Thermalhydraulic Characteristics for Wolsung-1 after retubing

Jun Ho Bae [*], Joo Hwan Park
Korea Atomic Energy Research Institute P.O.Box 105, Yusong, Daejon, 305-600, Korea
[*] *Corresponding author: bjh@kaeri.re.kr*

1. Introduction

The ROP margin in a CANDU reactor is decreasing over time due to the Primary Heat-Transport System (PHTS) aging effect. Adjustment of the ROP trip setpoint is required to maintain a high trip-probability and ROP trip effectiveness. Especially, for Wolsong-1, which is scheduled to change the old pressure tubes in 2009, the trend of ROPT after the retubing should be re-evaluated[1]. Before setting a ROPT, the main thermal characteristics including Critical Channel Power (CCP) should be calculated by the NUCIRC code[2]. In this paper, the thermalhydraulic evaluation for Wolsung-1 was conducted with the updated Wolsung-1 PHTS data. Specifically, for the case of 0 EFPY (Effective Full Power Year) and 11 EFPY after the retubing, the distribution of the channel flow rate, channel exit quality, critical channel power, and critical power ratio (CPR) of the Wolsong-1 aged plant are calculated.

2. Methods and Results

2.1 Analysis Method

The retubing includes the installation of new pressure tubes, and new feeders. After retubing, the pressure tube diametral creep will be zero as new pressure tubes are being replaced. With the installation of new feeders, the magnetite transport effect on the PHTS is also disappeared after retubing for feeders and pressure tubes. Since no steam generator cleaning will be carried out during retubing, the steam generator models will assume the same behavior as that of before-retubing. For simulating a CANDU-6 reactor at 0 EFPY and 11 EFPY, the same NUCIRC input parameters can be employed, except for the pressure tube diametral creep and the parameters related to the magnetite transport behavior. The NUCIRC code predicts the CCP for each fuel channel of a CANDU reactor based on a given heat source and the boundary conditions such as an inlet and outlet header pressures and temperatures [Fig. 1].

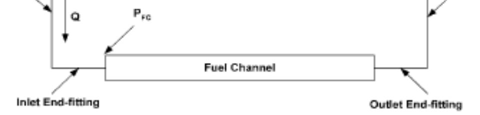

Fig. 1. Slave channel analysis model of the NUCIRC code

The thermalhydraulic analysis of a CANDU-6 reactor fuel channel was performed with an inlet header temperature of 278°C, an outlet header pressure of 9.99 MPa, and a header-to-header pressure drop of 1282 kPa.

2.2 Channel Flow Rate

As regard to ref. [3], there are several thermalhydraulic design requirements of a CANDU fuel bundle. These design requirements were categorized into the core flow rate, the fuel channel pressure drop, the thermal margin, and the channel exit quality[4]. Figure 2 shows the distribution of the channel flow rate for 0 EFPY and 11 EFPY after the retubing with respect to the core radius. The flow rates in the channels, which are located in the inner-core, maintain high values whereas the flow rates in the outer-core linearly decrease as the distance to the core center increases. The design requirement of the channel flow is that the channel flow rate may not be exceeded 27.4 kg/s. As can be seen in Fig.2, the calculated channel flows are below this limit for both 0 EFPY and 11 EFPY. It can be also seen that the flow rates for 0 EFPY and 11 EFPY have similar values, which results from the fact that the pressure tube creep has a role to increase the flow rate, while the decrease of a tube inner diameter by the magnetite deposition causes the flow rate to decrease.

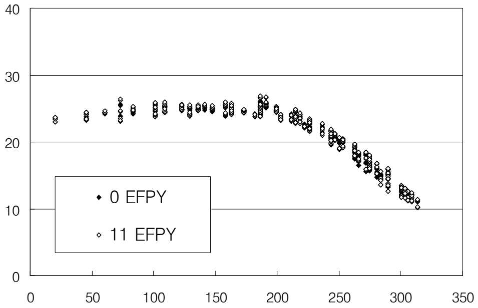

Fig. 2. Core flow rate distribution of 0 EFPY and 11 EFPY

2.3 Critical Channel Power

In a CANDU reactor, the CCP is generally used for the assessment of the thermal margin of a fuel channel. The CCP is defined as the channel power when a CHF occurs on the surface of a fuel rod under a given header-to-header pressure boundary condition. Figure 3 shows the CCPs for 0 EFPY and 11 EFPY after the retubing. It was found that the CCP of 0 EFPY was maintained just above 9MW in the inner-core, but decreased in the outer-core due to smaller flow rate in the outer-core. This overall pattern of the CCP for 0 EFPY is similarly shown for that of 11 EFPY, while the CCP of 11 EFPY is largely decreased compared to that of 0 EFPY. The maximum CCPs are found as 9,832 and 9,411 kW at the channel N-17 for the 0 EFPY and 11 EFPY, respectively. The decrease of CCP at 11 EFPY is due to the PHTS aging effects (i.e., pressure tube diametral creep & magnetite transport effect). Therefore, it is expected that the full power of a reactor at 11 EFPY should be moderated in order to establish a thermal safety margin.

