Thermalhydraulic Characteristics for Fuel Channels using Burnable Poison in the CANDU reactor

Jun Ho Bae [*], Gyu hong Roh, Yong Mann Song

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

1. Introduction

The power coefficient is one of the most important physics parameters governing nuclear reactor safety and operational stability, and its sign and magnitude have a significant effect on the safety and control characteristics of the power reactor. Recently, for an equilibrium CANDU core, the power coefficient was reported to be slightly positive when newly developed Industry Standard Toolset reactor physics codes were used [1]. Therefore, it is required to find a new way to effectively decrease the positive power coefficient of CANDU reactor without seriously compromising the economy. In order to make the power coefficient of the CANDU reactor negative at the operating power, Roh et al. [2] have evaluated the various burnable poison (BP) materials and its loading scheme in terms of the fuel performance and reactor safety characteristics. It was shown that reactor safety characteristics can be greatly improved by the use of the BP in the CANDU reactor. However, the previous study has mainly focused on the safety characteristics by evaluating the power coefficient for the fuel channel using BP in the CANDU reactor. Together with the safety characteristics, the economic performance is also important in order to apply the newly designed fuel channel to the power plant. In this study, the economic performance has been evaluated by analyzing the thermal-hydraulic characteristics for the fuel channel using BP in the CANDU reactor.

2. Methods and Results

2.1 Analysis Method

The main thermal characteristics including a critical channel power (CCP) have been calculated by the NUCIRC code [3]. 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. The thermalhydraulic analysis of a CANDU-6 reactor fuel channel was performed with an inlet header temperature of 262°C, an outlet header pressure of 9.99 MPa, and a header-to-header pressure drop of 1282 kPa.

2.2 Axial and Radial Power distribution

The power distribution within a fuel channel is an important parameter for the integrity of the fuel bundle and the thermal performance including CCP. Fig. 1 shows the axial power distribution of a fuel bundle using BP. The fuel bundle using BP is selected as the CANFLEX-RU fuel bundle loaded with 11.0 wt% Er_2O_3 in the central fuel rod (hereafter, called RU09-Er11), which is revealed to the most optimal design in the previous study [2]. It is revealed from the figure that the axial power distribution is slightly shifted to the front of fuel channel by the effect of 4-bundle shift fuel loading, which is necessary for the RU fuel. Since the dryout of fuel channel is generally occurred in the downstream of channel, the forwardly shifted power distribution of the fuel channel using BP is expected to increase the CCP.

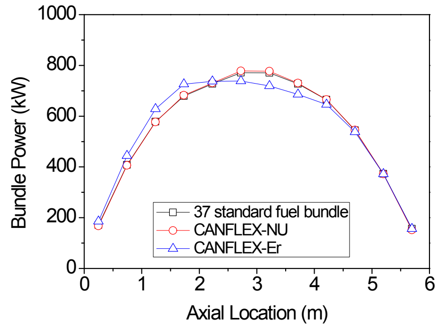

Fig. 1. Comparison of axial power distributions

Fig.2 shows the relative ringwise linear power distribution depending on the fuel burnup for CANFLEX-NU and the CANFLEX-RU09-Er11 fuel bundles. For the case of the CANFLEX-RU fuel bundle loaded 11.0 wt% Er_2O_3 in the central fuel rod, as expected, the linear power of the central rod greatly decreases in the beginning of the cycle and monotonically increases as the fuel burns. The highest linear power region is changed to the second ring as the fuel burns in the BP loaded fuel case.

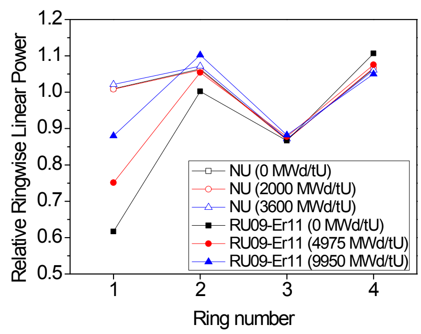

Fig. 2. Comparison of Radial power distribution

2.3 Critical Channel Power

The critical channel power (CCP), which 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, is generally used for the assessment of the thermal margin of a fuel channel.

Fig. 3 shows the CCP of the CANFLEX-RU fuel bundle loaded 11.0 wt% Er_2O_3 in the central fuel rod, together with that of standard 37 fuel channels and CANFLEX-NU. Irrespective to the fuel bundle type, the high power channels in a central core have the larger CCP compared to the low power channels in the outer core. It is also revealed from the figure that the CCPs of CANFLEX type fuel channels (CANFLEX-NU and CANFLEX-RU loaded 11.0 wt% Er_2O_3) have the larger value compared to that of standard 37 fuel channels due to the CANFLEX design characteristics of a dual-sized 43 element bundle.

