Effect of Partially Bowed Heated Rod on DNB in Coldwall Thimble Cell Geometry

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A series of test programs to determine the effect of a bowed rod on departure from nucleate boiling (DNB) in a coldwall thimble cell (a flow channel formed by three heated rods and an unheated control rod guide thimble) of a pressurized water reactor has been completed. This note briefly describes the concluding test which was done with a partially bowed (85% of the maximum possible closure) rod.

The effects of a rod bowed to contact in a thimble cell have been determined in the previous tests(1). The results of those tests indicated that there was no effect at low pressures (105 and 127 ata) and that at high pressure (148 and 169 ata) the effect of a rod bowed to contact was to cause a decrease in DNB heat flux, and that the magnitude of the reduction was given by a function of rod average heat flux and pressure.

Because heated rods bowed to contact have not been observed in irradiated reactor cores, it was decided to conduct a test more representative of the partial gap closures which are more often observed.

The bow geometry selected for this partial bow DNB test was one in which a heated rod was bowed into a thimble cell toward another heated rod and an unheated thimble tube. The results of this new test, combined with the previous results for contact (100% closure) and for no bow (zero closure) thus provide the data to describe the effect of rod bow on DNB as a function of gap closure.

REFERENCES

1. Test Description

The test was carried out in the same test loop of Columbia University as the previous bowed-to-contact test\(^1\). The parameter ranges and the test section geometry except the amount of bow were also the same as the previous test. Figure 1 shows elevation and cross-sectional view of the topmost span where the bowed geometry was made. One of central heated rods was bowed toward the thimble tube and an adjacent heated rod so that the minimum gaps between the bowed rod and these nearby rods were 15% of nominal gaps. The 85% of rod bow was selected from the standpoint that the amount of bow is sufficiently large compared with the observed bow data in operating reactors. Special care was taken to ensure that the heated rod gap was maintained to the desired value during the test. Thermocouple location and their installation method are the same as the previous test.

![Figure 1 Test section geometry of partial bow DNB test](image)

2. Results and Analysis of Data

Examination of the location of observed DNB signals showed that DNB signals at low pressures were mostly observed at T/C #2 and at high pressures, they were mostly observed at T/C #4. This pattern was similar to that for Unbow case\(^1\).

The method of data reduction for 85% closure test was the same as the previous test\(^1\). The measured-to-predicted DNB heat flux ratio \((q''_{\text{meas}}/q''_{\text{pred}})_{\text{pb}}\) was calculated by the W-3 correlation and the modified spacer factor\(^2\) based on coolant conditions calculated by the COBRA-III code\(^3\). The partial bow effect parameter \(\delta_{\text{pb,meas}}\) was given by

\[
\delta_{\text{pb,meas}} = \left( \frac{q''_{\text{meas}}}{q''_{\text{pred}}}_{\text{no bow}} - \frac{q''_{\text{meas}}}{q''_{\text{pred}}}_{\text{pb}} \right)
\]

where, \((q''_{\text{meas}}/q''_{\text{pred}})_{\text{no bow}}\) was given by the average of the original\(^4\) and unbow data\(^1\).

Figure 2 shows plots of \(\delta_{\text{pb,meas}}\) vs. inlet pressure, and the repeatability limits of ±12% as shown in Ref. (1). These plots show that the 85% bow closure effect is much smaller than was observed for the contact bow. Nevertheless, the effect is large enough to be measurable. There is no discernible effect at low pressures (105 and 127 ata) but a definite effect at high pressures (148 and 169 ata).

![Figure 2 Partial bow effect parameter \(\delta_{\text{pb,meas}}\) vs. inlet pressure](image)

The plots of \(\delta_{\text{pb,meas}}\) indicate that the partial bow data are qualitatively similar to contact data, though much smaller in magnitude. It was thought, therefore, these data can be correlated by a simple extension of the contact bow correlation \(\delta_{\text{bow,pred}}\), which was given in Ref. (1). The ratio of \(\delta_{\text{pb,meas}}\) and \(\delta_{\text{bow,pred}}\), \(F_{\text{pb}}\), was calculated for each data point,

\[
F_{\text{pb}} = \frac{\delta_{\text{pb,meas}}}{\delta_{\text{bow,pred}}}
\]
Figure 3 shows the plots of $F_{pb}$ vs. local mass velocity $G_{loc}$, and the best fit line of the plots.

![Graph](image)

**Fig. 3** $F_{pb}$ vs. local mass velocity

Using the best fit of plots of $F_{pb}$, the 85% gap closure bow effect parameter $\delta_{pb}$ can be correlated by

$$\delta_{pb, pred} = F_{pb} \delta_{bow, pred}.$$  \hspace{1cm} (3)

Figure 3 also shows that at a typical PWR operating condition which has the local mass velocity of about $10^7$ kg/hr·m$^2$, the reduction of DNB heat flux for 85% bow is about 1/3 of that for contact bow. This means that when a small gap exists between rods, the reduction of DNB heat flux will be much less than the contact bow case.

3. Conclusions

The results of this test permit the following conclusions to be drawn:

(1) The effect of partially bowed heated rods on DNB is much smaller than that of heated rods bowed to contact. This effect is only slightly greater than repeatability.

(2) The effect of partially bowed heated rods resembles that of heated rods bowed to contact in that it is seen only at high pressure.

(3) The reduction of DNB caused by partially bowed heated rods can be correlated by a modification of the thimble cell contact bow correlation. This modification is in the form of a partial rod bow factor which is a function of flow.

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**References**


