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A Design of He-Molten Salt Intermediate Heat Exchanger for VHTR

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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°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 [1].

Selection of the heat transporting fluid for the intermediate heat transport loop is important in consideration of safety and economical aspects. Although helium is currently the primary interest for the intermediate loop fluid, several safety concerns of gas fluids have been expressed [2]. If the pressure boundary of the intermediate loop fails, the blowdown of the gas may overcool the reactor core and then the heat sink is lost after the blowdown. Also the large inventory of gas in the intermediate loop may leak into the primary side. There is also a recommendation that the nuclear plant and the hydrogen production plant be separated by a certain distance to ensure the safety of the nuclear plant in case of accidental heavy gas release from the chemical plant. In this circumstance, the pumping power of gas fluid in the intermediate loop will be large enough to degrade the economics of nuclear hydrogen.

An alternative candidate for the intermediate loop fluid in consideration of these safety and economical problems of gas fluid can be molten salts. 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. The pumping power analysis for simplified geometry of circular pipes between the reactor and the H_2 plant is summarized in Table 1. For 1 km apart and 600 MWt reactor power, the pumping power of helium is as high as 50 MW for 0.75 m diameter pipe and for Flinak it is as low as 0.1 MW for 0.5 m pipe.

The melting point of this eutectic salt mixture is 454°C and the major physical properties [3] are given in Table 1 together with the properties of helium.

Table 1 Pumping power estimate for 1 km distance and 600 MWt

	He			Flinak		
Mass flow, kg/s	321			887		
Volume flow, m^3/s	66.7			0.439		
Pipe ID, m	0.75	1.0	1.25	0.3	0.4	0.5
Velocity, m/s	151	84.9	54.3	6.21	3.49	2.24
Pressure drop, bars	7.41	1.89	0.66	24.3	6.20	2.15
Pumping power MW	49.4	12.6	4.37	1.07	0.27	0.10

Table 2 Physical properties of molten Flinak and helium gas at 700°C (He at 7 MPa)

	Flinak	He
Melting point, °C	454	-
Density, kg/m^3	2020	4.818
Specific heat, kJ/kgK	1.88	5.19
Viscosity, mPa·s	2.90	0.036
Thermal conductivity, W/mK	0.92	0.281

One of disadvantages of the molten salt is the high melt temperature so that the returning temperature from the process plant must be higher than the melting point. Also an accidental freezing of the salt coolant may cause a severe operational problem. A recent proposal of the modular helium reactor design for hydrogen production, H2-MHR, showed the increased inlet temperature of the primary coolant to provide higher flow rate in the core for better convective heat transfer. Accordingly the return temperature of the intermediate loop fluid is raised to 565°C. This could bring a good margin between the operating temperatures and the melting point of the salt.

2. Intermediate Heat Exchanger for He-Flinak

In designing the intermediate heat exchanger for helium and Flinak fluid pair, it must be considered, besides its high temperature, that the helium side pressure is high up to 70 bars and the Flinak pressure is near the atmospheric pressure, resulting in large differential pressure between the two fluids.

This large pressure difference could be a problem in constructing a compact heat exchanger using diffusion bonding technique when high pressure is applied inside the diffusion-bonded channel. The diffusion bonding may not be successful under such high temperature and high pressure loads. However, for He-Flinak IHX, this large pressure difference can be an advantage when the low-pressure Flinak flows inside the channels made by diffusion bonding and the high-pressure helium flows

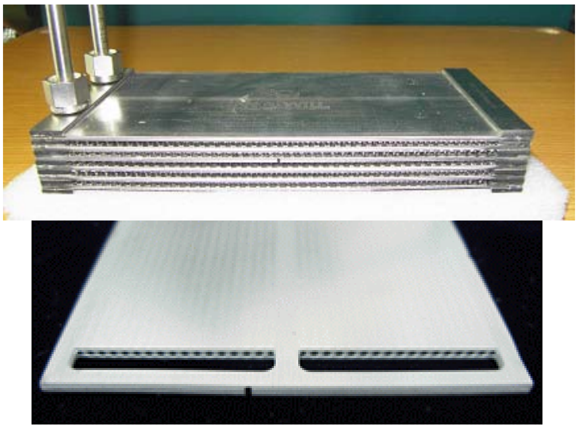

Fig. 1 Plate-fin (offset) compact heat exchanger (top) and diffusion-bonded small channels of plate (bottom)

outside the channel, namely plate-fin geometry. The force of pressure difference between helium and Flinak acting in the direction of pressing the diffusion-bonded plates helps maintaining the structural integrity of the plates.

