Preliminary Analysis of PGSFR ADHRS Heat Exchanger Using STELLA-2 Facility

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1. Introduction

The STELLA-2 facility has finished its basic design and is scheduled to be constructed starting from 2017. The main purpose of the facility is to investigate the integral effect of the PGSFR Decay Heat Removal System (DHRS) interaction with Primary Heat Transfer System (PHTS) [1]. The DHX of DHRS is a shell-and-tube type counter-current flow sodium-to-sodium heat exchanger. Each unit is designed for rated thermal power of 2.5 MWt, which is corresponding to the nominal design capacity of a single passive decay heat removal system (PDHRS) and active decay heat removal system (ADHRS) loops, such that the system heat load during the temperature transient can be removed. The ADHRS consist of two independent loops and in each loop there are one sodium-to-sodium decay heat exchanger (DHX), and one forced-draft sodium-to-air heat exchanger (FHX) as shown in Fig.1.

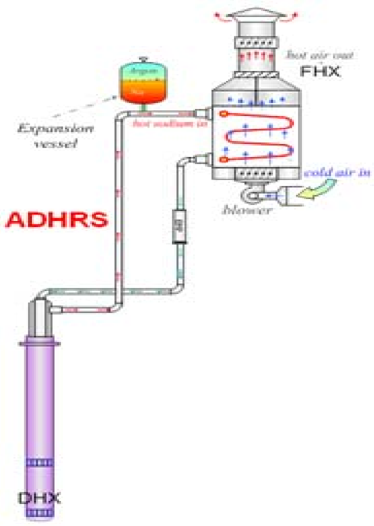

Fig. 1. Schematic diagram of active decay heat removal system [1].

In this paper, a preliminary analysis of the performance of the ADHRS loop was performed using the MARS-LMR code [2] to analyze the design value of the DHX and FHX heat exchanger and to support its basic design with the STELLA-2 facility.

2. Methods and Results

2.1 Heat Transfer Models for ADHRS

Sodium-air heat exchanger bundle type needs two correlations for tube and shell sides. The convective heat transfer correlations in the tube and shell side were used in MARS-LMR with Aoki's correlation [3] and Zukauskas correlation [4], respectively.

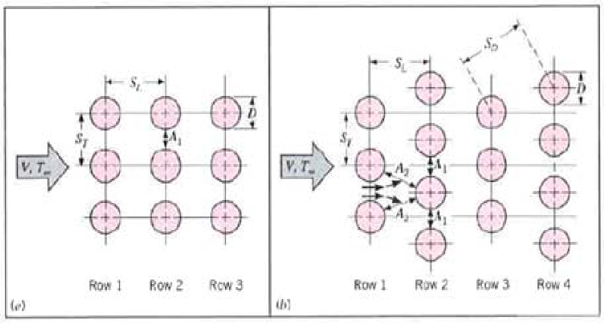

Fig. 2. Tube arrangement in a bank: (a)in-lined (b)staggered [5].

The tube rows of a bank can be either in-lined or staggered in the direction of the fluid flow. The configuration is characterized by the tube diameter, D and by the transverse pitch, S_T and longitudinal pitch S_L measured between tube centers as shown in Fig. 2. For large S_L, the influence of upstream rows decrease, and heat transfer in the downstream rows is not enhanced. For this reason, operation of in-lined tube bank with $S_T / S_L < 0.7$ is undesirable. For the staggered tube array, the path of main flow is more tortuous, and mixing of the cross-flowing fluid is increased relative to the in-lined tube arrangement. In general, heat transfer enhancement is favored by the more tortuous flow of a staggered arrangement, particularly for small Reynolds numbers (Re < 100) [5].

2.2 MARS-LMR Modeling of the ADHRS

The MARS-LMR code has used for a preliminary analysis of the ADHRS. This code is developed to simulate the sodium thermal-hydraulic and neutronic behavior such as reactivity feedbacks for liquid metal cooled fast reactor [2].

Table. 1. STELLA-2 DHX Design Data [1].

