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Preliminary Analysis of Heat Exchanger in STELLA-2 PDHRS using MARS-LMR code

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1. Introduction

The STELLA-2 (Sodium Integral Effect Test for Safety Simulation and Assessment) started its specific design this year and is scheduled to be constructed starting from 2017. The main purpose of the facility is to investigate the performance of the PGSFR Safety System, especially the interaction of Decay Heat Removal System (DHRS) with the Primary Heat Transfer System (PHTS) [1]. The DHRS in STELLA-2 has two kinds of decay heat removal types. The one is active type called a passive decay heat removal system (PDHRS) and the other is an active decay heat removal system (ADHRS). The DHRS is consisted of two loops of PDHRS and ADHRS, respectively. The ADHRS has two kinds of heat exchangers which are Sodium-to sodium decay heat exchanger (DHX) and helical-type sodium-to-air heat exchanger (AHX), respectively. The ADHRS performs decay heat removal of cold pool in reactor vessel after shutdown [1]. Figure 1 shows schematic of PDHRS in STELLA-2.

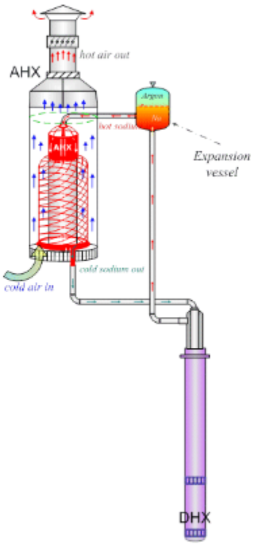

Fig. 1. Schematic diagram of passive decay heat removal system [1].

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

2. Methods and Results

2.1 Heat Transfer Models for PDHRS

The DHX is a shell and straight tube type heat exchanger. Heat transfer models for tube and shell side of DHX are apply for Aoki's correlation [3] and Graber-Reiger's correlation [4], respectively, in MARS-LMR. However, the AHX is a helical type shell and in-lined tube heat exchanger. 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 [5], respectively.

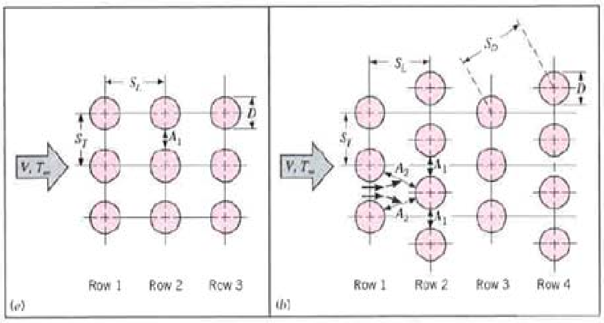

Fig. 2. Tube bundle arrangement: (a)in-lined (b)staggered [6].

The rows of tube bundle can be either in-lined or staggered in the direction of the fluid flow. The influence of tube bundle 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. Flow around the tubes in first row of a tube bundle is similar to that for a single cylinder in cross flow. Correspondingly, the heat transfer coefficient for a tube in the first row is approximately equal to that for a single tube in cross flow. For downstream rows, flow conditions depend strongly on the tube arrangement. In-lined tubes beyond the first row reside in the wakes of upstream tubes and for moderate values of S_L convection coefficients associated with downstream rows enhanced by mixing, or tabulation of the flow. Typically, the convection coefficient of a row increases with increasing row number until approximately the fifth row. For large S_L, the influence of upstream row decrease, and heat transfer in the downstream rows in not enhanced. For this reason, operation of in-lined tube with S_T/S_L <0.7 is undesirable [6].

2.2 MARS-LMR Modeling of the ADHRS

The MARS-LMR code is developed to analyze the safety and the sodium thermal-hydraulic and neutronic behavior such reactivity feedback for liquid metal reactor [2]. Using MARS-LMR code, preliminary analysis of heat exchanger in PDHRS is performed.