A plate-fin type compact heat exchanger for IHX was designed and a sample heat exchanger was constructed as shown in Fig. 1. Using the concept of printed circuit heat exchanger, the 1.2 mm diameter, half-circular grooves were etched on a 2 mm thick plate of Inconel 600 and two etched plates were diffusion-bonded. The plates and fins were then brazed to construct a heat exchanger unit.

3. Pressure Drop Measurement of Flinak Flow in Small Channels

The experimental apparatus consists of molten salt loop and high-temperature gas loop as shown in Fig. 2. By applying a differential pressure in the range of 0.1~0.3 bar across the supplying tank and the receiving tank of the salt, the molten salt flow rates of 4.4~11.5 kg/hr were obtained. This range of salt flow rates corresponds to the Re number of 250~600 in the 1.4 mm ID test tube, indicating the salt flow is a laminar flow, as expected for small-diameter tubes. The temperature range of the molten salt was 500~650^{o}C.

The correct measurement of pressure drop in the present experiment must include the hydrostatic head of the molten salt rising in the guide tube to the differential pressure transducer. The measurement of the height of the molten salt in the guide tube was possible by inserting a metered wire through the guide tube from the sensor side while the power to heating jacket covering the guide tube was off temporarily to freeze the molten salt the guide tube.

The measured pressure drop data for the Flinak was reduced to friction factors using the relation of pressure drop and the friction factor. As shown in Fig. 3, the measured friction factor shows a good agreement with the analytical relation of 64/Re for laminar flow in circular tube, implying that the Flinak molten salt is a Newtonian fluid in small-diameter channels.

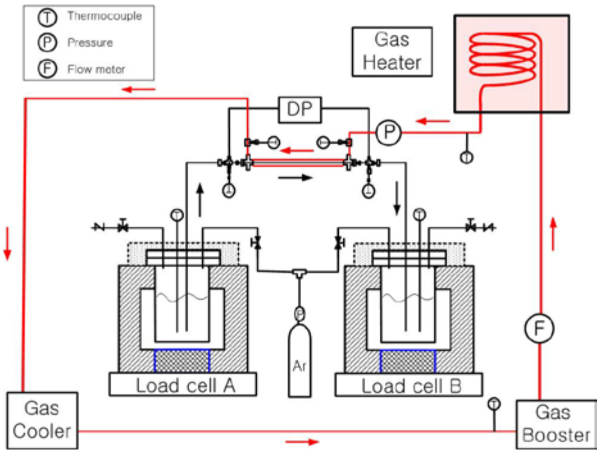

Fig. 2 A schematic diagram of molten salt loop

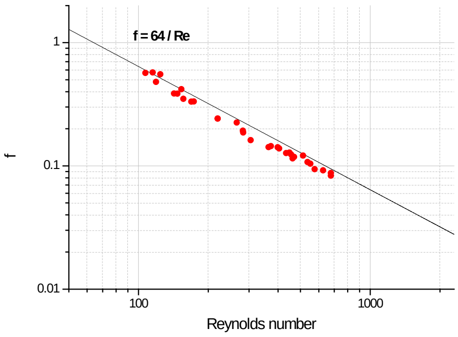

Fig. 3 Measured friction factors of Flinak flow

4. Summary

The molten salt Flinak, a potential candidate as a working fluid for the intermediate heat transport loop of VHTR, was experimentally studied for its thermal and flow behavior in a small channel of a compact heat exchanger. Also a plate-fin heat exchanger for He-Flinak IHX was designed and fabricated using the techniques of printed-circuit etching and diffusion bonding.

Acknowledgement

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References

[1] P.F. Peterson et al., “Functional Requirements Overview for a 50 MW(t) Liquid-Salt Intermediate Loop for NGNP,” UC Berkeley Report UCBTH-05-007, 2005.

[2] C.W. Forsberg et al., “Safety Related Physical Phenomena for Coupled High-Temperature Reactors and Hydrogen Production Facilities,” HTR2008, Washington, DC, USA, September, 2008.

[3] D.F. Williams, L.M. Toth, K.T. Clarno, “Assessment of Candidate Molten Salt Coolants for the Advanced High-Temperature Reactor,” ORNL/TM-2006/12, March 2006.