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The Heat Transfer Characteristics in the Radially Separated DTBSG

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1. Introduction

In a LMR development, the sodium-water reaction is a critical problem. To resolve it, many design concepts have been proposed. Recently, KAERI suggested a DTBSG concept with various structures and the analyses for the performance and 1-dimension sizing are being studied [1]. However, throughout this analysis, multidimensional effects were not considered, so multidimensional studies are needed in view of the experimental and CFD analysis. There are 4 DTBSG types based on their shapes. In this study the radially separated DTBSG(RSDTBSG) is chosen and analyzed and heat transfer characteristics of RSDTBSG are studied experimentally and numerically.

2. Experiments and Numerical analysis

2.1 Experiments

RSDTBSG is constructed with three components. There are two helical coil tubes for hot and cold fluids and a shell for a medium fluid. This configuration is shown in Fig.1 and the region for analysis is shown in Fig. 2.

In a hot tube bundle region φ6mm helical coiled tubes are located in the shell with 4,4,5,6 tubes in each row and a cold tube bundle region is consist of tubes which located with 8, 8 and 9 tubes in each row. The other dimensions are depicted in Fig. 2. Thermocouples for the shell side temperature measurement are located in the tube bundle area at intervals of 40mm in the z direction. For the circumstantial temperature distribution measurement, thermocouple groups are installed at intervals of 120°. To mimic a liquid metal flow, woodmetal is adopted in shell side, and subcooled water flows through in the tubes.

Experiments were performed at 30 conditions to resolve the effects of a thermal capacity ratio for each fluid and heat transfer characteristics as shown in table 1. These conditions are classified in three categories by inlet mass flow condition. The reference case is the number 1-1, in group 2 mass flow rate for each tube and

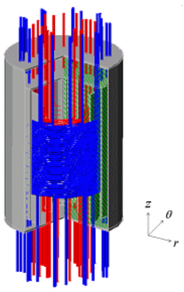

Fig.1 Configuration of RSDTBSG

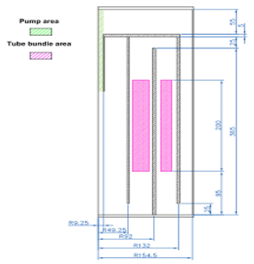

Fig. 2 Schematic of the analysis region

Table. 1 DTBSG experiment conditions

No.	Hot tube Inlet Pressure (kg/cm^2)	Hot tube Inlet Temp. (℃)	Hot tube Outlet Temp. (℃)	Hot tube Flow rate (l/min)	Shell Flow rate (l/min)	Cold tube Inlet Pressure (kg/cm^2)	Cold tube Inlet Temp (℃)	Cold tube Outlet Temp (℃)	Cold tube Flow rate (l/min)
1-1	4.51	150.41	126.29	7.838	18.56	1.86	101.35	125.69	7.897
2-1	5.014	150.18	141.89	3.961	1.24	1.194	99.29	106.93	4.009
2-2	4.63	150.03	131.42	5.894	7.18	1.598	101.43	119.79	5.850
2-3	4.506	150.22	126.54	7.706	13.11	1.602	99.87	122.12	7.727
2-4	4.494	150.00	126.32	9.516	19.05	1.642	101.05	124.09	9.544
2-5	4.374	150.83	127.41	11.313	24.99	1.598	100.08	123.24	11.381
2-6	4.336	150.90	127.30	13.177	30.93	1.602	101.36	123.46	13.269
3-1	4.47	150.33	145.10	7.747	1.24	1.11	100.00	104.44	7.875
3-2	5.81	150.11	133.78	7.840	7.18	0.81	100.05	114.92	7.851
3-3	6.03	150.59	127.31	7.815	13.11	1.20	100.33	122.88	7.777
3-4	6.22	150.24	125.41	7.754	19.05	1.48	100.34	124.89	7.738
3-5	6.86	149.87	124.45	7.820	24.99	1.49	100.22	125.42	7.773
3-6	7.19	150.24	124.44	7.778	30.93	1.43	99.69	124.94	7.735
4-1	9.29	149.26	116.65	3.993	18.56	0.98	100.03	116.83	7.723
4-2	7.85	149.82	122.01	5.858	18.56	1.20	101.93	121.31	7.761
4-3	6.41	149.93	125.75	7.645	18.56	1.30	100.48	123.25	7.759
4-4	6.10	149.75	129.20	9.551	18.56	1.48	100.37	125.05	7.802
4-5	6.80	149.88	132.43	11.332	18.56	1.52	100.20	125.95	7.801
4-6	7.06	150.33	134.58	13.221	18.56	1.61	99.65	126.43	7.863
5-1	6.32	150.18	132.44	7.768	18.56	2.21	100.07	134.00	4.020
5-2	6.86	150.54	129.44	7.768	18.56	2.31	99.64	130.03	5.746
5-3	7.27	150.34	126.59	7.807	18.56	1.56	99.61	125.00	7.712
5-4	7.73	149.81	125.05	7.767	18.56	1.33	100.00	121.61	9.421
5-5	8.30	149.69	123.54	7.786	18.56	1.03	99.95	118.20	11.363
5-6	8.49	149.31	122.99	7.783	18.56	0.98	100.27	116.42	13.210

shell are varied, in group 3 medium mass flow rate is growing up, in group 4 mass flow rate of hot tube is increased and in group5 mass flow rate of cold tubes is done.

