Effects of sodium mal-distribution on AHX thermal characteristics

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1. Introduction

The uniform distribution of a refrigerant is very important to the heat transfer performance of heat exchangers [1]. In particular, for a sodium-to-air heat exchanger (AHX), transferring heat from high temperature liquid metal to air, a mal-distribution of the refrigerant can cause degradation of heat transfer performance or even failure of system by unexpected sodium solidification in flow paths[2,3]. However, there are little quantitative studies about the effect of mal-distribution on thermal characteristics with liquid metal as a coolant.

This paper discusses the effects of mal-distribution on heat transfer performance and cold-spot temperature of liquid sodium coolant at the branched tube outlet in AHX unit. The technical issues, which need to be verified for the robust AHX design regarding uniform flow distribution inside heat transfer sodium tubes, are tentatively proposed as well.

2. Methods

Fig. 1 shows a schematic view of a sodium-to-air heat exchanger (AHX) of STELLA (Sodium Test Loop for Safety Simulation and Assessment) [4], a shell-and-tube type counter flow heat exchanger. Liquid sodium and air are introduced into the tube- and shell-side, respectively. The sodium coolant is distributed into 36 branched helical-shaped tubes and the intake air temperature is nominally set as 25 ℃. Table I shows the tested conditions to examine the effects of variables (air flow rate, sodium flow rate, and sodium inflow temperature) on the heat transfer performance and the sodium outlet temperature with varying the degree of mal-distribution. The heat removal rate and the outlet temperature of each branched tube are calculated, similar to Kim et al [4].

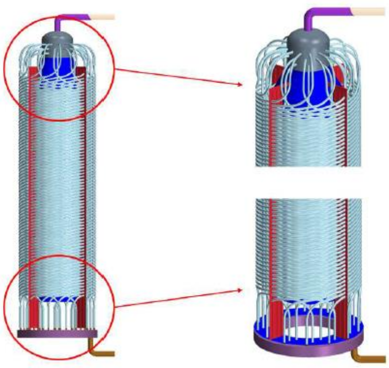

Fig. 1. Schematic view of AHX of STELLA [4].

Table I: Tested condition

No.	Air (Shell) Flow rate (W_{air}, kg/s)	Sodium (Tube) Flow rate (W_{Na}, kg/s)	Sodium (Tube) Inlet Temp. ($T_{Na,inlet}$, ℃)	Effect
1	4.5	4.5	400	Reference
2	4.5	4.5	200	$T_{Na,inlet}$
3	4.5	2.5	400	W_{Na}
4	2.5	4.5	400	W_{air}
5	2.5	4.5	200	-
6	2.5	2.5	400	-

The flow rates of each branched tubes are shown in Fig. 2. The flow rate of each tube belongs to distinguished two flow conditions (i.e. the high or low flow rate) and all tubes are categorized into high and low flow rate tubes. For high flow rate tubes, the flow rate is 20% higher than the evenly distributed flow rate to 36 branched tubes. Then, rest of flow is evenly distributed to the remained tubes (i.e. the low flow rate tube). The degree of mal-distribution is adjusted by changing the number of high flow rate tubes.

3. Results

Fig. 3 shows the effects of sodium mal-distribution on the heat removal rate. The Y-axis is the total heat removal rate of AHX, and the X-axis is the number of high flow rate tubes, i.e., the degree of mal-distribution. As shown in Fig. 3, the total heat removal rate decreases with an increase in the degree of mal-distribution but there are no remarkable changes (Max. 6.4%). However, the outlet temperature difference between high and low flow rate tubes ($\Delta T_{Na,out}$) considerably increases as the degree of mal-distribution increases, as shown in Fig. 4. In particular, for case 3, that the total sodium flow rate decreases, the outlet temperature difference is

