Proceedings of the Canadian Society for Mechanical Engineering International Congress
32nd Annual Conference of the Computational Fluid Dynamics Society of Canada
Canadian Society of Rheology Symposium
CSME-CFDSC-CSR 2025
May 25–28, 2025, Montréal, Québec, Canada

EXPERIMENTAL AND NUMERICAL STUDY ON A PILOT-SCALE HIGH-GRADE ROCK BED THERMAL ENERGY STORAGE

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ABSTRACT

This study investigates the thermo-fluid performance of the SAUNA rock bed storage facility at Stellenbosch University. The facility features a 1.5 m³ storage volume filled with 2480 kg of dolerite samples to evaluate charging performance. A diesel burner downstream of the fan raises the inlet temperature to a maximum of 600°C. The experiments were performed for the highest temperature and maximum mass flow rate achievable based on the burner maximum capacity of 148 kW. The results are used as a benchmark against volume-averaged method predictions from Ansys Fluent, a commercial computational fluid dynamics software. The findings indicate that the volume average method accurately predicts temperature distribution provided that key design and flow parameters are considered. One key consideration, for instance, is that a two-dimensional axisymmetric flow assumption is inadequate, as it underestimates heat loss. Therefore, it is necessary to model the full three-dimensional model of the storage bed for an accurate prediction of the thermal performance. Another key observation is the necessity of implementing a fan intake boundary condition in rock bed simulations, especially for the purpose of numerical sensitivity analysis and optimal design considerations. Smaller particles for instance will obstruct flow, reducing mass flow rate and reducing the expected improvements in heat transfer for smaller particles. This will directly affect the optimal design for a rock bed storage. Not surprisingly, the local thermal non-equilibrium (LTNE) assumption is essential despite the use of relatively small particles. Interestingly, incorporating a modified specific surface area in the LTNE framework, considering particle non-sphericity, improves agreement with experimental data, which is a parameter that has received much less consideration in the literature. Incorporating particle non-sphericity, aligns well with results obtained using the Wakao correlation for particle-solid interfacial heat transfer. Additionally, shell conduction can be safely employed for outer surface heat transfer to account for the 15 cm insulation layer, significantly simplifying the simulation. Without this approach, numerical modeling would require coupling three surfaces: the fluid region of the packed bed, the solid region of the packed bed, and the solid insulation layer. The study concludes that radiation effects can be neglected even at high temperatures for the conditions considered in this study. However, further research is recommended, as radiation may become significant at lower mass flow rates or higher inlet temperatures. Overall, this research successfully validates the numerical model and provides insights for numerical implementation and optimization guidelines for rock bed storage systems.

ACKNOWLEDGMENTS

HE and APS gratefully acknowledge the financial support from Natural Sciences and Engineering Research Council of Canada and Fond de Recherche du Quebec Nature et Technologies. LA would like to thank the Department of Mechanical Engineering, University of Sherbrooke, for its financial support.