Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2016

A Study on Temperature Distribution in the Hot Leg Pipes considering the Variation of Flow Rate in RCS

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1. Introduction

In the hot leg pipes of Reactor Coolant System (RCS) of APR1400, four Resistance Temperature Detectors (RTDs), to obtain the average hot leg temperature, are installed at each hot leg pipe (two in the upper region and the other two in the lower region around the wall of the hot leg pipe). There is a deviation in temperature distribution in the hot leg pipe due to the sudden changes in the flow direction and area from the reactor core exit to the hot leg pipe. The non-uniform temperature distribution in the hot leg pipe can affect the measurement of the plant parameters such as the reactor power and the reactor coolant flow rate.

In this study, a computational analysis is performed to predict the deviation in the temperature distribution in the hot leg pipe according to the flow rate variation in RCS.

2. Methods and Results

2.1 Configuration of Geometric Model

The Reactor Vessel Internals (RVIs) are composed of Core Support Barrel (CSB) assembly, Lower Support Structure (LSS), In-Core Instrumentation (ICI) nozzle assembly and Core Shroud (CS). A numerical model is assumed by half model and symmetry condition even though the ICI nozzle components of RV have a non-symmetry model.

2.2 Simulation Parameters

The numerical analysis is performed on the normal operation condition for pressure and temperature. A working fluid is water (IAPWS-97) and the mass flow rate, thermal power and operating pressure are shown in Table I. The inlet flow corresponds to the flow rate of one reactor coolant pump, 5,231.2 kg/s. The mass flow rate for one-half core model is 10,462.4 kg/s.

Table I. Parameters of the reactor analysis

	Value	SI Unit
Thermal power	1,991.5	MWth
Operation pressure	15.51	MPa
Temperature (T_{cold})	290.6	°C
Mass flow rate	10,462.4	kg/s

The flow paths and geometry model of the RVIs are shown in Fig. 1. A reactor coolant temperature goes up while passing through the reactor core, which releases heat of 1,991.5 MWth that is the amount of heat generation from one-half core model. Also, a thermal porous media methodology is applied to experimental data for the reactor fuel [1]. The wall boundary of reactor outside is adiabatic condition.

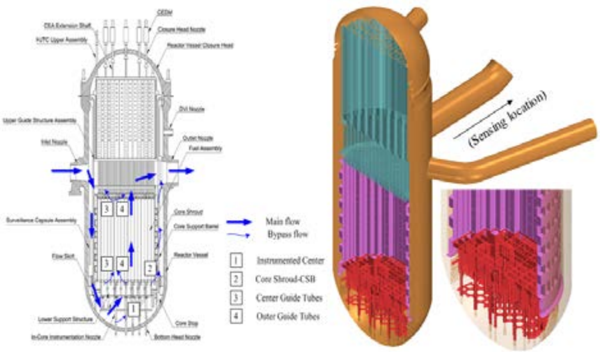

Fig. 1 Flow paths and geometry model of RVIs

RTDs are installed at 5.77m away from the vertical center line of RV. Fig 2 shows the schematic diagram for coolant flow path from core exit plane to RTD location installed in hot leg pipe.

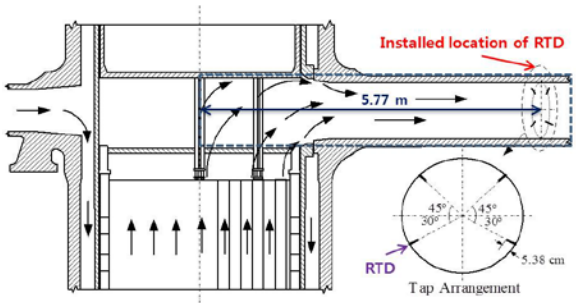

Fig. 2 Coolant flow path from core exit plane to RTDs location

As shown in Fig.2, the coolant exiting core center region is mainly passed through the upper part of hot leg pipe, while the coolant from core peripheral region is mainly passed through the lower part of hot leg pipe.

Fig 3 shows the circumferential location of RTDs installed in hot leg pipe.

