FINAL PROJECT

COMPUTATIONAL FLUID DYNAMICS STUDY ON THE EFFECT OF DIMPLED SURFACE ON CONVECTIVE HEAT TRANSFER PERFORMANCE IN A CYLINDRICAL PHASE CHANGE MATERIAL CONTAINER

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ABSTRACT

Global energy demand continues to rise as a result of population growth and industrial expansion, a large portion of which is still met by fossil fuels such as coal, oil, and natural gas. These finite resources produce harmful emissions that contribute to environmental degradation, highlighting the urgent need for cleaner and more sustainable energy alternatives. Solar energy is among the most promising renewable resources due to its abundance and environmental friendliness, however, solar thermal systems suffer from intermittency, as their performance is strongly dependent on sunlight availability and is reduced during nighttime or cloudy conditions. Thermal Energy Storage (TES) systems address this limitation by storing excess heat when solar radiation is high and releasing it when needed. Phase Change Materials (PCMs) such as paraffin wax are effective for TES due to their high latent heat capacity, but their low thermal conductivity limits heat transfer performance. This study investigates the effect of teardrop-shaped dimples on the convective heat transfer performance of a cylindrical RT27 paraffin PCM container using three-dimensional CFD simulations in ANSYS Fluent. Smooth and dimpled geometries were compared at Reynolds numbers of 500, 2500, and 5000, using Large Eddy Simulation coupled with the enthalpy-porosity method for PCM melting. The numerical model was validated against established reference data for both external flow and internal melting behavior, achieving average deviations of 2.54% and 7.06%, respectively. Results show a strong Reynolds number dependency, at Re 500, the dimpled surface reduced heat transfer by 0.36% due to a stagnant dead-zone effect within the dimple cavities, at Re 2500, ejection-driven mixing increased heat transfer by 27.01% (881.40 over 693.98 W/m^{2}K), at Re 5000, the enhancement effect diminished to only 0.05%. The dimpled container also melted faster, reaching full melting at 1038 seconds compared to 1106 seconds for the smooth container.

Keywords: Phase Change Material, Convective Heat Transfer, Dimpled Surface, Computational Fluid Dynamics (CFD), Paraffin Wax