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Hydraulic Experimental Study of wire-wrapped rod bundle for Sodium-cooled Fast Reactor

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1. Introduction

Sodium-cooled Fast Breeder Reactor (SFR) adopted helical wire-wrap for its fuel rod spacing with the distinctive difference in thermal-hydraulic behavior compared to the conventional spacer-grid rod bundles. Novendstern [1] suggested semi-empirical model of pressure losses and Cheng and Todreas [2] subdivided the flow regimes (laminar, transition, and turbulent) resulting in more accurate correlations. However, the main focus of previous study was the correlations of accuracy. In this study, wire-wrapped rod bundle experiment was conducted to see the P/D effect by preparing diverse geometrical test sections and viscosity effect using diverse fluids.

2. Experiment

2.1 Test loop design

The experiment loop includes Surge tank, Pump, Electro-magnetic flowmeter, Heater, Cooler(Condenser). The layout of the experiment loop is shown in Fig. 1. The test section is installed with the reference core geometry of KALIMER-600 design (Table 1) and it consists of 19 rods in a bundle. To investigate the core geometry effect, especially Pitch-to-Diameter effect, 3 test sections were prepared(P/D=1.167, 1.2, 1.333).

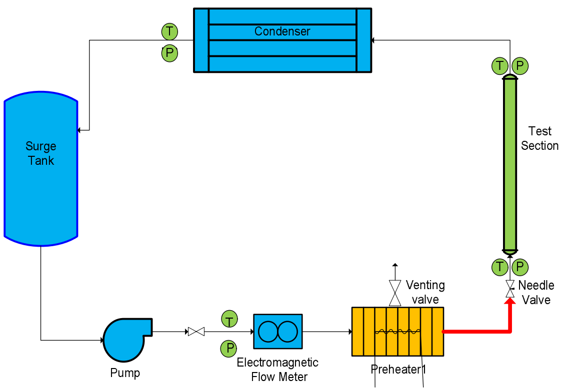

Fig. 1 Experiment loop layout

Table 1 Geometry data of fuel rod bundle

Fuel pin	9 mm
Wire-wrap	1.4 mm
Section length	2460 mm
Pin pitch	10.5 mm
Wire-wrap pitch	204.9 mm

Fig. 2 19 rod bundle test section

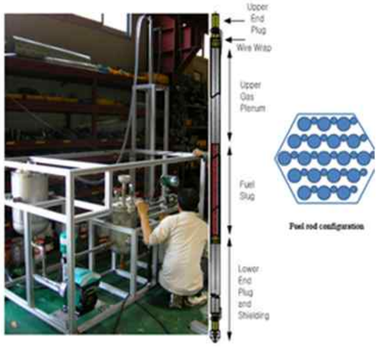

Fig. 3 Overall layout of test loop

2.2 Experiment fluids

Historically water has been commonly used as a substitute of sodium in hydraulic experiment due to their similar hydraulic characteristic. However, there exists viscosity difference between liquid sodium at 500^{o}C and water at 25^{o}C. Table 2 is the list of materials with lower viscosity than water. In this study, methanol was selected and to see the further effect ethanol was added. Therefore the experiment fluids were water, ethanol, and methanol.

Table 2 List of materials with lower viscosity than water

	Temp.	Density	Visco.	Conduct.
	K	kg/m^3	NS/m^2	W/mK
Water	300	997.05	0.00089	0.609
Sodium	818	825.1	0.0002298	64.802
Methanol	300	786.3	0.00056	0.202
Chloroform	300	1465	0.00053	0.118
Decane	300	726.3	0.000859	0.147
Ether	300	713.5	0.000223	0.130
Heptane	300	679.5	0.000376	0.128
Hexane	300	654.8	0.000297	0.124
Octane	300	698.6	0.00051	0.131
Toluene	300	862.3	0.000550	0.133

3. Results

Pressure drop was measured and the results are described in terms of Reynolds number and friction factor.

3.1 P/D effect and viscosity effect

3 different types of fluids(water, ethanol, methanol) were tested in 3 different P/D (1.167, 1.2, 1.333) test sections. Acquired data were non-dimensionalized into friction factor and Reynolds number. The results are shown in Fig. 4 – 6 and overall results followed similar trend of previous studies.

Fig. 4 – 6 was set in same scale to distinguish the P/D difference. As P/D increases, the result graph becomes stiffer. The gradient change due to P/D was not expected – data is in non-dimensional numbers – and hence, further investigation and improvements through additional experiment will be needed.