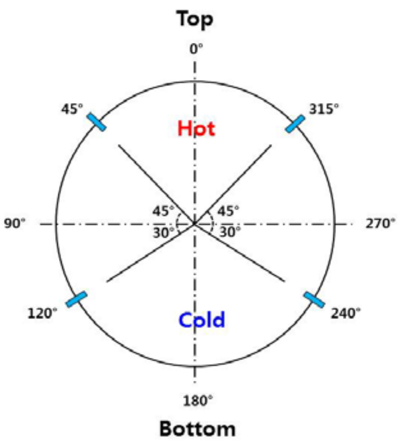

Fig. 3 Circumferential location of RTDs

2.3 Analysis Method

The Computational Fluid Dynamic (CFD) analysis is carried out using the commercial code, STAR-CCM+ [2]. Fig. 4 shows that the conservative thermal power ratio of reactor core is distributed by axial-direction [3]. A mesh with ~ 37×10^6 cells is generated with polyhedral cells, to be called the "Test 1" mesh case. After preliminary simulations and subsequent examinations of the $y+$ values, two additional meshes are created. The "Test 2" mesh with $\sim 61\times10^6$ cells has further refinements in RVI internal structures in order to attain a maximum $y^+ > 30$.

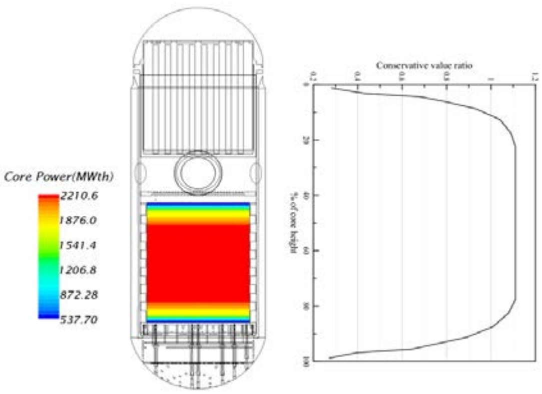

Fig. 4 Thermal power distribution for reactor core

In the "Test 3" mesh case, the additional refinements are made to the cells in the internal fluid volume and the prism-layer meshes on the fluid surface. This increases the total cell count to $\sim 70\times10^6$.

In order to evaluate mesh independence, all simulations are monitored with the temperature distribution and the average absolute pressure at RTDs location installed in hot leg pipe. The results of the temperature distribution and the pressure drop of RV are shown in Fig. 5.

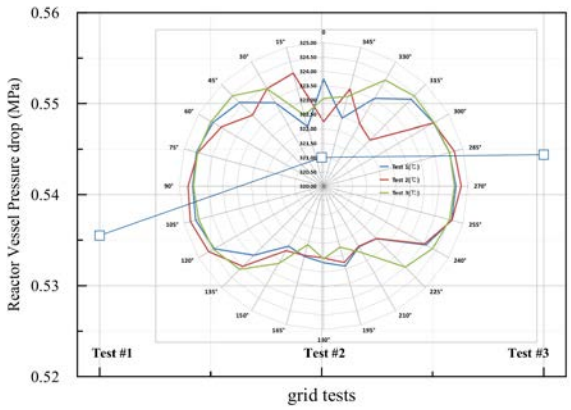

Fig. 5 Results of grid test
(RV Pressure drop/Temperature distribution)

As shown in Fig.5, the pressure drop of RV for test 2 model is constant. But the temperature distributions are unstable at hot leg pipe due to the thermal stratification. Test 3 model has a lot of grids so as to compute numerical model. So, test 2 model is selected with Realize k-ε turbulence model.

2.4 Result

Fig. 6 shows the schematic of traverse port locations for temperature measurement.

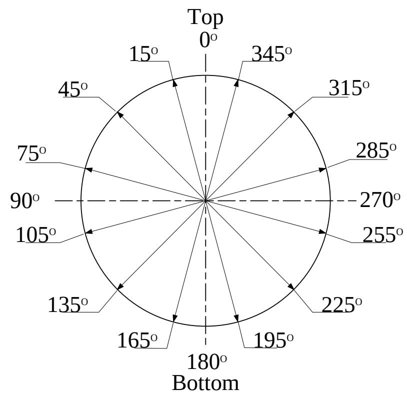

Fig. 6 Schematic of traverse port
locations for temperature measurement

Fig.7 shows the temperature distribution in accordance with the measured position on the range of flow rate in RCS (100% QD, 105% QD and 110% QD). The measured positions are the five measurement points (from 3.04m to 5.58m) according to the z-axis direction from the origin.

