PERFORMANCE INVESTIGATION OF A PACKED BED SOLAR ENERGY STORAGE SYSTEM HAVING SPHERES WITH PORES AS PACKING ELEMENTS

Ph.D. THESIS

by

ABHISHEK GAUTAM

DEPARTMENT OF HYDRO AND RENEWABLE ENERGY
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE-247667 (INDIA)
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ABHISHEK GAUTAM

DEPARTMENT OF HYDRO AND RENEWABLE ENERGY
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
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ABSTRACT

The solar energy is one of the most adopted renewable energy resource due to its abundant availability and eco-friendly behavior. However, there is a need to manage few technical obstacles like low efficiency, instability in energy supply and monetary impediment for its sustainable development. In order to eliminate instability in energy supply, the solar energy systems require an effective energy storage technology to store the energy during its availability and deliver it on its requirement. For solar thermal energy systems, many thermal energy storage (TES) techniques exist and packed bed storage system (PBSS) is the one which can be integrated with applications of all temperature range.

For low temperature applications, TES in the form of sensible heat is recommended due to its lesser storage cost. There are various modes of energy transfer involved in PBSS, however, the thermal performance is majorly dependent on the convective heat transfer between heat transfer fluid and packing elements in low temperature applications. The convective heat transfer rate between heat transfer fluid and packing elements is a function of the physical properties of heat transfer fluid and packing elements, local temperature at surface of packing element, various characteristics of packed bed such as void fraction, packing arrangement, sphericity and mass flow rate of heat transfer fluid.

The shape of the packing element is one the parameter that affects the thermo-hydraulic performance PBSS. It is therefore, the shape of the packing element affects the flow pattern and influence the mixing of flowing streams by developing eddies under the complex set of flow passages. The performance of various shapes as packing elements of large size had been investigated in previously reported studies. Based on the literature review, it is found that spheres of smooth surface results with better thermo-hydraulic performance out of all the shapes. However, the effect of pores over the surface of spherical packing element has not been investigated so far. Therefore, the influence of diameter, depth and number of pores over the surface of spherical packing element on thermal and hydraulic performance of PBSS have been investigated and reported under the present study. In view of the above, the objectives of the present study are as: i.) To investigate the Nusselt Number and friction factor of a packed bed storage system having spheres with pores as packing elements. ii) To develop the correlations for Nusselt number and friction factor as a function of design and operating parameters. iii) To investigate the thermo-hydraulic behavior of the

packed bed storage system having spheres with pores as packing element. iv.) To select the optimal design parameters of the packed bed storage system having spheres with artificially created pores as packing element under different operating conditions.

An indoor experimental study was planned to achieve the aforementioned objectives. Therefore, an experimental set up is designed, fabricated and experiments were conducted to collect the required data through which the heat transfer and friction characteristics of the considered PBSS can be analyzed in terms of Nusselt number, friction factor and Reynolds number. In order to represent the investigated parameters in non-dimensional form, pore diameter, pore depth and number of pores are reduced to pore to sphere diameter ratio (*d/D*), pore depth to sphere diameter ratio (*t/D*) and perforation index (*PI*), respectively. Experimentations are carried out for the values of *d/D*, *t/D*, *PI* and Reynolds number within the range of 0.06 to 0.20, 0.05 to 0.20, 0.06 to 0.22 and 200 to 800, respectively.

During the analysis of experimental results, it is found that Nusselt number and friction factor are the strong function of *d/D*, *t/D*, *PI* and Reynolds number. The results are also presented in terms of thermo-hydraulic parameter that gives the effective value of energy by considering heat transfer coefficient and pressure drop of the PBSS simultaneously. The correlations for Nusselt number and friction factor are also developed based on the obtained experimental data. It is found that the correlations for Nusselt number and friction factor can predict the values with mean absolute deviation of 6.7% and 7.5%, respectively.

The developed correlations for Nusselt number and friction factor are used for performance analysis of PBSS with the help of mathematical simulation techniques of a developed model. The performance analysis under the present study is carried out in terms of thermo-hydraulic efficiency for different investigated system parameters. As the performance of PBSS is influenced by operating parameters i.e., temperature rise parameter (*ΔT/I*) and solar radiation (*I*) intensity, it is necessary to obtain the optimized value of investigated system parameters for different values of *ΔT/I* and *I*. Therefore, optimized values of *d/D*, *t/D* and *PI* for different values of *ΔT/I* and *I* on the basis of maximum thermo-hydraulic efficiency are presented and discussed that may help during the designing of PBSS for low temperature based solar thermal energy systems.