Simulation of Thermal Stratification in Inlet Nozzle of Steam Generator

Hyun-Chul Jeong,a Bum-Soo Youn,a Sang-Nyung Kim,a Hak-Gi Yeom b
a Dep. Of Nuclear Eng. , Kyung Hee Univ., 1 Seocheon-dong, Kiheung-Gu, Yongin-Si, Kyunggi-Do,
tanglley@khu.ac.kr
b Korea Power Engineering Co,.Inc (KOPEC), 360-9 Mabuk-dong, Kiheung-Gu, Yongin-Si, Kyunggi-Do

1. Introduction

Thermal stratification refers to layering of low-velocity fluids of different temperatures in power plant components or piping system due to density difference. Nuclear power plant components suffer pipe shedding, cracking, thermal fatigue, bending and supporting bracket breakage during their life span. Notably, the horizontal inlet nozzle of steam generator is prone to thermal stratification frequently due to its operational characteristics. Accordingly, the US Nuclear Regulatory Commission (NRC) requires the integrity of the nuclear power plant piping system exposed to potential thermal stratification such as main feedwater pipe and reactor coolant system pipe to be proven in the Bulletin 79-13, 88-08 and 88-11. In Korea as well, it is recommended in the regulations applicable to nuclear power plants that the horizontal pipe among the tributary pipes connected to reactor coolant system be subject to a variety of thermal stratification inspections. In addition, steam generator is a very critical component in terms of nuclear power plant integrity and safety. However, thermal stress resulting from thermal stratification within piping system was not reflected sufficiently on the design of W power plants in Korea.

Therefore, this study conducted an simulation the thermal stratification and thermal cycling in relation to the volume of auxiliary feedwater injected into the horizontal inlet nozzle of steam generator using CFD code CFX-10.0. Also, this study was assumed that thermal sleeve was installed that was carried out of the thermal strain and numerical analysis of alleviation the thermal stress in the horizontal inlet nozzle of steam generator in Korea.

2. Methods and Results

2.1 Operating Parameters

This simulation was intended to test thermal stratification behavior in the horizontal inlet nozzle of steam generator in W power plant and the test was designed and fabricated on the actual nuclear power plant operating conditions (table 1).

Table 1 Operation Parameters of Nuclear Power Plants

Operation Parameters \ Plant Type	W Power Plants	
	min	max
Temp. Diff. between MFW & Aux. Feedwater (Δ T)	200	290
Avg. Thermal Expansion Coeff. (1/℃) x 10^{-3}	1.38	3.52
AFW Volume Range (m^3/min)	1.4	1.9
Richardson number	10.6	72.4
Inlet Nozzle Diameter (m)	0.364	
Curvature Radius of Inlet Pipe (D : Nozzle Diameter)	1.5D	
Hot Water Volume Flowing into Horizontal Inlet Pipe (m^3/min)	Impossible to calculate water volume with accuracy (Test water volume was considered)	

2.2 Numerical Methods

The numerical simulation used a commercial CFD code CFX 10.0 (ANSYS CFX) based on the finite volumes method.

(1) Two simulation domains were created: one solid, corresponding to the pipe, and one fluid for the water in its interior.

(2) Three simulation domains were created: two solid geometry (pipe and thermal sleeve, thermal sleeve was located in fluid domain), and one fluid.