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

Parameter		DHX		Ideal scale ratio
		PGSFR	Model	
Heat transfer rate, Q (kWt)		$2.5x10^3$	44.73	0.018
Heat transfer Area (m^2)		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 AHX Design Data [1].

Parameter		AHX		Ideal scale ratio
		PGSFR	Model	
Heat transfer rate, Q (kWt)		$2.5x10^3$	43.56	0.018
Heat transfer Area (m^2)		48.27	43.31	1.0
Tube Arrangement		Helical coil type		P
$(P/D)_L$ & $(P/D)_T$		1.71 & 2.5	1.71 & 2.5	1.0
Tube bundle height (m)		4.13	0.826	0.2
Number of tubes (EA)		190	42	N/A
Tube inclined angle (degree)		9.9	9.8	1.0
Heat transfer Tube	ID (m)	0.0307	0.0114	N/A
	OD (m)	0.034	0.0138	N/A
	thck. (mm)	1.65	1.2	N/A
Flow rate (kg/s)	tube-side	17.54	0.3138	0.018
	shell-side	10.65	0.1950	0.018

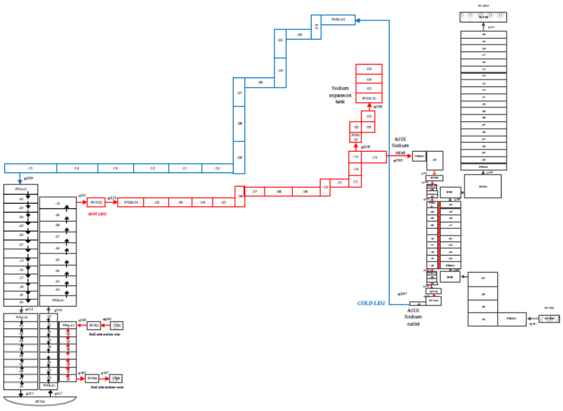

Fig. 3. MARS-LMR nodalization scheme for the PDHRS.

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

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 DHX in the PDHRS at normal operation condition. The calculation results of the DHX showed good agreement with the values of the basic design. The calculation results of MARS-LMR expected less than design value. Power, tube side △T and shell side △T difference is -2.84%, -0.42% and -0.76%, respectively.

Table. 3. Comparison of the MARS-LMR results with design value for DHX.

Parameter		Design	MARS-LMR
Power (kW)		44.73	43.46
Power difference (%)		-	-2.84
Tube side	Inlet temperature (℃)	226.2	226.2
	Outlet temperature (℃)	334.6	334.15
	△T (℃)	108.4	107.95
	△T difference (%)	-	-0.42
Shell side	Inlet temperature (℃)	390.0	390.0
	Outlet temperature (℃)	239.7	240.84
	△T (℃)	150.3	149.16
	△T difference (%)	-	-0.76

Table 4 shows a comparison of the MARS-LMR results with design value for AHX in PDHRS at normal operation condition. Power, tube side △T and shell side △T difference is -7.2%, -4.77% and -12.51%, respectively. The results of MARS-LMR for sodium to air heat transfer under-predicted by comparison with design value.

Table 4. Comparison of the MARS-LMR results with design value for AHX

Parameter		Design	MARS-LMR
Power (kW)		43.56	41.5
Power difference (%)		-	-4.72
Tube side	Inlet temperature (℃)	334.6	334.6
	Outlet temperature (℃)	226.2	231.38
	△T (℃)	108.4	103.22
	△T difference (%)	-	-4.77
Shell side	Inlet temperature (℃)	40.0	40.0
	Outlet temperature (℃)	279.0	249.1
	△T (℃)	239.0	203.1
	△T difference (%)	-	-12.51

3. Conclusions

A preliminary analysis of the performance of the PDHRS loop was performed using the MARS-LMR code to analyze the design value of the DHX and AHX heat exchanger and to support its basic design with the STELLA-2 facility. The results of code calculation for DHX were in good agreement compared to the design values, however, AHX results of code calculation under-predicted by comparison with design values.

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