The Heat Transfer Characteristics in Helical Tube Bundle for DTBSG Concepts

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1. Introduction

In LMR development, Sodium-water reaction is very a critical problem. To resolve it, many design concepts have been proposed. Recently, KAERI suggested DTBSG concept with various structures and analysis for performance and 1-dimension sizing are studied[1]. However, throughout this analysis, multidimensional effects are not considered, so multidimensional studies are needed in view of experimental and CFD analysis. Basically, DTBSG concept is a combination of 2 kinds of heat exchanger system, hot tube and cold shell system (reverse 2 components system), and cold tube and hot shell system (normal 2 components system). In this paper, characteristics of heat transfer in basic two configurations with 2 fluid components are studied experimentally and numerically.

2. Experiments and Numerical analysis

2.1 Experiments

To investigate the effects of heat transfer in DTBSG basically, two configurations are considered. First, hot fluid flows in the tube and cold fluid flows in the shell. This configuration named as normal 2 components system. In vice versa, Reverse 2 components system. The shell side of test section has φ178mm outer cylinder and φ100mm inner cylinder and φ6mm helical coiled tubes are located in the shell with 4,4,5,6 tubes in each row. Tube bundle area has height of 206mm. and tube length is 1.4m. The other dimensions are depicted in Fig. 1. Thermocouples for shell side temperature measurement are located in tube bundle area at interval 40mm in z direction. For radial temperature distribution measurement, thermocouple groups are installed at interval 120°. To mimic liquid metal flow, woodmetal is adopted in shell side, and subcooled water is flown in the tubes.

In prior to experiment, thermal and hydraulic properties are measured and formulated by

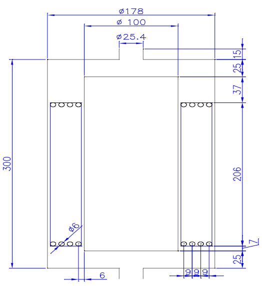


Figure 1. Test section for 2 components heat exchanger system

Table 1. 2 components normal system experimental conditions

2 components Normal	Tube side (water)			shell (woodmetal)	
	Inlet Pressure (Mpa)	mass flow rate (kg/s)	Inlet Temp (℃)	Inlet Temp.(℃)	mass flow rate(kg/s)
Exp1-1	0.614	0.08366	150.08	111.03	2.892
Exp2-1	0.800	0.02964	150.46	111.12	0.999
Exp2-2	0.740	0.04639	150.65	111.10	1.589
Exp2-3	0.690	0.06327	149.65	111.19	2.188
Exp2-4	0.614	0.08366	150.08	111.03	2.892
Exp3-1	0.689	0.07421	150.78	111.18	2.892
Exp3-2	0.564	0.13491	150.23	111.21	2.892
Exp3-3	0.556	0.19626	150.32	111.20	2.892
Exp3-4	0.544	0.25998	150.25	111.05	2.892
Exp4-1	0.592	0.08253	149.93	111.07	0.523
Exp4-2	0.661	0.08255	150.02	111.18	1.351
Exp4-3	0.677	0.08249	149.93	111.12	2.416
Exp4-4	0.681	0.08251	150.78	111.04	2.892

Table 2. 2 components reverse system experimental conditions

2 components, Reverse	Tube (water)			shell (woodmetal)	
	Inlet Pressure (Mpa)	mass flow rate (kg/s)	Inlet Temp.(℃)	Inlet Temp..(℃)	mass flow rate(kg/s)
Exp1-1	0.282	0.08679	111.01	150.23	2.892
Exp2-1	0.543	0.03066	111.06	150.38	0.999
Exp2-2	0.536	0.04824	111.12	150.45	1.589
Exp2-3	0.513	0.06579	111.05	150.30	2.188
Exp2-4	0.282	0.08679	111.01	150.23	2.892
Exp3-1	0.308	0.07698	111.06	150.00	2.892
Exp3-2	0.277	0.13970	111.18	150.50	2.892
Exp3-3	0.266	0.20331	111.15	150.77	2.892
Exp3-4	0.244	0.26933	111.00	150.38	2.892
Exp4-1	0.493	0.08561	111.01	150.04	0.523
Exp4-2	0.491	0.08581	111.07	150.59	1.351
Exp4-3	0.504	0.08544	111.19	150.35	2.416
Exp4-4	0.294	0.08547	111.13	150.22	2.892

$$c_p = 164(J/kgK) \quad (1)$$

$$\rho = 9510(kg/m^3) \quad (2)$$

$$k = 3.61 + 0.003T(W/mK) \quad (3)$$

$$\mu = 7.3\times10^{-3} - 0.01\times10^{-3}T(cP) \quad (4)$$

where T is temperature of shell. Experiments are performed by 12 inlet conditions to resolve the effects of thermal capacity ratio for each system shown in table 1 and table 2. For each case, heat balance errors are calculated within 20% with measured thermal and hydraulic properties. And in radial direction, with temperature's low deviation, the axisymmetric assumption is valid for these systems.