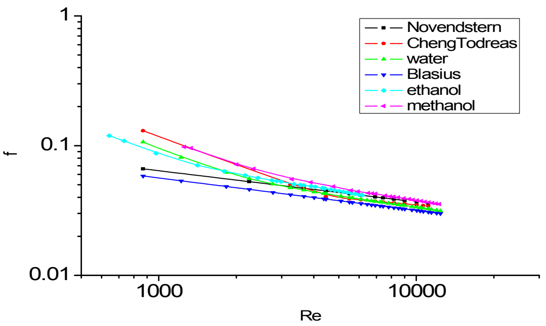

Fig. 4 Result of P/D=1.1667 (3 fluids and previous studies)

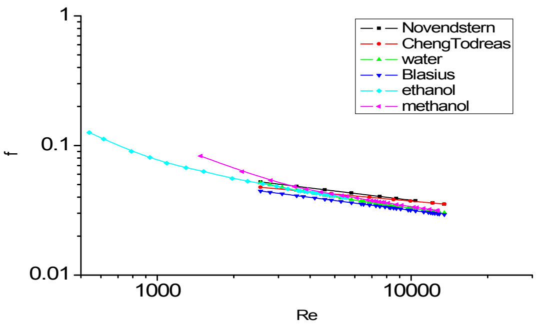

Fig. 5 Result of P/D=1.2 (3 fluids and previous studies)

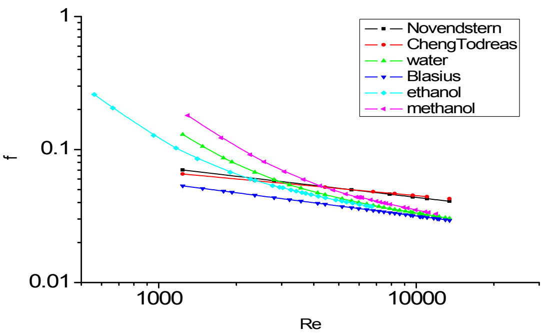

Fig. 6 Result of P/D=1.1667 (3 fluids and previous studies)

3.2 Pressure drop correlation

The pressure drop correlation for each case can be suggested by using the following equation.

$$f = \frac{a}{\mathrm{Re}^b} \quad (1)$$

The constant *a* and *b* were controlled(Fig. 7) and the most optimum curve from correlation fitting was selected(Table 3).

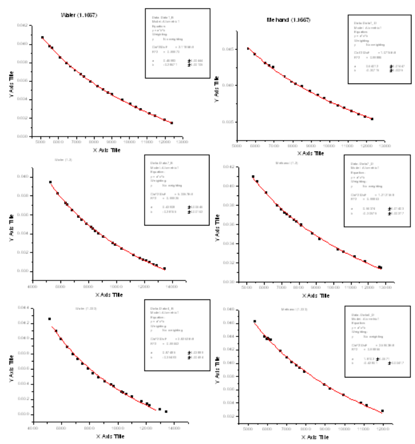

Fig. 7 Correlation fitting graph of ΔP data

Table 3 Constant value for various experiment conditions

	P/D	*a*	*b*
Water	1.167	0.47	0.29
	1.2	0.43	0.28
	1.333	0.87	0.35
Methanol	1.167	0.64	0.31
	1.2	0.56	0.31
	1.333	1.8	0.43

4. Conclusion

The hydraulic characteristic of wire-wrapped 19 rod bundle was investigated by experimental work with various fluids and geometry. The focus was on the P/D effect and viscosity influence that previous studies overlooked. The results partly agreed with the previous studies. For improvements, further experiment will be needed.

REFERENCES

[1] E. H. Novendstern, Turbulent flow pressure drop model for fuel rod assemblies utilizing a helical wire-wrap spacer system, Nuclear Engineering and Design, Vol. 22, Issue 1, pp. 28-42, 1972.
[2] S. Cheng and N. E. Todreas, Hydrodynamic models and correlations for bare and wire-wrapped hexagonal rod bundles – Bundle friction factor, subchannel friction factors and mixing parameters, Nuclear Engineering and Design, Vol. 92, pp. 227-251, 1986.
[3] KAERI, A study on the supporting structure for SFR and multi-dimensional pool model development, KAERI CM-1581/2011.