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Assessment of helical coil heat transfer models of MARS-KS code by using experimental data from MASLWR test facility

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1. Introduction

SMART reactor which is being developed recently adopts helical coil type steam generator for producing superheated steam. This is because the helical coil imposes large centrifugal force on fluids and a resulting secondary flow distributes coolant in a periphery direction effectively within the steam generator tube with delaying dry-out phenomenon. Consequently, heat transfer improves greatly and superheat steam can be easily obtained with a relative short steam generator tube length. This heat transfer augmentation feature of the helical coil type heat exchanger compared to straight type one requires new wall-to-fluid heat transfer models and corresponding modifications were implemented on the MARS-KS thermal-hydraulic code [1]. Key features of modifications in the MARS-KS code are introduction of Mori and Nakayama [2] helical coil heat transfer correlation and modification of dry-out (static quality > 0.8) criteria for tube side of helical coil heat exchanger in addition to introduction of Zukauskas [3] heat transfer correlation for tube bundle of shell side of helical coil heat exchanger.

In spite of these modifications of the MARS-KS code, assessment of validity of these models change has not been performed thoroughly yet. Therefore, in the present study, validity of change of heat transfer models for the helical coil geometry are evaluated with reference to recent experimental data obtained from MASLWR (Multi-Application Small Light Water Reactor) test facility at Oregon State University in the US. In the following, brief introduction to the MASLWR test facility and its experimental data are given first. And then the MARS-KS code (version 002) simulation results with and without the helical coil geometry specific modifications in addition to those of RELAP5Mod3.3p3 are given and compared to the experimental data. Finally conclusion of present study is briefly given.

2. MASLWR Experimental Facility and Its Data

MASLWR experimental facility (See, Fig. 1) which is located at the Oregon State University in the US has a helical coil type steam generator similar to SMART reactor. However, unlike SMART reactor, the primary system coolant circulates naturally by buoyancy force owing to density difference of fluids. Otherwise, in SMART reactor, primary coolant circulates by electric pumps. In spite of this difference of circulation method, the introduction of the same helical coil geometry type steam generator in both of facilities makes experimental data [4] from the MASLWR facility useful for evaluating the validity of models change for helical coil heat exchanger in the MARS-KS code.

Among experimental data set of the MASLWR test facility, a steady state experiment with core power of 210kW (MASLWR-OSU-003A#10) is investigated in the present study. This is because exact heat balance between the primary and the secondary systems through heat transfer by helical coil steam generator is established under the steady state condition and as a result, it can be a good validation example of the new helical coil heat transfer modifications of the MARS-KS code. For the experiment considered, measured values for the primary system were 499K (core inlet temperature), 526K (core outlet temperature), 7.64MPa (pressurizer pressure) and 1.6kg/sec (primary mass flowrate). For the secondary system, 293K (feedwater temperature), 509K (steam outlet temperature), 1.567MPa (steam outlet pressure) and 0.076167kg/sec (secondary mass flowrate) were measured.

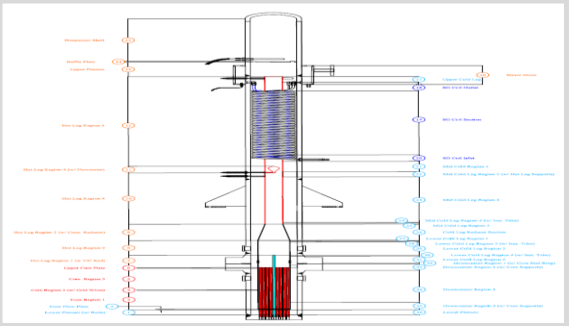

Fig. 1. MASLWR Test Facility Primary System.

3. Results of Thermal-Hydraulic Codes Simulations

Based on test facility description report [5], numerical model for codes simulation was developed by using SNAP tools of USNRC. Figure 2 shows nodalization scheme used in the present study.

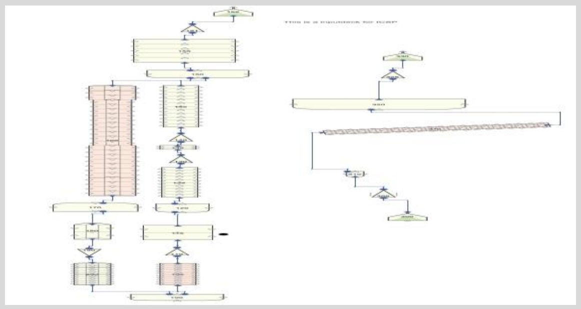

Fig. 2. Nodalization for MASLWR Test Facility.

