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

Jun Ho Bae [*], Jong Yeob Jung

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

1. Introduction

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.

In a view of safety, the fuel temperature coefficient (FTC) is an important safety parameter and it is dependent on the fuel temperature. For an accurate evaluation of the safety-related physics parameters including FTC, the fuel temperature distribution and its correlation with the coolant temperature should be accurately identified. Therefore, we have evaluated the fuel temperature distribution of a CANFLEX fuel bundle loaded with a burnable poison and compared the standard 37 element fuel bundle and CANFELX-NU fuel bundle.

2. Numerical Methods

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 by using NUCIRC code [3].

In the present calculation, a fuel temperature was calculated only for a representative fuel element in each ring. The coolant temperature is firstly obtained from the relation between the enthalpy rise of coolant and bundle power input in one-dimensional analysis and then the fuel temperature is calculated by considering the heat transfer from the fuel to coolant. The detailed calculation procedure for the gap and fuel temperature is well documented in the reference [4].

3. Results

The power distribution within a fuel channel is an important parameter affecting the fuel temperature characteristics. Fig.1 shows the relative ring wise linear power distribution depending on the fuel burnup. 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].

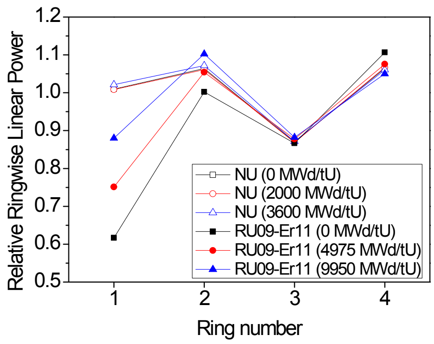

Fig.1 Comparison of radial ring power distribution.

Relative linear power is the ratio of specific element power relative to the average element power, which is obtained from HELIOS calculation. For the case of the CANFLEX-RU09-Er11 fuel bundles, 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 shows the representative fuel temperature in the each ring with the variation of fuel burnup for the case of the CANFLEX-RU09-Er11 fuel bundles. Since the relative linear power mainly affects the fuel temperature, the fuel temperature shows a similar profile as in the linear power. That is, the fuel temperature of a center ring has the lowest temperature among 4 rings at the beginning of fuel burnup and it is largely increased with fuel burnup, which brings the final temperature profile to have w-shaped profile.

The fuel temperature was compared between the standard 37 fuel bundle and CANFLEX-NU and CANFLEX-RU09-Er11 fuel bundle and the result was shown in Fig. 3. It is noted that for the standard 37-element, the minimum relative linear power occurs at the central element and it increases monotonically with the ring number, while for the CANFLEX fuel, the 3^{rd} ring has the minimum linear power and a w-shape radial power profile is observed. Similarly with the radial power ratio of each fuel bundle, the CANFLEX fuel temperature in the 3rd and 4th rings has the lower value compared to that of 37-element. The CANFLEX-RU09-Er11 fuel bundle has the similar temperature profile with the CANFLEX-NU, except that the central rod fuel temperature is smaller by the loading of Er in the central ring, while it has the higher temperature compared with that of CANFLEX-NU except the central fuel rod.

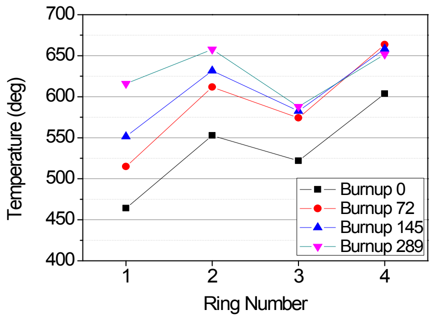

Fig. 2 The representative fuel temperature in each ring for CANFLEX-RU09-Er11 fuel bundle.

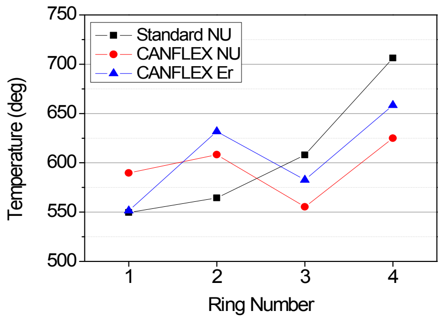

Fig. 3 Fuel temperature comparison for each ring.

Fig. 4 shows the fuel temperature distribution over 380 channels in the whole core for the case of CANFLEX-RU09-Er11 fuel bundle. It is noted that the 4th ring having the maximum fuel temperature among elements shows about 100°C lower temperature for the CANFLEX-RU09-Er11 fuel bundle compared with that of standard 37 fuel bundle in the high power region. In general, a lower fuel temperature results in a lower fuel temperature coefficient. Therefore, it is expected that the CANFLEX-RU09-Er11 fuel bundle can slightly improve the fuel temperature coefficient of the CANDU reactor.

The fuel bundle temperatures over 380 channels in the whole core are compared and shown in Fig. 5. The CANFLEX-RU09-Er11 fuel bundle has the similar fuel bundle temperature with that of CANFLEX-NU, which has the lower temperature value compared with that of standard 37 fuel bundles.

4. Conclusions

Although the CANFLEX RU fuel bundle loaded 11.0 wt% Er_2O_3 are originally designed focused on the safety characteristics, the fuel temperature characteristics is revealed to be not deteriorated but rather is slightly enhanced by the decreased fuel temperature in the outer ring compared with that of standard 37 fuel bundle.

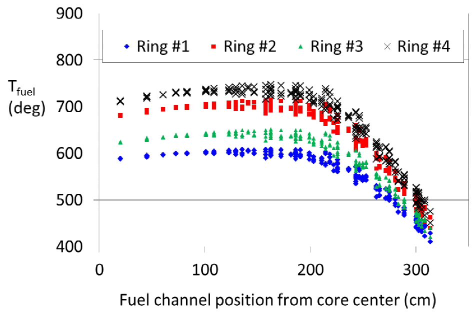

Fig. 4 Fuel temperatures of CANFLEX-RU09-Er11 fuel bundle.

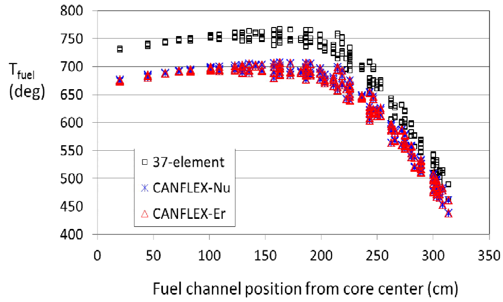

Fig. 5 Fuel temperature comparison between fuel bundles.

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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)

[4] J. H. Bae et al., "Comparison of Fuel Temperature Characteristics between Standard 37 element and CANFLEX Fuel Bundles, Korean Nuclear Society Autumn Meeting (2010)