Parameter	DHX		Ideal scale ratio
	PGSFR	Model	
Heat transfer rate, Q (kWt)	2.5×10^3	44.73	0.018

Heat transfer Area (m2)		13.44	0.232	0.018
Pitch to Diameter ratio (P/D)		1.5	1.5	P
Effective tube length (m)		1.733	0.356	0.2
Number of tubes (EA)		114	12	N/A
Heat transfer Tube	ID (m)	0.0184	0.014	N/A
	OD (m)	0.0217	0.0173	N/A
	thck. (mm)	1.65	1.65	N/A
Flow rate (kg/s)	tube-side	17.54	0.3140	0.018
	shell-side	12.76	0.2280	0.018

Table. 2. STELLA-2 FHX Design Data [1].

Parameter		FHX		Ideal scale ratio
		PGSFR	Model	
Heat transfer rate, Q (kWt)		2.5×10^3	44.06	0.018
Heat transfer Area with Fin (m^2)		656.34	11.642	0.018
$(P/D)_L$ & $(P/D)_T$		2.05 & 2.5	2.05 & 2.5	P
Finned tube length, total (m)		8.0	1.6	0.2
Number of tubes (EA)		96	18	N/A
Fin height (mm)		15.0	8.5	N/A
Fin thickness (mm)		1.5	0.8	N/A
Heat transfer Tube	ID (m)	0.0307	0.0149	N/A
	OD (m)	0.034	0.0191	N/A
	thck. (mm)	1.65	2.1	N/A
Flow rate (kg/s)	tube-side	17.54	0.3138	0.018
	shell-side	13.63	0.2657	0.018

Using information described in Table 1 and 2, ADHRS was modeled for MARS-LMR code. Fig. 3 shows the MARS-LMR nodalization scheme for the ADHRS, which includes the DHX, hot-leg pipe, cold-leg pipe, a sodium expansion tank, and FHX.

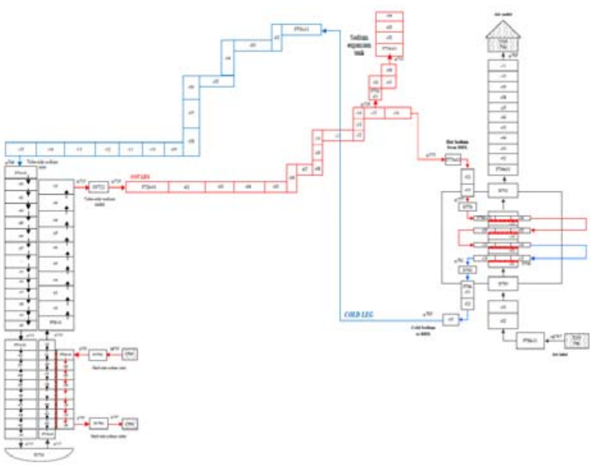

Fig. 3. MARS-LMR nodalization scheme for the ADHRS.

2.3 Results of MARS-LMR

Table 3 shows a comparison of the major parameters of the design value and MARS-LMR calculation results of the ADHRS at normal operation condition. The calculation results of the ADHRS showed good agreement with the values of the basic design. The calculation result of the outlet temperature of the shell-side of the FHX was slightly deviated compared to the design value. The difference error was about 5.5%.

Table. 3. Comparison of the results of MARS-LMR and design values.

Parameter		Design	MARS-LMR
Power		44.06	44.2
Power error (%)		-	0.32
FHX Tube	Inlet temperature	334.6	334.6
	Outlet temperature	227.6	224.65
	dt	107	109.95
	dt Error (%)	-	2.76
FHX Shell	Inlet temperature	40.0	40.0
	Outlet temperature	211.4	201.97
	dt	171.4	161.97
	dt Error (%)	-	-5.50

3. Conclusions

A preliminary analysis of the performance of the ADHRS loop was performed using the MARS-LMR code to analyze the design value of the DHX and FHX heat exchanger and to support its basic design with the STELLA-2 facility. The results of code calculation were in good agreement compared to the design values.

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