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Orifice Erosion Effect on Channel Flow in CANDU6 Reactor

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1. Introduction

Carbon steel feeder thinning due to flow accelerated corrosion in the mild steel feeders of a CANDU 6 reactor is a contributing factor to premature and hugely expensive replacement of the reactor core in a process termed as refurbishment. There are three contributing factors to this erosion. The first is a poor choice of material ASTM SA 106-Grade B low chromium steel which may have a Chromium content as low as 0.04% out of a maximum possible in that grade of 0.4%. This makes the feeders susceptible to higher rates of oxidation and erosion. The second is the naturally occurring Flow Accelerated Corrosion (FAC) and the third is a not-optimum fluid chemistry control leading to continued inclusion of solid particles eroded from the extraordinarily large surface area of carbon steel piping in the reactor core and its deposition onto downstream surfaces. Wall thinning in feeders has been estimated as being of the order of 150 μm/year and results in changes in overall core thermal hydraulics that is rarely captured in safety assessments.

The flow restriction orifices installed in 200 of the 380 inlet feeders also become subject to degradation as their surface erode further due to flow accelerated corrosion of these components that see higher flow velocities than the pipes within which they are mounted. There are no data available on the state of these orifices as they are typically located in the upper end of the feeder, half way or higher onto the headers and all feeder thinning measurements have only been made close to the end fittings.

Flow orifice erosion is subject of some concern in chemical and process industries as it affects system and instrumentation reliability. It is now being investigated for CANDU reactors, where a large number of fuel channels sport flow reduction orifices. Effect of erosion of pipes (feeder thinning) that these orifices are installed in, goes hand in hand with erosion of flow orifice surfaces. The effect of former has been documented and parametrically analyzed for all 380 fuel channels using the channel thermal hydraulic codes PTLEAK [1, 2] and PTCRACK [3, 4].

This report summarizes the pertinent information about these feeder orifices and presents the effect of their degradation on individual channel thermal hydraulics. The net effect of these geometric changes on normal operation is estimated and recommendations made on safety assessments that must be undertaken to demonstrate their effect on analyses used for licensing. Under normal conditions, the net effect of orifice degradation will be reducing the channel flows in the critical inner 180 fuel channels that are not orificed as flow resistance within the outer channel flow paths decreases.

2. Flow Reduction Orifices in CANDU6 PHWR

In CANDU 6 reactors at Wolsong site, low orifices are installed in 200 of the 380 outer fuel channels to reduce the flows to try to match the desired ratio of thermal power to channel flows as part of the flow-power matching in fuel channels whose powers range from 2506 to 6210 kW and flow through feeders that must remain of a limited number of standard sizes and a whole range of flow paths as shown in Fig. 1.

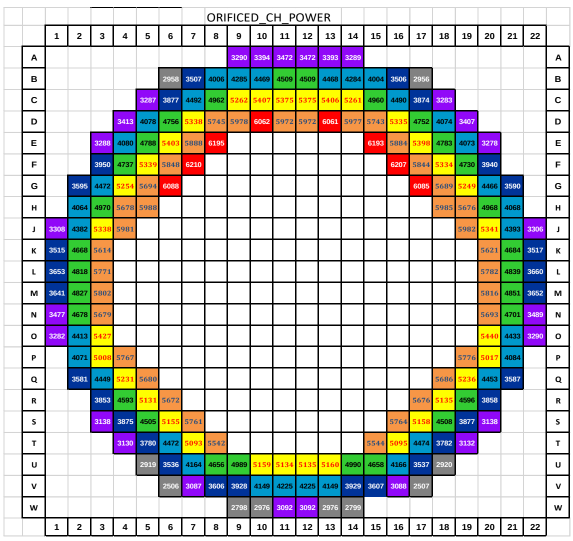

Fig. 1. Identification of CANDU 6 fuel channels that have flow reduction orifices installed in their inlet feeders.

It is evident that the Orifices are installed for the purposes of providing a flow power match in outer channels representing a full range of channel powers. The nominal flows through these channels are summarized in Fig. 2. Not all channels are orificed the same. The effective K factor (determined primarily by the ratio of orifice bore and pipe diameters and orifice shape) for 200 orificed channels is tabulated in Fig. 3.

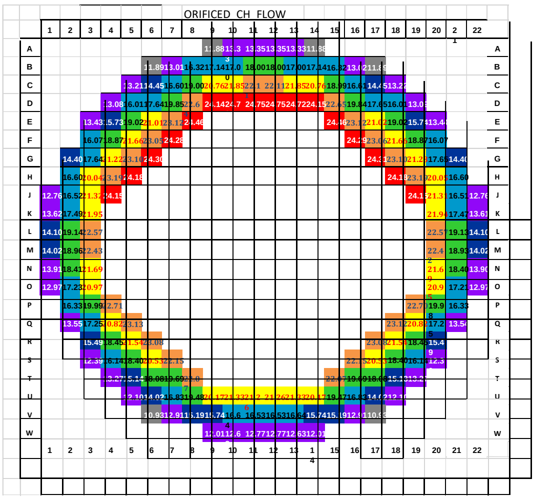

Fig. 2. Computed nominal flows through the Orifice channels.

