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Evaluation of a heat exchanger performance plugged in the RCP facility

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1. Introduction

In the Pressurized Water Reactor (PWR), Reactor Coolant Pump (RCP) play an important role in the circulation of high flow rate coolant water (10m^3/s) from steam generator to the reactor core and back to the steam generator. In order to evaluate the thermal hydraulic performance of the RCP, experiments have been performed in RCP test facility which was constructed in the Korea Atomic Energy Research Institute (KAERI). With a continuous operation of the RCP, loop temperature might be increased.

A heat exchanger was installed to control the loop temperature maintain a prescribed thermal margin.

The strong vibration from the pump might affect to the heat exchanger causing some cracks on the surface of welding tubes. Two inspection methods which are Penetration Test (PT) and Eddy Current Test (ECT) have been applied to identify the cracks. A total of 25 cracking points were found after the inspection.

The thermal hydraulic performance and vibration effect from the RCP can be analyzed using Computational Fluid Dynamics (CFD). The analysis results are presented in the paper

2. Methods and Results

Use CFD program based on The Tubular Exchanger Manufacturers Association (TEMA) code and the ASME VIII Div.1 Code. The TEMA contains a description of the type of heat exchanger and the provisions of the Regulations. And ASME VIII Div.1 is the code for the pressure vessel. The above codes are required to interpret the RCP heat exchanger.

The customer do not receive detailed information about the heat exchanger. Most manufacturers do not comment on the thermal margin and vibration analysis. Because it could be disadvantageous. The thermal margin and vibration were calculated using CFD.

2.1 Heat exchanger design

Shell and tube heat exchanger has been installed in the RCP test facility. The shell has B.E.U geometry type. The shell total length is 6.75 m with inner radius of 1.09m. U-tubes were installed inside the shell. In the primary side, the design pressure is of 18.4 MPa and the temperature is of 343°C. For the secondary side, the pressure is of 0.5 MPa and the temperature is designed of 60°C. Tube material is SA688 TP304 Weld- Tube of which the O.D is 19.05 mm and the wall thickness is 2.108 mm. The total number of U-tube is 682, the arrangement is disposed 30 degrees in order to increase the heat transfer efficiency. Flow rates of the heat exchanger are 68.8kg/s in the hot side and 240.2kg/s in the cold side.

2.2 Inspection of the U-tubes in Heat exchanger

During the RCP performance test, the water level in surge tank was slowly rising due to the secondary coolant. In the end of the RCP test, no external flow of cooling water was obtained. So it was suspicious that there might be leakages or cracks on the U-tube of heat exchanger as shown in Fig. 1. In order to inspect the crack on the U-tube surface, the shell was opened to insert the detector. Several cracking detection methods have been applied. Firstly, Penetrant Test (PT) was used to check the welding tubes and tube sheet joint. However, there was no crack has been detected. Another inspection method of Helium gas test was carried out and found 7 crack points on the tube sheet. Finally, the Eddy Current Testing (ET) was decided to adopt in order to have more accurate detection. Total of 682 points on the elbow and straight tube section have been inspected.

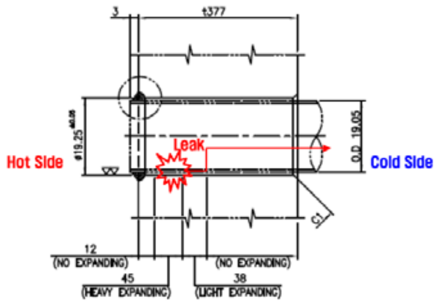

Fig. 1. Tubesheet joint Leak

As a result, 25 cracking points have been identified by using the ET inspection technique as demonstrated in Fig. 2. The weakness on the welding of the tubes which is made of SA-688 TP304 material can be easily affected by the vibration from RCP. The cracks may occur from these welding points.

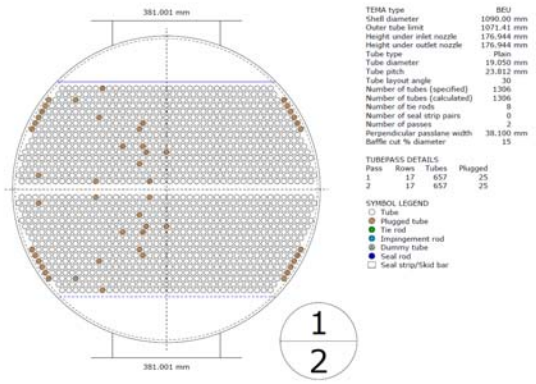

Fig. 2. Tube sheet plugging

Process Conditions		Cold Shellside		Hot Tubesude	
Fluid name					
Flow rate	(kg/s)		240.231		68.8286
Inlet/Outlet Y	(Wt frac vap.)	0.000	0.000	0.000	0.000
Inlet/Outlet T	(Deg C)	35.00	45.000	80.10	45.00
Inlet P/Avg	(kPa)	0.000	0.000	0.000	0.000
dP/Allow	(kPa)	72.518	100.002	14.194	100.002
Fouling	(m2-K/W)		0.000090		0.000090
		Exchanger Performance			
Shell h	(W/m2-K)	8535.29	Actual U	(W/m2-K)	1256.05
Tube h	(W/m2-K)	3972.85	Required U	(W/m2-K)	1181.13
Hot regime	(--)	Sens Liquid	Duty	(MegaWatts)	10.0594
Cold regime	(--)	Sens Liquid	Area	(m2)	522.518
EMTD	(Deg C)	16.2	Overdesign	(%)	6.34

Fig. 4. After Plugging Tubes Design

2.3 Performance evaluation of heat exchanger

Normally, in the purchase process, the specific information on the thermal margin is unspecified. Therefore, in order to use the heat exchanger in the RCP facility, evaluation of the thermal margin should be calculated using CFD.