2.3 Numerical analysis

In this paper, to simulate the flow in these 2 components heat exchanger, COMMIX-AR/P code is modified. From assumption of axisymmetric, 2D analysis is considered and tube bundle area is modeled thermal and force construction. For tube bundle, 1-dimensional and 1-directional flow is assumed. Because the tubes are divided at inlet and outlet plenum, pressure drop in each tube are same. That is,

$$w = \sum w_i \quad (5)$$

$$p_{inlet} = p_{i,inlet} \quad (6)$$

$$p_{outlet} = p_{i,outlet} \qquad (7)$$

Tube bundle are modeled by Kalish and Dwyer correlation [2] and modeled by Gunter-Shaw correlation [3] for pressure drop model. Also, the inner flows in tubes are modeled by Mori-Nakayama correlation [4] for pressure drop and heater transfer.

2.4 Results and Discussion.

Physically some case in 2 component reverse system is not solved for that in these cases pressure drop is not found in flow direction. For a comparison of analysis, 1D analysis code (ISGA) which is originated from sizing code for DTBSG was referred[5]. From Figure 2 and 3, 2D analysis code predict more accurate heat transfer rate then 1D code does. But these two analysis code overestimate the heat transfer. Temperature profile along the z direction has + curvature in Fig. 4 in contrary to Fig. 5 due to the thermal capacity ratio of two fluids. In Fig.4 and Fig.5, abrupt temperature variation is measured. These effects illustrate that the flow in shell side across the tube bundle is not fully developed and in this area local heat transfer coefficient is varied along the flow. In the heat transfer modeling of tube bundle in shell side, the application of length averaged Nusselt number does not simulate the effects. In reverse 2 components system, at shell side near the tube inlet, lowest temperature is shown and outlet temperature is higher then this temperature. The woodmetal flow near to the wall has minor heat exchange effects and the temperature is retained in shown in Fig.6(a). After woodmetal being mixed throughout the tube region, the outlet temperature is higher and shown in Fig. 4. In normal 2 components system, as like reverse 2 components system, wood metal temperature near to tube inlet region is higher then outlet temperature and shown in Fig 6(a).

3. Conclusion

From this study, 2D analysis code gives the more accurate temperature data in comparison to ISGA code and these two code overestimate the heat transfer rate.

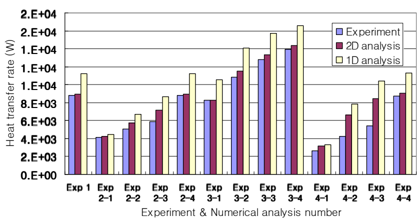


Figure 2. 2 component normal system heat transfer rate

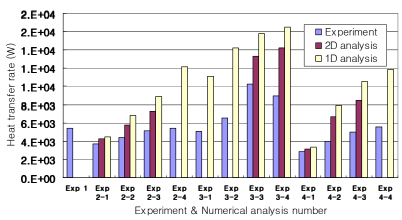


Figure 3. 2components reverse system heat transfer rate

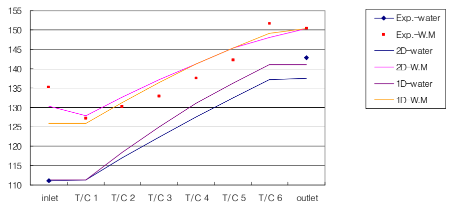


Figure 4. Temperature comparison for 2 component reverse case 2-3

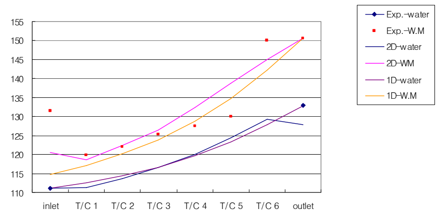
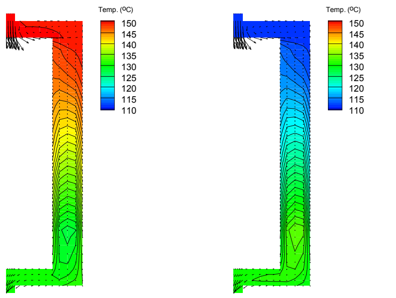


Figure 5. Temperature comparison for 2 components reverse case 4-2



(a) (b)

Figure 6. Shell side temperature distribution
(a) 2 component reverse system
(b) 2 component normal system

And multidimensional effects are investigated which is not shown in 1D analysis. To describe the temperature distribution of tube bundle region more precisely, the study of local Nusselt number is needed.

Acknowledgement

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