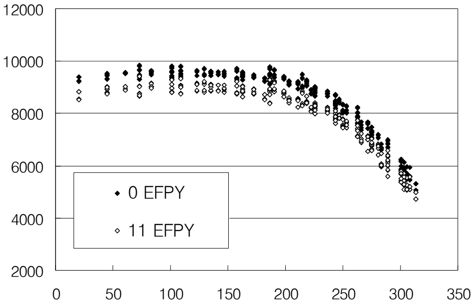

Fig. 3. CCP distribution of the 0 EFPY and 11 EFPY

The critical power ratio (CPR) is a ratio of the CCP over the actual channel power, which is a direct measure of the thermal margin of a fuel channel. The CPRs for 0 EFPY and 11 EFPY after the retubing are plotted in Fig.4. Different from the CPP distribution in Fig.3, the CPRs for 0 EFPY and 11 EFPY have a minimum value in the intermediate-core region and increase in the outer-core region due to the larger decrease of the actual channel powers than a decrease of CCP. As shown in Fig.4, the minimum CPR was found as 1.429 at channel O-17 for 0 EFPY, while it is 1.334 at the channel H-17 for 11 EFPY. Therefore, the minimum CPR of 11 EFPY is 7% lower compared to that of 0 EFPY. This result shows that the thermal margin of a fuel channel at 11 EFPY is largely decreased due to the aging effect, although the design requirement of the CPR (1.12) is satisfied for both 0 EFPY and 11 EFPY.

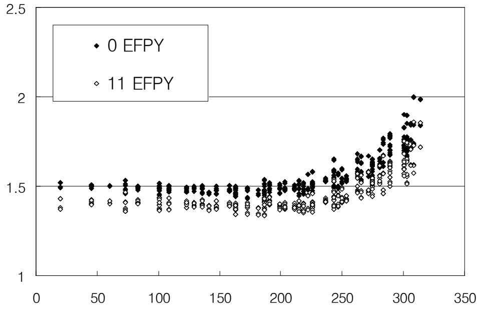

Fig. 4. CPRs distribution of the 0 EFPY and 11 EFPY

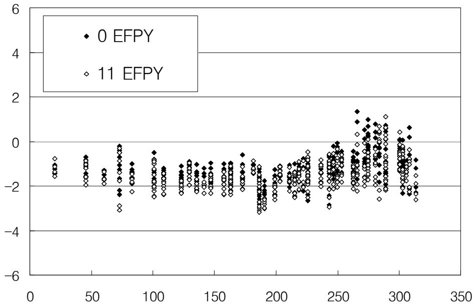

Fig. 5. Channel exit quality of the 0 EFPY and 11 EFPY

2.4 Channel Exit Quality

The channel exit quality is a result of the interaction between the channel power and channel flow distribution, which indicates the balance between heat generation and heat removal via a coolant distributed by the inlet feeder for each fuel channel[4]. In order to satisfy the design requirement [3], the exit quality should not exceed the design limit of 4%. Fig.5 shows that the exit qualities of 0 EFPY and 11 EFPY have a similar pattern and exit qualities for both cases do not exceed the design limit. It can be seen from the figure that the highest exit quality are observed in the outer-core region, where both the channel power and the flow rate are low.

3. Conclusions

Although the thermalhydraulic design requirements of a CANDU fuel bundle are satisfied for both 0 EFPY and 11 EFPY, the CCP and CPR of 0 EFPY and 11 EFPY reflect that the thermal margin of a fuel channel of 11 EFPY is largely decreased due to the PHTS aging effect. While the channel flow rate and channel exit quality have a similar value for 0 EFPY and 11 EFPY, the minimum CPR of 11 EFPY is 7% lower compared to that of 0 EFPY.

ACKNOWLEDGMENT

This work was carried out under the Nuclear Research and Development Program of the Korea Ministry of Education, Science and Technology.

REFERENCES

[1] W. H. HARTMANN, H. CHOW, V. CAXAJ, "ROP Trip Setpoint Aging Trends for Wolsong-1,", AECL 59-03330-AR-001, Rev 0 (2004)

[2] M. F. LIGHTSTONE, "NUCIRC-MOD1.505 Users Manual," TTR-516, Atomic Energy of Canada Limited (1993)

[3] I. E. OLDAKER, "Fuel Design Manual for CANDU-6 Reactors," DM-XX-37000-001, Atomic Energy of Canada Limited (1989)

[4] J. H. PARK, J. W. PARK, H. CHOI, "Progress of the Dupic Fuel Compatibility Analysis – II: Thermal Hydraulics," Nuclear Technology, vol. 153 (2006)