Experimental Study on the Thermal Behavior of Molten Salt FLiNaK Flow in a Small Channel

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1. Introduction

The Very High Temperature Reactor (VHTR), one of the most challenging next generation nuclear reactors, has recently drawn an international interest due to its higher efficiency and the operating conditions adequate for supplying process heat to the hydrogen production facilities. To make the design of VHTR complete and plausible, the designs of the Intermediate Heat Transport Loop (IHTL) as well as the Intermediate Heat Exchanger (IHX) are known to be one of the difficult engineering tasks due to its high temperature operating condition (up to 950^{o}C). A type of compact heat exchangers such as printed circuit heat exchanger (PCHE) has been recommended for the IHX in the technical and economical respects.

The Flinak molten salt, a eutectic mixture of LiF, NaF and KF (46.5:11.5:42.0 mole %) is considered to be a potential candidate for the heat transporting fluid in the IHTL due to its chemical stability against the structural material as well as low pumping power compared to a gas flow such as helium[1]. The melting point of this eutectic salt mixture is 454^{o}C and the major physical properties are given in Table 1[2]. In the present study, preparation, melting and thermal behavior of the Flinak flow in a small channel of millimeter-range hydraulic diameter has been experimentally investigated.

2. Experimental Apparatus

The Flinak is a eutectic mixture of LiF, NaF and KF and the molten salt flow is operated at high temperature above 500^{o}C. The handling and operation requires an oxygen and humidity-free and high temperature system. The experimental apparatus consists of molten salt loop and high-temperature gas loop. To avoid using a mechanical pump for high temperature salt flow, two crucible tanks are used and the differential pressure across these two tanks provides molten salt flow. The whole flow pipes are maintained above the melting point of the salt using electric heating jackets.

Table 1. Physical properties of molten FLiNaK at 700^{o}C

Melting point	454 ^{o}C
Density	2020 kg/m^3
Specific heat	1.88 kJ/kgK
Viscosity	2.90 mPa·s

A double-pipe type heat exchanger using small-diameter tubes was constructed for the heat exchange between the molten salt and the gas (helium or argon). The outer and the inner diameters of the inner tube are 3.18 mm and 1.40 mm and for the outer tube are 6.35 mm and 4.57 mm, respectively. The length of the test section is 500 mm. The molten salt flows through the inside of the inner tube and the gas flows through the annulus of 0.7 mm gap. A schematic diagram of the molten salt loop is given Fig. 1.

The molten salt is prepared in a crucible made of Inconel 600 placed in an electric furnace. The molten salt flow is produced by differential pressure between this crucible and another twin set of crucible system without using a mechanical pump. The flow rate of the molten salt is calculated from the weight changes of both crucibles measured by load cells. Temperatures of the two heat exchanging fluids at various points as well as pressure drop across the test tube are measured to obtain flow and heat transfer characteristics of the molten salt flow.

The gas loop is to provide high temperature gas flow of either helium or argon to the heat exchanger and it consists mainly of gas booster, furnace-coil type gas heater, pressure regulator, coriolis-type flow meter, and a cooler. The gas loop is designed to operate at high pressure (< 6 MPa) and high temperature (< 950^{o}C).

3. Experimental Observations

The three types of salts making the Flinak in a powder form were mixed according to the required