To calculate thermal margin from CFD , design values of the heat exchanger such as mass flow rate, pressure, etc…, from the manufacturer should be initially input. The analysis results showed that the initial heat exchanger design had a thermal margin of 9.03% and a thermal margin is 6.34% after plugging the leakages. The decrease of 2.7% in thermal margin is affordable during the repair process. The calculation results before and after plugging the leakages were demonstrated in Fig 3 and Fig 4.

Process Conditions		Cold Shellside		Hot Tubesude	
Fluid name					
Flow rate	(kg/s)		240.231		68.8286
Inlet/Outlet Y	(Wt frac vap.)	0.000	0.000	0.000	0.000
Inlet/Outlet T	(Deg C)	35.00	45.000	80.10	45.00
Inlet P/Avg	(kPa)	0.000	0.000	0.000	0.000
dP/Allow	(kPa)	72.048	100.002	13.784	100.002
Fouling	(m2-K/W)		0.000090		0.000090
		Exchanger Performance			
Shell h	(W/m2-K)	8523.43	Actual U	(W/m2-K)	1240.46
Tube h	(W/m2-K)	3855.42	Required U	(W/m2-K)	1137.71
Hot regime	(--)	Sens Liquid	Duty	(MegaWatts)	10.0594
Cold regime	(--)	Sens Liquid	Area	(m2)	545.637
EMTD	(Deg C)	16.2	Overdesign	(%)	9.03

Fig. 3. Original Design

2.4 Vibration evaluation

The flow induced vibration from single-phase or two-phase flow may strongly affect to the heat exchanger shell and tube sheet. The effect might be remarkable and ruin the tube bundle configuration if it is poorly designed. The vibration analysis has been performed using CFD to investigate its effect on the heat exchanger.

In order to reduce the vibration damage, design of U-tube sheet and heat exchanger shell should be cautiously designed, particularly in the baffle arrangement.

Position In The Bundle		Inlet	Center	U-Bend
Length for natural frequency	(m)	1.078	1.078	1.169
Length/TEMA maximum span	(--)	0.708	0.708	0.488
Number of spans	(--)	7	7	1
Tube natural frequency	(Hz)	32.0	32.0	12.2 +
Shell acoustic frequency	(Hz)			
Flow Velocities		**Inlet**	**Center**	**U-Bend**
Window parallel velocity	(m/s)	2.41	2.42	2.42
Bundle crossflow velocity	(m/s)	0.78	0.79	1.46 *
Bundle/shell velocity	(m/s)	1.07	1.08	2.00
Fluidelastic Instability Check		**Inlet**	**Center**	**U-Bend**
Log decrement	HTRI	0.100	0.100	0.038
Critical velocity	(m/s)	1.61	1.61	0.99
Baffle tip cross velocity ratio	(--)	0.6140	0.6224	1.8672 *
Average crossflow velocity ratio	(--)	0.4845	0.4912	1.4733 *
Acoustic Vibration Check		**Inlet**	**Center**	**U-Bend**
Vortex shedding ratio	(--)			
Chen number	(--)			
Turbulent buffeting ratio	(--)			
Tube Vibration Check		**Inlet**	**Center**	**U-Bend**
Vortex shedding ratio	(--)	0.234	0.238	1.151 *
Parallel flow amplitude	(mm)	0.027	0.027	0.162
Crossflow amplitude	(mm)	0.136	0.140	0.774 *
Tube gap	(mm)	4.763	4.763	4.763
Crossflow RHO-V-SQ	(kg/m-s2)	600.43	616.54	2107.43
Bundle Entrance/Exit (analysis at first tube row)			**Entrance**	**Exit**
Fluidelastic instability ratio		(--)	0.802 *	2.440 *
Vortex shedding ratio		(--)	0.388	0.728 *
Crossflow amplitude		(mm)	0.41610	3.64231 *
Crossflow velocity		(m/s)	1.29 *	2.42 *
Tubesheet to inlet/outlet support		(mm)	None	None
Shell Entrance/Exit Parameters			**Entrance**	**Exit**
Impingement plate			No	
Flow area		(m2)	0.214	0.214
Velocity		(m/s)	1.13	1.14 *
RHO-V-SQ		(kg/m-s2)	1270.66	1275.71

Fig. 5. Result of vibration analysis

+ Frequency ration are based upon lowest natural of acoustic frequency
** Items with asterisk exceed a conservative lower limit for vibration-free design.*

3. Conclusions

The evaluation of thermal margin of a heat exchanger was carried out using CFD. The inspection in the RCP test facility showed 25 leakage points from the tube surface by using ET technique.

An evaluation of thermal margin of the heat exchanger before and after plugging the leakages as well as vibration analysis were carried out using the CFD.

The analysis results showed that the thermal margin difference between initial heat exchanger and leakage plugged heat exchanger is 2.7%. It is acceptable according to the operating conditions.

The mitigation of flow induced vibration can be accomplished by well design the tube sheet configuration and alignment.

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