The looming uncertainty over future energy supplies, and concern over environmental protection has drawn the attention of researchers to the utilization of renewable energy and waste heat sources. The major technical constraint that prevents the successful implementation and effective utilization of renewable energy and waste heat sources, is their intermittent nature, and time mismatched availability and demand. In order to reduce this mismatch, the system utilizing these sources should be integrated with energy storage units. Thermal energy can be stored in the form of the sensible heat of a solid or liquid medium, the latent heat of a phase change substance or by a chemical reaction. The Latent Heat Storage (LHS) unit is particularly attractive due to its high-energy storage density and its isothermal behavior during the energy storing and retrieval process (phase change process). The complexity of the phase change problems arises due to the moving boundary of the solid-liquid interface, the location of which is an unknown function of time. Further, practical situations that involve complex boundary conditions are multidimensional in nature. For these reasons, the modeling of phase change problems has received considerable attention. Among the various types of storage system, the packed bed unit filled with encapsulated Phase Change Material (PCM) balls received the attention of the researchers for various applications in recent years. A good understanding of the heat transfer processes involved in a packed bed latent heat storage system unit is essential, for accurately predicting the thermal performance of the system and for avoiding a costly system over design.
In the present work, a detailed survey has been made on the modeling of the phase change problem, with different formulating methods and physical assumptions, for different configurations. Three different mathematical models are developed for a packed bed latent heat storage system, comprised of a cylindrical storage tank filled with paraffin encapsulated spherical containers. The first one is a continuous solid phase model, in which all the PCM capsules are considered to be a continuous domain, and the internal conductive resistance inside the individual PCM capsule is ignored, and also the conduction along the flow direction is neglected. In the second model, the effect of conduction along the flow direction in the Heat Transfer Fluid (HTF) and the PCM is included. The third model is a conduction dominated model, which considers the thermal gradient inside the PCM capsules. An experimental investigation is performed on a packed bed latent heat storage system, designed similar to the physical configuration considered in the formulation of models. Commercial grade paraffin and air are considered as the PCM and HTF respectively. The experimental results are used to validate the accuracy of the mathematical models, for the problem considered in the analysis. Further, a numerical analysis is performed using the models for two different heat transfer fluids of air and water at different mass flow rates, and the ball sizes and the complexity required in the model for a given problem are reported. The validated model was also used to analyze the effect of various parameters, such as the ball size, inlet heat transfer fluid temperature, mass flow rate and effective thermal conductivity, that influence the performance of the storage system.
It was observed from a comparison of the first and second models, that the effect of axial conduction in the heat transfer fluid and storage capsules is negligible, compared to the convective heat transfer by the flowing fluid in the axial direction. The third model that considers the thermal gradient inside the PCM capsules is in good agreement with the experimental results, when compared with the first and second models. However, the continuous solid phase model can be used with reasonable accuracy, when air is the heat transfer fluid in combination with the small diameter of the PCM capsule and low mass flow rate of the HTF.

The results of the parametric study reveal that increasing the thermal conductivity of the PCM has no effect on the heat transfer enhancement because of the major role played by the high surface convective resistance, with air as the heat transfer fluid. The major factors which are favorable to increase the heat transfer during the charging process are, i. increasing the heat transfer area with smaller size balls; ii. higher temperature difference between the HTF inlet and the phase change temperature of the PCM, and iii. increasing the mass flow rate of HTF. However, in order to achieve uniform instantaneous heat retrieval during the discharging process, the above factors should be reversed. Hence, while designing the storage system, among the three parameters that influence the performance, the size of the ball being a geometrical parameter, an optimum size has to be selected, while the other two dynamic parameters may be selected accordingly for the charging and discharging processes.