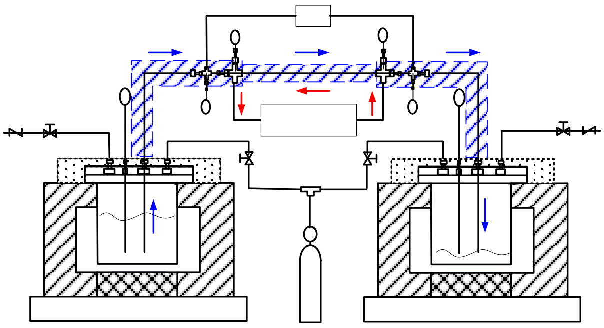

Fig. 1. A schematic diagram of molten salt loop

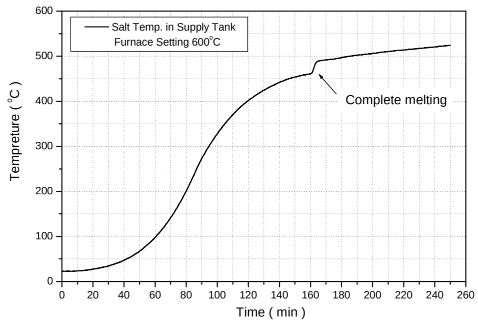

Fig. 2. Salt temperature trace during melting

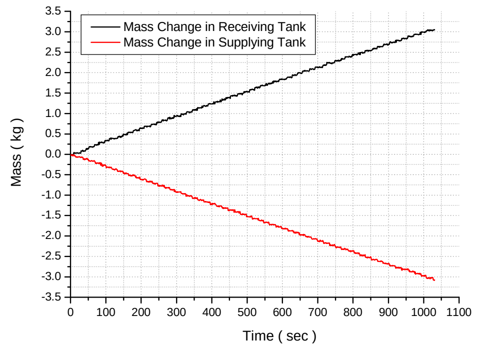

Fig. 3. Salt Mass changes for flow rate measurement

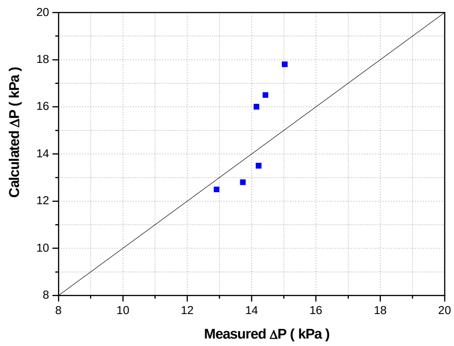

Fig. 4. Comparison of measured and calculated pressure drop across the test section

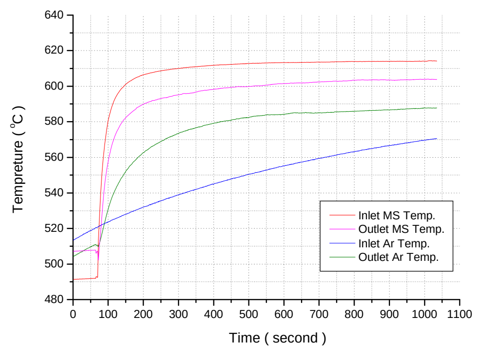

Fig. 5. Temperature traces of molten salt and Ar gas across the double-pipe heat exchanger

mass fraction in a moisture-free, inerted glove box and the mixed powder was loaded in the crucible placed in the electric furnace. The first melting was successful according to the observed salt temperature. After the first melting the salt was solidified in the crucible and it was re-melted for the next experimental run. A typical temperature trace of the salt inside the crucible indicating the heatup and melting is given Fig. 2. According to this temperature trace the melting begins at ~460°C and completed at ~490°C.

By applying a differential pressure of 0.1~0.3 bar across the supplying tank and the receiving tank of the salt, the molten salt flow rates of 4.8~6.4 kg/hr were obtained. Fig. 3 illustrates the weight changes of the supplying and receiving tanks and the flow rates were deduced from these data. This range of salt flow rates corresponds to the Re number of 390~560 in the 1.4 mm ID test tube, indicating the salt flow is a laminar flow. The measurement of the pressure drop of the molten salt flow across the test section was often a problem due to an unexpected freezing of the salt inside the pressure guide tubes. Some of the successfully measured pressure drop data were compared with the prediction in Fig. 4. The deviation is as large as 18% and it can be attributed to the uncertainty in the measurement of flow rate and pressure drop as well as the physical properties used in the prediction.

The heat transfer tests were run in the double-pipe type heat exchanger and the typical temperature traces of the two working fluids at both inlet and outlet were shown in Fig. 5. Heat transfer analysis will be made after a complete set of data is obtained.

4. Summary

The molten salt Flinak, a potential candidate as a working fluid for the intermediate heat transport loop of VHTR, has been experimentally studied for its thermal and flow behavior in a small channel of a compact heat exchanger. The molten salt was successfully prepared and melted and the salt flow loop was run to produce preliminary thermal-hydraulic data.

Acknowledgement

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