular heat exchanger (CTHE) modules appear to be particularly well suitable for compact and cost-effective applications.

In this paper, we report a simple cold storage module developed by our team for low-cost cold storage applications. It consists of a multi-coil tubular heat exchanger integrated in a tank filled with a phase change material (PCM). The operation principle is that during charging, at night-time hours, the heat transfer fluid at the inlet of the CTHE has a temperature lower than the PCM solidification point. This fluid is pumped through the CTHE and progressively freezes the PCM in the tank. Then, during discharging, at the period of on-peak load with more expensive electricity costs, the energy (cold) accumulated in the PCM tank at night-time, can be extracted to use in an external cooling system (food storage, acclimatization, etc.). The charging/discharging cycle duration depends upon the job criteria and cold storage strategy selected by the user.

The practical implementation of a high-efficient CTHE module requires an appropriate approach for design optimization related to a complex multivariate problem. Accordingly, we need a computational tool that makes it possible to simulate the temperature field variation, as well as the melting and solidification front evolution in computational domains having a complex 3D geometry. In this work, we use the well proven COMSOL Multiphysics® software package. We estimate the effect of different design parameters (such as the temperature and flow rate of the heat transfer fluid, coil tube radius, axial pitch, number of turns, etc.). In our study, the objective function is the energy storage efficiency. It is worth noting that most commercial cold storage applications operate at a relatively narrow temperature range, close to the PCM melting point, where the viscosity is relatively large. Therefore, our numerical models involve a simplified approximation, in which the heat transfer in the PCM is dominated by conduction. Finally, the initial guess values for the coil-to-coil tube distances were generated by solving the classical one-dimensional Stefan problem.

Keywords—latent heat cold storages, multi-coil heat exchanger, cold storage tank.