The plane average temperatures of RTD location on the range of flow rates in RCS are 323.64 °C (100% QD), 322.25 °C (105% QD) and 320.94 °C (110% QD), respectively. The standard deviation for each location is about 0.91 with a constant deviation.

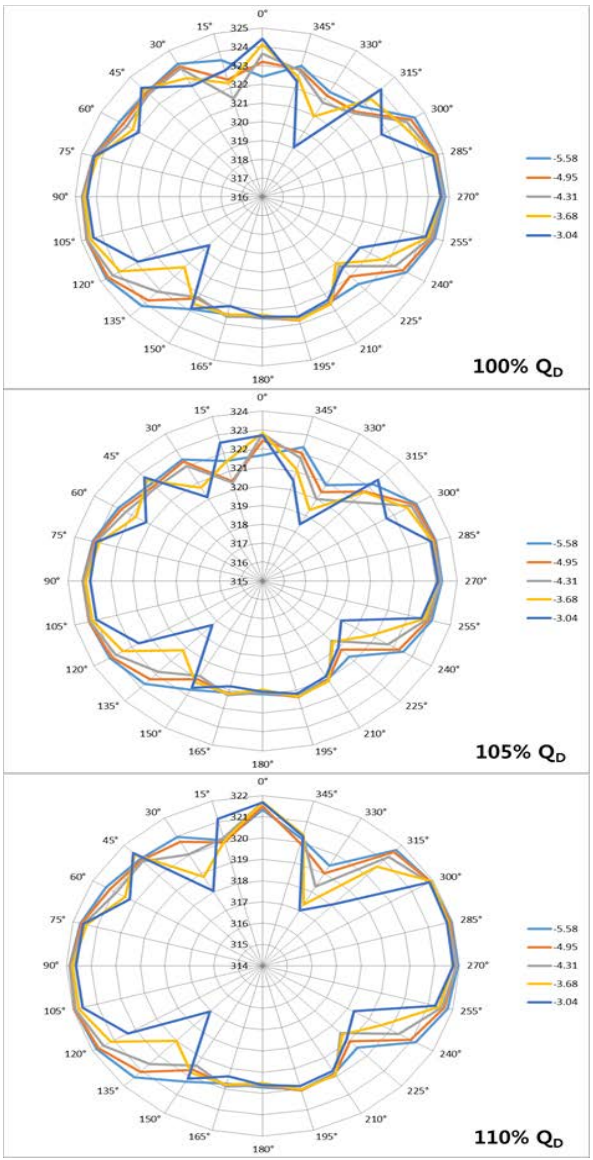

Fig. 7 Temperature distribution through the hot leg

Fig. 8 shows a temperature distribution for each angle of the sensor position of the RTD on the range of flow rates in RCS.

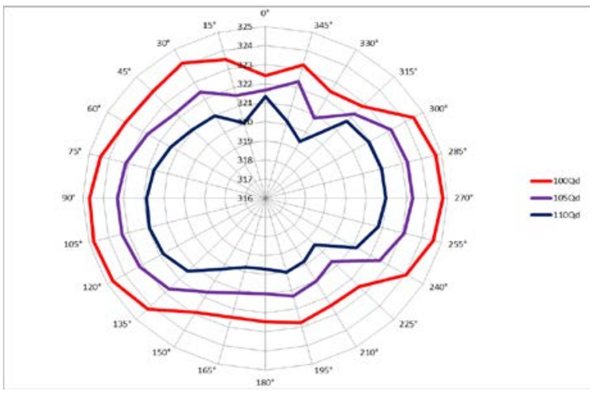

Fig. 8 Temperature distribution at the RTDs location

3. Conclusions

The following conclusions are reached through this study.

1) The non-uniform temperature distribution in the core exit is sustained to some extent through the entire region of hot leg pipe.

2) The temperature ranges having a uniform pattern are 45 ~ 120° and 240 ~ 315°. The sensor positions of RTDs are located in this interval (45 ~ 120° and 240 ~ 315°) and this sensor positions of RTDs show the appropriate temperature measurement. Also, the temperature distribution shows the similar pattern without reference to the flow rate variation in RCS.

In the future, the various turbulence models under the steady state condition will be performed in order to evaluate the effect of turbulent flows.

REFERENCES

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