Experiment has a 4.5% heat balance error in average for the hot and cold tubes heat transfer rate.

2.3 Numerical analysis

In this paper, to simulate the flow in the DTBSG COMMIX-AR/P code was modified. From the assumption of ax symmetric, 2D analysis is considered and the tube bundle area is modeled as a thermal and force construction. For the tube bundle, 1-dimensional and 1-directional flows are assumed. Because the tubes are divided at the inlet and outlet plenums, pressure drop in each hot and cold tube is same. That is,

$$w = \sum w_i \tag{5}$$

$$p_{inlet} = p_{i,inlet} \tag{6}$$

$$p_{outlet} = p_{i,outlet} \tag{7}$$

Tube bundle is modeled by the Kalish and Dwyer correlation [2] and by the Gunter-Shaw correlation [3] for the pressure drop model. Also, the inner flows in the

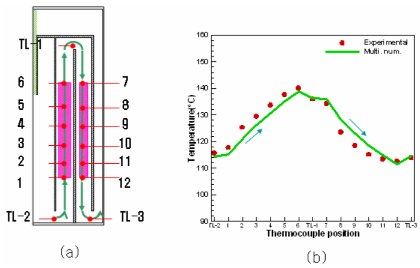

Fig. 3 Temperature distribution in the shell
(a) Thermocouple position
(b) Temperature comparison for experiment and analysis

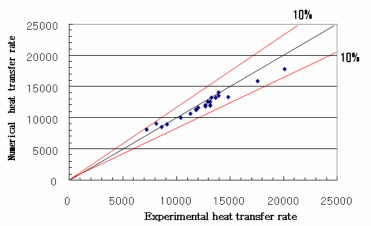

Fig. 4 Comparisons of heat transfer rate

tubes are modeled by the Mori-Nakayama correlation [4] for the pressure drop and heater transfer.

2.4 Results and Discussion.

Numerical analysis code overestimates the heat transfer with comparison to experiment owing to the simplification of modeling. Temperature profile along the z direction has a + curvature in Fig. 3 in hot tube region in contrary to the cold region due to the effect of the thermal capacity ratio for each fluid. In average, the temperature difference for experiment and numerical analysis has 11% error. In Fig. 3 an abrupt temperature variation is measured. These effects illustrate that the flow in the shell side across the tube bundle is not fully developed and in this area the local heat transfer coefficient is varied along the flow. In the heat transfer modeling of the tube bundle in the shell side, the application of a length averaged Nusselt number does not simulate the effects. Almost cases, heat transfer rate difference is very low as shown in Fig.4. But difficulties of measurements of flow rate gave the errors in the heat rate for the low heat transfer rate. From this result numerical analysis code used in this analysis is good for the analysis of DTBSG.

In Fig. 5 temperature distribution and velocity profile in the shell are shown. The velocity of the area near to shroud is low due to the friction of shell but is very uniform in the tube bundle region. The coiling effects of helical coil tube affect the distribution of flow rate in the tubes. The secondary flow effect is related to the tube curvature and interior tube flow is affected by secondary flow. This increase of friction makes the reduction of flow rate in interior tube in shown Fig. 5. Also because heat transfer rate follows the mass flow rate, heat transfer rate is increased in proportional to the tube curvature and mass flow rate. As the experimental conditions, tube side mass flow rate increase gives the total heat transfer rate growth.

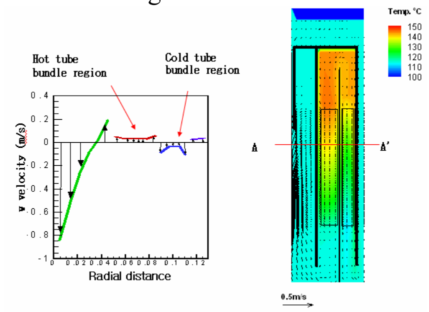

Fig. 5 Temperature and velocity field in the shell

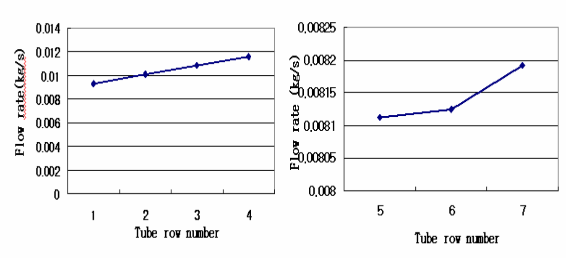

Fig. 6 Distribution of mass flow rate for each tube

But the medium flow increase does not mean the increase of overall heat transfer rate owing to the heat transfer coefficient variation between tubes and medium fluid. Lager mass flow rate in the shell make heat transfer more activated and the temperature difference between two fluid decreased.

3. Conclusion

From this study Analysis code for RSDTBSG is developed. And with the experiment, verification is performed. This analysis code predicts the temperature distribution and the heat transfer rate with error 11%. So this code will be applicable for the design of radially separated DTBSG.

Acknowledgement

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