A subchannel analysis of CANDU fuel bundle in a crept fuel channel

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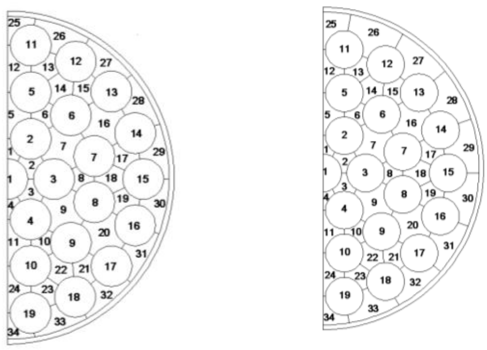
1. Introduction

In a CANDU reactor, the fuel channel diameter increases due to the pressure tube creep resulting from neutron irradiation damage. It is well known that a crept pressure tube leads to a non-uniform coolant flow resulting to a decrease of dryout power. The previous experimental study [1] reported the dryout power and the location the first dryout occurs for the uncrept and crept channel. However, it has the limitation to reveal the detailed thermal-hydraulic characteristics for the local flow field. The subchannel technique is known to be very useful for investigating the thermal behavior of fuel assembly in a nuclear power reactor. In this study, the subchannel analysis has been conducted for the uncrept and crept channel. The objective of this study is to examine the change of thermal-hydraulic characteristics by the pressure tube creep and to assess the thermal margin of each rod in a fuel bundle.

2. Numerical methods

In this study, the ASSERT-IV code [2] was used for the subchannel analysis of the uncrept and crept fuel channel. In subchannel analysis, the complex geometry of the rod bundle is divided into smaller sections. Since gravity is perpendicular to the direction of channel flow in CANDU reactors, at least half of the bundle should be modeled for the subchannel analysis. Figure 1 shows the subchannel models for the uncrept and crept fuel bundles, together with the element and subchannel numbers. The subchanel model for the standard fuel bundle includes 19 powered elements and 34 subchannels.

The pressure tube creep is reflected in ASSERT code by means of geometry variation values for subchannel flow area, gap size, and wetted perimeter along the axial location. The conservation equations of mass, momentum and energy are solved for each subchannel while taking into accout the intersubchannel interactions as source terms. The transverse interchange phenomenon between subchannels is decomposed into three components that are the flow diversion, turbulent mixing and void drift. In this study, the Wallis's model is used for the drift velocity and the mixing coefficient is set to 0.01 instead of the default value of 0.05, based on the result of previous study [3]. The calculation was performed with an inlet fluid temperature of 256°C, an outlet header pressure of 10.0 Mpa and mass flux of 20.0 kg/s.



(a) Uncrept channel (b) 5.1% crept channel

Fig. 1 Subchannel model of a CANDU fuel bundle

3. Results

The CHF prediction has been performed subsequent to flow distribution calculation by using CHF look-up table option. The ASSERT code reports a CHF assessment by means of the CHF ratio (CHFR) and predicts the incipient dryout when the minimum CHFR (MCHFR) has the value of 1.0. In actual calculation, the dryout power is secured by adjusting the channel power until the value of MCHFR has the range of 0.95 < MCHFR < 1.05.

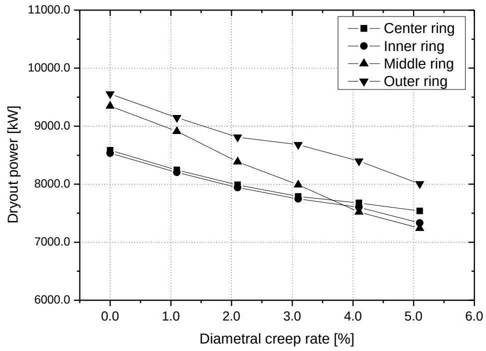


Fig.2 Dryout power at each ring with creep rate

Figure 2 shows the variation of dryout power of each ring with respect to the pressure tube creep. It is revealed from the figure that the dryout power of each ring tends to decreases with the increase of the diametral creep rate due to the bypass flow through the most outer subchannel in the upper region. For uncrept channel, the first dryout is anticipated to occur at the center or inner rings since they have the minimum dryout power among four rings. From the figure, it is revealed that the middle ring is the largest dependent on the creep rate and the dryout power shows the steepest decrease with the creep rate. By the result, the middle ring become to have the minimum dryout power for the creep rate over 4.0%. The present results for the locations of dryout power are in accord with the previous experimental study [1], which showed that the first dryout occured at upper elements in the inner or middle ring in radial direction and at three fourths of the fuel channel length from the inlet.