Fig. 4 shows the CCP ratio of CANFLEX-RU fuel bundle loaded 11.0 wt% Er_2O_3 compared to that of standard 37 fuel bundle. It is shown that the relative ratio of CCPs has the increased value for the 15 and 30 EFPY (Effective Full Power Years) compared to the beginning of the plant because the radial power distribution become to be more flat shape as the burnable poison in the central fuel rod burns with plant operation. Fig. 5 shows the CCP ratio of CANFLEX-RU fuel bundle loaded 11.0 wt% Er_2O_3 compared to that of CANFLEX-NU fuel bundle. It is revealed that the CCP of CANFLEX-RU fuel bundle loaded 11.0 wt% Er_2O_3 has the increased value for all the channels compared to that of CANFLEX-NU except the channels in outer core for 30 EFPY. This indicates that the loading of 11.0 wt% Er_2O_3 in central fuel rod does not reduce the thermal performance of fuel bundle but rather the thermal performance is increased by the axial heat flux distribution of the RU fuel bundle when compared to that of the CANFLEX-NU bundle, although a CHF decrease was assumed from the radial heat flux distribution of the RU fuel. It is noted that the relative increase of CCP is noticeable for the high power channels in the central core, which is mostly related to the operating margin of a core.

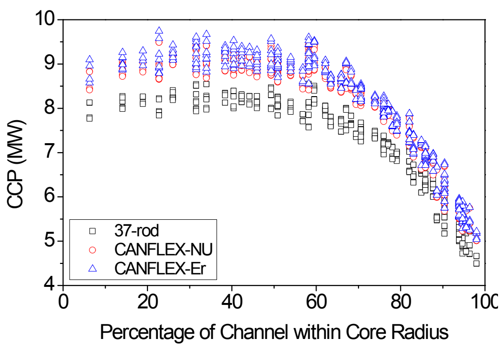

Fig. 3. Comparison of CCPs for the different fuel channels

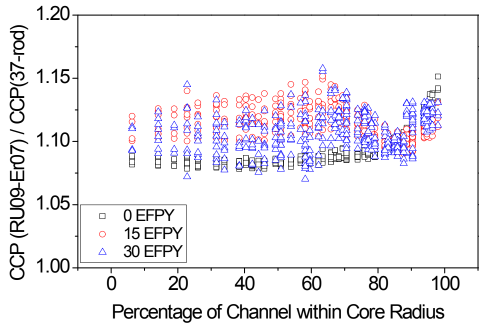

Fig. 4. The CCP ratio of CANFLEX-RU09-Er11 compared to that of standard 37 fuel bundle

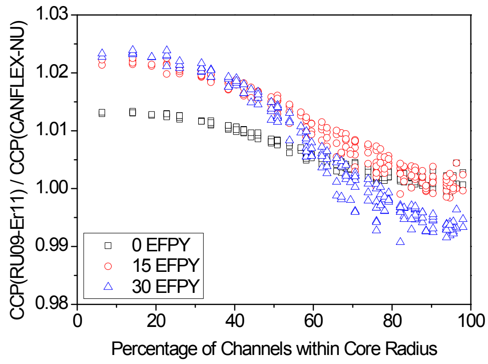

Fig. 5. The CCP ratio of CANFLEX-RU09-Er11 compared to that of CANFLEX-NU fuel bundle

3. Conclusions

Although the CANFLEX RU fuel bundle loaded 11.0 wt% Er_2O_3 are originally designed focused on the safety characteristics, the thermal-hydraulic characteristics is revealed to be not deteriorated but rather is slightly enhanced by the axial heat flux distribution of the RU fuel bundle when compared to that of the CANFLEX-NU bundle.

ACKNOWLEDGMENT

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REFERENCES

[1] T. E. Schaubel, "CNSC Staff Review of Pickering NGS-B Integrated Safety Review", Safety Analysis Safety Factors Report (2008)
[2] M. F. LIGHTSTONE, "NUCIRC-MOD1.505 Users Manual," TTR-516, Atomic Energy of Canada Limited (1993)
[3] G. H. Roh et al., "Improvement of Power Coefficient by Using Burnable Poison in the CANDU Reactor" Nuclear Engineering and Design, vol. 241, pp. 1565-1578 (2011)