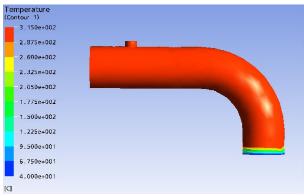
Table 2 Input Parameters

Fluid Model	Heat Transfer model	Thermal energy
	Turbulent model	K-epsilon
	Buoyancy model	Production and Dissipation
Cold Inlet	Flow regime	Subsonic
	Mass and Momentum	1.4 m^3/min
	Static Temp.	40℃
Hot Input	Flow regime	Subsonic
	Mass and Momentum	Normal Speed (1cm/s)
	Static Temp.	315℃
Wall Condition	Wall Influence on Flow	No slip
	Heat transfer Coefficient	Adiabatic
	Wall Temp.	315℃

Initial Condition	Pressure	15MPa
	Temperature	315℃
Richardson number	49.359	

2.3 Result

2.3.1 Fluid part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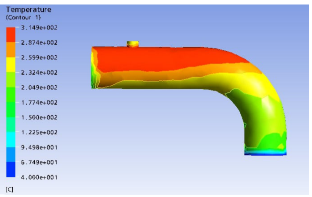
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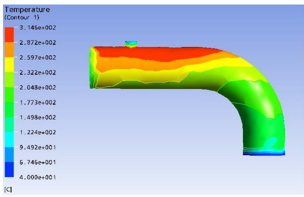
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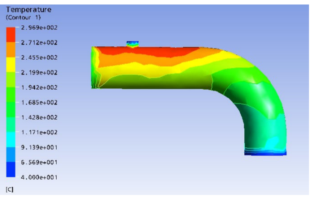
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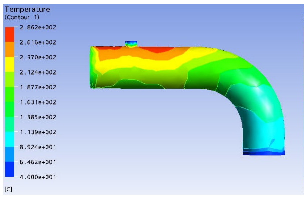
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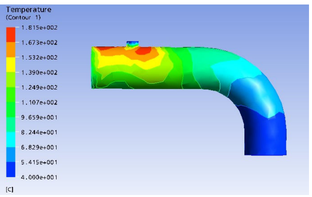
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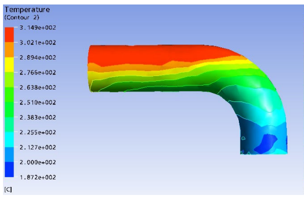
2.3.2 Solid (pipe) part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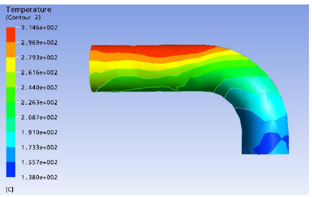
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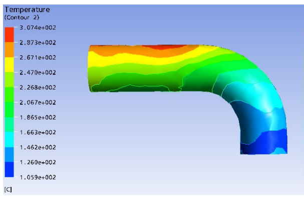
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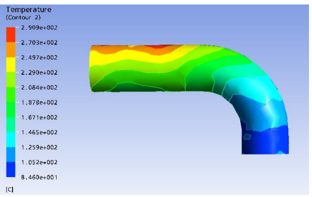
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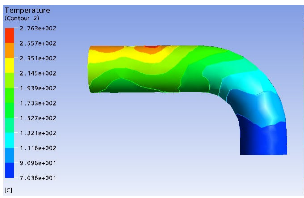
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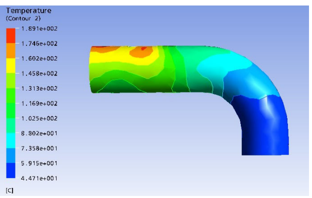
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3. Conclusion

Thermal stratification that occurs in the horizontal inlet nozzle as be injected auxiliary feedwater which is one of the components highly critical to the operation and the safety of nuclear power plant threatens the integrity of the piping system in nuclear power plant.

Therefore, we performed assessment of thermal stratification in the horizontal inlet nozzle of the steam generator in W power plants in reference to effect of thermal sleeve as well to arrive at the following conclusions:

(1) Thermal stratification is highly likely to occur in the horizontal section of the steam generator inlet nozzle in the old power plants when auxiliary feedwater is injected;

(2) Thermal stratification is more at the mercy of the auxiliary feedwater flow than the flow conditions(hot water) within steam generator;

(3) Thermal cycling was hardly observed in the thermal cycling and stripping experiments targeting the horizontal inlet nozzles of the steam generator in W power plants;

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