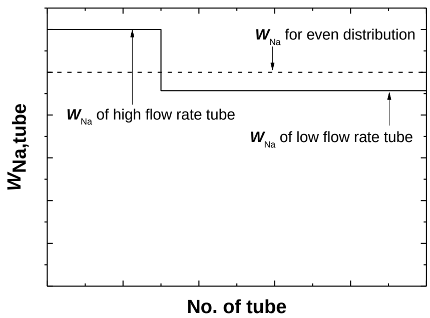

Fig. 2. Mal-distributed flow rate

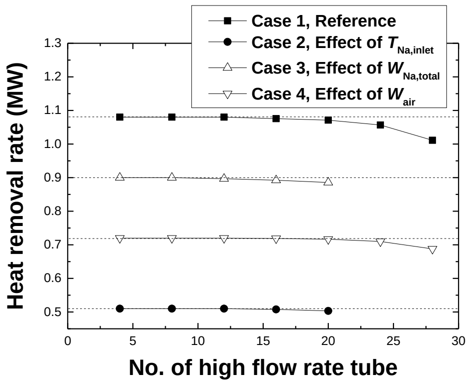

Fig. 3. Effects of sodium mal-distribution on heat removal rate.

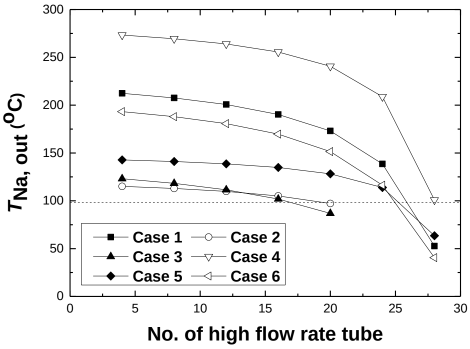

Fig. 5. Effects of sodium mal-distribution on outlet sodium temperature of low flow rate tubes.

comparable to reference condition, case 1, although the heat transfer rate is smaller than that. It is inferred that the large difference of the outlet temperature with a small change of the heat transfer performance is caused by the characteristics of liquid metal, low Prandtl number. In other words, the outlet temperature of low level tubes largely decreases because of the high heat transfer rate, however, the total heat removal rate difference is not remarkable because of a relatively low thermal capacity. Fig. 5 shows the outlet temperature of low flow rate tubes. As expected, the outlet temperature decreases as the degree of mal-distribution increases. Furthermore, for some conditions, it reaches the sodium solidification temperature that can lead to a system failure.

4. Conclusion

In this paper, the effects of sodium mal-distribution on heat removal rate and sodium outlet temperature at the branched tubes of the AHX were quantitatively investigated and the following features were tentatively obtained

- The effect of mal-distribution on the total heat removal rate is not significant.
- The outlet temperature difference between low and high flow rate tubes ($\Delta T_{NA,out}$) increases as the degree of mal-distribution increases.
- In some conditions, the outlet temperature of branched tube reaches the sodium solidification temperature when the degree of mal-distribution increases.

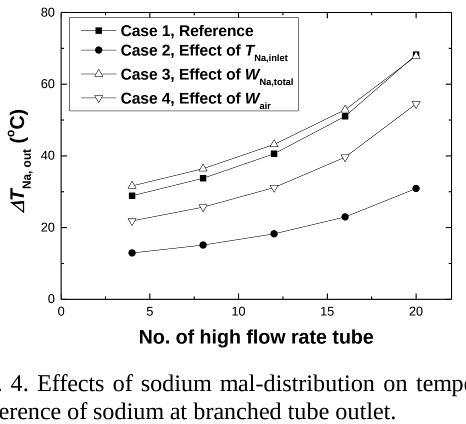

Fig. 4. Effects of sodium mal-distribution on temperature difference of sodium at branched tube outlet.

An important point is that the sodium mal-distribution would finally result in a system failure by unexpected sodium solidification. Therefore, the studies about the improvement of coolant distribution at the AHX unit need to be conducted by carefully considering characteristics of liquid metal coolant as a future work.

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