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CFD investigating thermal-hydraulic characteristics of FLiNaK salt as a heat exchange fluid

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ABSTRACT

Concentrated solar thermal (CST) power plants are promising energy sources for electricity production in the near future. Thermal energy storage via a heat transfer fluid (HTF) is a crucial requirement to enable such plants to deliver electricity. With advantages of high boiling temperature, large specific heat, and low price, molten salts are very suitable for use as HTFs. Therefore, a computational fluid dynamics (CFD) methodology is proposed in this paper for investigating the thermal-hydraulic characteristics of FLiNaK salt. The proposed model is validated through comparison with existing correlations and experimental data of friction factor (f_w), Nusselt (Nu) number, and hydraulic and thermal entrance length (L_h,L_{th}) in a simple round tube under various inlet Reynolds numbers (Re). Specifically, the predicted fully-developed f_w corresponds well with that calculated by the Blasius correlation and the Moody diagram. The predicted Nu number is also in close agreement with that determined using Gnielinski's correlation, revealing that this correlation is more suitable for predicting the heat transfer characteristics of FLiNaK salt.

1. Introduction

Molten salts are relatively inexpensive and have the high boiling temperature, low vapor pressure, high specific heat, and good chemical stability, making them suitable for use as heat exchange fluids in energy-related applications involving high temperatures and low pressures. Such applications include thermal solar energy storage and heat transfer in advanced nuclear reactors, as well as advanced oil recovery and biomass gasification [1–3]. In particular, molten salts are able to satisfy the requirements of heat transfer fluid (HTF) for thermal energy storage in concentrated solar thermal (CST) power generation [4–7]. CST solar thermal power is a promising technology for future large-scale energy generation, and thermal energy storage is critical for such systems to be able to deliver electricity without backup as well as meet peak demand. Solar thermal energy in such systems is collected and delivered via an HTF into a steam generator, which in turn drives the turbine for electricity production. The efficiency of this Rankine cycle can be increased by using an HTF with a high operating temperature, such as a molten salt. A comprehensive understanding of the thermal-hydraulic characteristics of molten salts would therefore contribute to the development of more efficient CST technologies.

Most of the previous studies related to molten salts were based on the experimental works. These experiments essentially measured the physical properties of molten salts [8–10] and their heat transfer characteristics [11–17]. Several analytical studies [18–21] had also been carried out. Mandin et al. [18] used the Navier–Stokes and energy conservation equations to estimate thermal gradients in a molten salt. Ferri et al. [19] introduced the property definitions for molten salts in the RELAP5 code to perform transient simulations at the Prova Collettori Solari (PCS) test facility. Khokhlov et al. [20] proposed analytical equations to evaluate the density, viscosity, heat capacity, and thermal conductivity of various molten salt mixtures of Li, Na, Be, and Zr fluorides. Yang and Garimella [21] developed a comprehensive, two-temperature model to investigate energy storage in a molten salt thermocline under different environmental boundary conditions.

Although the high melting temperature of molten salts is one of the benefits of these materials, it also causes difficulties in performing experiments. These difficulties include salt solidification and container corrosion during tests, which are significant for a molten salt mixture of LiF(46.5)-NaF(11.5)-KF(42) (mol%) (known as FLiNaK) due to its high melting temperature of ~727 K. Analytical methods are therefore of particular assistance in evaluating the thermal-hydraulic characteristics of FLiNaK salt. In the present study, these characteristics, including the friction factor (f_w) and Nusselt (Nu) number distributions, and the hydraulic and

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