By employing experimental data described in section 2 as boundary conditions, a steady run was performed first by RELAP5Mod3.3p3 code which has no specific modifications of models for helical coil geometry. In this simulation, the primary side mass flowrate was adjusted to measured value of 1.6kg/sec as possible as can by tuning form loss coefficients of components within the primary system. The simulation was performed until 20,000sec to reach a steady state and Fig. 3 and 4 show results of the simulation.

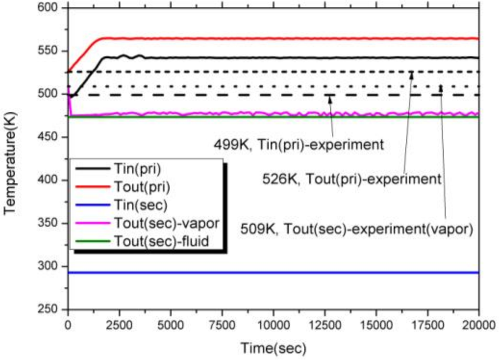

Fig. 3. Temperature trends for 1st and 2nd systems.

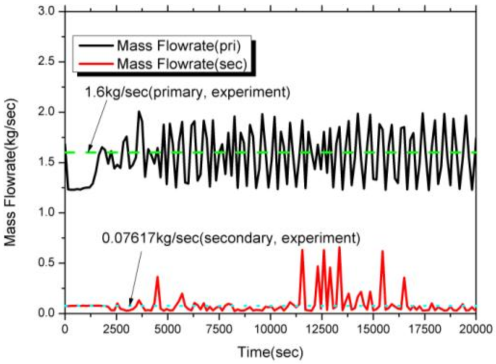

Fig. 4. Mass Flowrate trends for 1st and 2nd systems.

Calculated steady state T_{in} and T_{out} of the primary system were predicted as 542K and 564K, respectively which were much different from the experimental values of 499K and 526K. For the secondary system, steam outlet temperature was estimated to 478K with static quality value of 0.9. It was also much different from the experimental value of 509K with superheated steam state. For mass flowrates, although predicted mass flowrates seem to agree with experimental values in the average sense, oscillations were observed for both of the primary and the secondary systems. These oscillations seem to be originated from local boiling in the primary system because very high temperatures of the primary system were estimated by the code to compensate insufficient heat transfer from the primary system to the secondary system through the helical coil steam generator without helical coil specific heat transfer models. Note that saturation temperature at 7.64MPa is about 565K.

Above these findings imply heat transfer augmentation through helical coil type steam generator is indispensible for reliable calculation. To verify this concept, heat transfer area of the original helical coil was increased to 2.08 times artificially and simulations were performed with RELAP5Mod3.3p3 code and the MARS-KS code without turning on helical coil specific heat transfer models option. Simulation by the MARS-KS code using helical coil specific heat transfer models was also made with retaining the original heat transfer area. Table 1 shows summary of those calculations results. Here, T_{out1} and T_{out2} in the secondary system mean vapor temperatures at exit of helical coil tube and steam drum, respectively. The steam drum in which generated steam collects is located immediately downstream of the exit of helical coil tube. QE and QS represents equilibrium and static qualities.

The results show that steady state predictions are much improved for various runs compared to the previous RELAP code run without any oscillatory behavior in mass flowrate and temperature. Considering artificial modification of heat transfer area was not made for the simulation by the MARS-KS code using helical coil specific heat transfer models, these comparative simulation results corroborates helical coil specific heat transfer models implemented in the MARS-KS code seem to be acceptable. In spite of this favorable aspect, there still exists large deviation from experimental data in predicted value of steam outlet superheating. This fact means even the current helical coil geometry specific heat transfer model needs to be improved further or more elaborated new heat transfer model should be developed.

Table 1: Summary of Calculations Results

	Primary System			Secondary System			
	T_{in}	T_{out}	$\dot{m}$	T_{in}	T_{out1}	T_{out2}	$\dot{m}$
					QE_{out1}	QE_{out2}	
					QS_{out1}	QS_{out2}	
Exp.	**499.0**	**526.0**	**1.60**	**293**	**N/A**	**509.0**	**0.07617**
					N/A	**1.0**	
					N/A	**1.0**	
RELAP (Area*2.08)	500.7	528.5	1.59	293	506.7	491.6	0.07617
					1.026	1.026	
					0.98	0.99966	
MARS (Area*2.08)	500.9	528.8	1.59	293	509.9	492.6	0.07603
					1.034	1.026	
					0.98	0.99961	
MARS (helical) (Area*1.0)	497.0	524.9	1.60	293	494.1	492.5	0.07568
					1.026	1.026	
					0.997	0.99962	

4. Conclusion

Performance of helical coil geometry specific heat transfer models implemented in the MARS-KS code was assessed through recent experimental data of MASLWR test facility. Simulations made for a steady state experimental data show the current helical coil specific models behave reasonably but there still exists rooms for improvement of the models.

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