INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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Thesis Title: **Design, Simulation and Experimental Investigation of High Temperature Solid-state Sensible Heat Storage Systems**

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SHORT ABSTRACT

The work on the thesis is framed to propose high-temperature thermal energy storage, mainly focusing on the design, development and performance investigation of solid SHS. A high-temperature test facility has been built to study the performance characteristics of the TES modules. In the initial phase of research, the study focused on detailed experimental and numerical investigations on a cast steel based sensible heat thermal energy storage system using air as a heat transfer fluid. A dedicated test facility has been designed and developed for studying the performance of the storage system operating in the temperature range of 393 K to 573 K. Three-dimensional (3-D) and one-dimensional (1-D) models are developed for predicting the heat transfer characteristics of the storage system. The developed storage prototype has a shell and tube configuration having 19 passages in the tube side for heat transfer fluid flow. The performance of the storage system during the charging and discharging processes is analysed by varying the operating temperature range and flow velocity of air. The heat transfer characteristics of the system in terms of axial and radial temperature variations are recorded and analysed. Both the experimental and 3-D simulation results show a significant temperature variation in the axial direction than radial direction. The charging and discharging rates are found to be faster at a higher flow velocity of air. The predictions from both 3-D and 1-D models are consistent with the experimental data. The validated 1-D model can be used for real-time monitoring, control, optimisation and integration with various storage applications.

In the next phase of research, the work presents the concept of developing a cost-effective Concrete based Thermal Energy Storage (CTES) system by performing extensive experimental studies and numerical simulations. A stand-alone experiment facility to study the performance of high-temperature thermal energy storage system, which operates up to 773 K using air as the heat transfer fluid, has been developed. The CTES module is made of shell and tube configuration, where the concrete is filled in the shell side, and 22 air passages are provided on the tube side.

The inlet air temperature and velocity are the decision parameters used for analyzing the thermal behaviour of the CTES module. From the spatial variations of temperature, it is observed that the heat transfer rate is uniform and faster along all radial planes, whereas, the heat transfer rate drops gradually along the length of the CTES module due to drop in Heat Transfer Fluid (HTF) temperature. The parametric investigation conducted shows that the charging and discharging times were reduced by approximately 48% and 29%, respectively, with a change in inlet temperature of 40 K and at a fixed air velocity of 2 m/s. A 3-D model for the CTES module developed using the finite element method has been validated with experimental results. The temperature contours plotted from 3-D simulation describes the spatial variation of CTES temperature at different inlet air temperatures. Further, a 1-D dynamic model has been developed, which is fast and accurate with a maximum error of ±4.9 K with reference to real-time experiments and provides a substantial scope of integrating the CTES with industrial applications.

In the final phase of research, a comprehensive coupling strategy is developed to evaluate the performance of a multi-module SHS system using the 1-D dynamic model. The validated 1-D model developed in our previous studies are adopted to scale-up the heat storage capacity for large scale application. The SHS modules used in this study are made of materials such as cast steel, cast iron and concrete with the design similar to shell and tube configuration. Air is used as the heat transfer fluid at a velocity of 15.2 m/s. Six Cases are framed to evaluate the charging (493-573 K) and discharging (373-573 K) behaviour of SHS module coupling strategies in different series and/or parallel arrangements. The performance of the charging and the discharging processes for all the Cases are estimated and compared for forward flow and reverse flow patterns and reverse module arrangements. The cost of the net energy discharged (USD/kW-h) from each arrangement is evaluated. The result shows that the performance of Case 6 (three parallel channels, with two different SHS modules in each channel) is better in terms of heat transfer rate and however, the cost of net energy discharged in Case 6 is 62.26 USD/kW-h, which is very expensive. The Case 3 (six concrete in the series arrangement) can store and discharge more amount of heat with slow heat transfer rate, and the cost of net energy discharged in this Case is 1.18 USD/kW-h. The developed flowsheet models are highly beneficial for studying the performance of the different storage module arrangements along with large scale applications.

The outcomes from the studies highlight that cast steel and concrete TES storage modules are the cost-effective and viable high-temperature storage option for multiple thermal cycles with excellent durability.