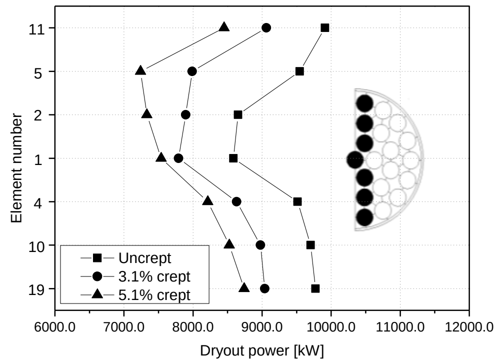


Fig.3 Dryout power distribution at central-positioned elements.

In order to scrutinize the effect of creep rate on the local flow field, the dryout power variation for each element is examined. Among 19 elements, the elements on the vertical centerline are considered since these elements experience the largest variation of property by the buoyancy effect. Figure 3 shows the dryout power at the central-positioned elements for a various creep rate. For the uncrept channel, the elements of the center ring and inner ring in the upper region are shown to have the minimum dryout power. As the creep rate increases, the dryout powers of elements decrease for all the elements. It is important to note that the elements in the upper region experience a larger decrease of dryout power rather than the elements in the lower region. The buoyancy drift always acts in such a way as to transfer void towards the physically higher subchannel. Hence, the properties are varied more steeply in the upper region and the effect of creep rate on the dryout power is well reflected on the elements in this region. In acutal, the element of number 5 in a middle ring has the steepest decrease of dryout power and it results the first dryout to occur on the middle ring for 5.1% creep rate as shown in Fig. 2. It is noted that the elements of most outer ring in the upper region has a slight variation of dryout power, in different with the elements of the other rings, since there are the increased bypass flow with a diametral creep.

The flow enthalpy variation in the subchannels on the vertical centerline are examined in Fig. 4. As the creep rate increases, the flow enthalpies of subchannels tend to increase for all the subchannels. The mixture enthalpy peak has been found to be in the central region of a fuel bundle due to the smallest flow rate in spite of the low ring power ratio.

If we consider the subchannels neighboring the central fuel element, the mixture enthalpies in the upper subchannels are consistently higher than those in the lower subchannels. Also, the enthalpy variation by the creep rate is larger in the upper region, which is in line with the results of Fig. 3. It can be explained from the gravity effect since the fuel element powers are symmetric around the central fuel element.

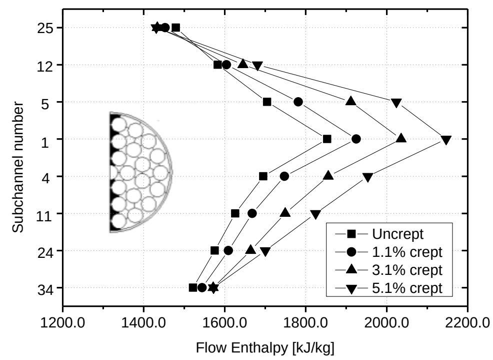


Fig.4 Flow enthalpy at central-positioned subchannels.

4. Conclusions

As the creep rate increases, the dryout power of each element tends to decrease, while the flow enthalpy to increase. Especially, the elements in the upper region have the larger variation of dryout power as well as property rather than those in the lower region. As the creep rate increase, the element of a middle ring in the upper region experience the steepest decrease of dryout power, which results the first dryout of fuel bundle to occur in the middle ring for the creep rate over 4.0%.

ACKNOWLEDGMENT

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