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A computational fluid dynamics study of turbulence flow in a heat-pipe-heat exchanger for application in micro reactor

High Temperature Reactors (HTRs), particularly the very high temperature reactor (VHTR), represents a significant advancement in nuclear reactor technology. Reactors operate at temperatures exceeding 1000 ℃, which enhance the thermal efficiency and allow the potential for hydrogen production through thermochemical processes. In a VHTR, the generated impurities in the helium coolant can lead to an environmental degradation of high-temperature alloys used in the reactor. These impurities, which may include water vapor and carbon compounds, can cause oxidation, carburization, or decarburization of the alloys. The heat pipe heat exchanger (HPHE) is a specific solution that can be implemented to eliminate the tritium contamination to enter the secondary cycle by balancing the temperature equilibrium between the hot and cold fluids in the micro reactor. Computational fluid dynamics (CFD) numerically solves the Navier-Stokes equation and predicts the thermal energy transfer in the HPHE. In this study we compared the performance of the HPHE based on the five different turbulence models, offering valuable insights into their accuracy and reliability in predicting the flow and temperature distribution of a HPHE. Results show that the k-ω model has the most comprehensive temperature range, where He has been reduced from 1000 K to 593 K and air increased from 403 K to 723 K. The k-ω Standard turbulence model (STD) is suitable for wall bounded flows with high Reynolds number flows and Shear stress transport (SST) is a hybrid model which combines the strengths of K –epsilon (k-ε) and k-ω transition models showed a higher turbulence kinetic energy values. While the Reynolds stress showed lower turbulence kinetic energy, the Large Eddy Simulation is computationally expensive. While all the turbulence models can influence heat transfer and thermal equilibrium in a HPHE, the k-ω improve the rate of heat convection in a HPHE. The results of this study highlight the importance of turbulence model selection in accurately predicting the HPHE performance in a micro reactor. Furthermore, valuable insights for optimizing heat exchanger design in VHTR using CFD is provided.

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