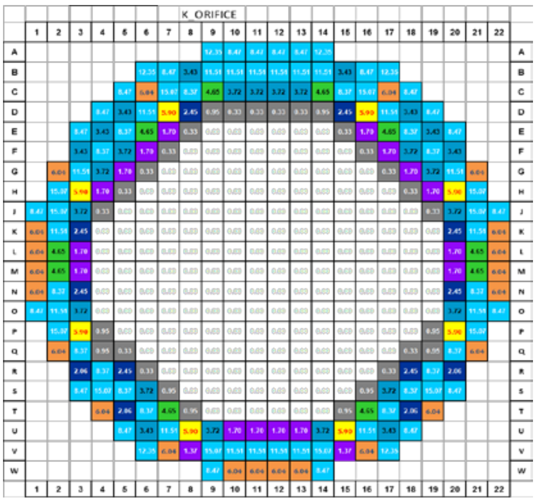

Fig. 3. Effective orifice flow resistance coefficient K value

It is interesting to note that the extent of flow power linearity achieved by installation of flow modulation orifices as shown in Fig. 4.

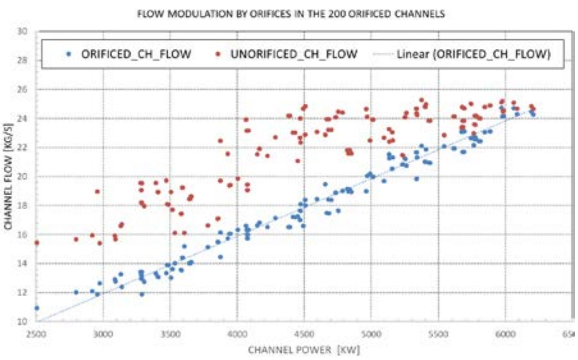

Fig. 4. Flow-power relationship in orificed/unorficed channels.

3. Effect of Orifice Erosion on TH Characteristics

The specified resistance coefficients of these orifices vary over a wide range from 0.2 to 15.6 in the two pipe sizes of 38.1 and 49.2 mm internal diameter (schedule pipe sizes 1.5 and 2.0 inches) based on the following equation for the full channel flow (Re > 10^5).

$$K = [(1-\beta) + 0.707 \cdot (1-\beta)^{0.375}]^2 \cdot [\beta]^{-2}$$

$$\beta = [\frac{d}{D}]^2,$$

D: feeder pipe internal diameter, d: orifice diameter

Figs. 5 and 6 show the K factor change due to the orifice degradation of 2 mm for the 49.2 mm and 38.1 mm feeder sizes, respectively. For example, in the case of channel A14, the inlet feeder pipe diameter at the orifice location is 49.2 mm and the K factor is 12.35 and after 2 mm change in orifice bore diameter (equal to 1mm wall thinning), the K factor changes to 8.47 and it means a drop of 31.3 %. This drop can now be applied to evaluation of channel flows to estimate the change in channel flow due to orifice degradation.

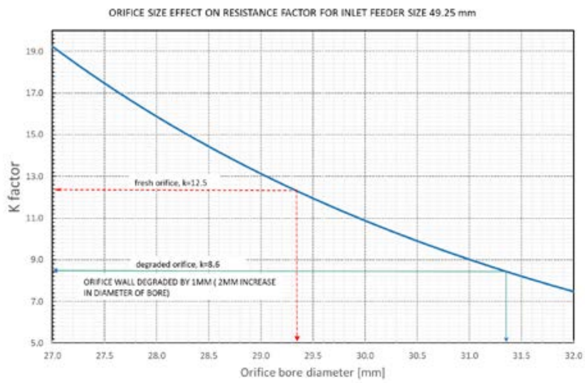

Fig. 5. Effect of erosion in an orifice in a 49.2 mm inlet feeder.

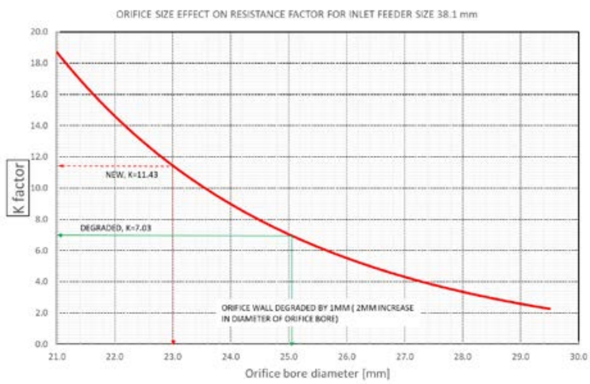

Fig. 6. Effect of erosion in an orifice in a 38.1 mm inlet feeder.

A global effect of 10% reduction in effective K factor on channel flows is summarized in Fig. 7. Analyses were conducted using the channel thermal-hydraulics computer code PTLEAK [1, 2] by assigning a 10%

smaller contribution of the orifice flow resistance in the pipe element of the inlet feeder that houses the flow reduction orifice. A reduction in flow resistance causes an increase in channel flows, assuming that the header conditions do not change. Effect is larger in those channels that have the largest pressure drop in the feeders. These typically as low power channels.

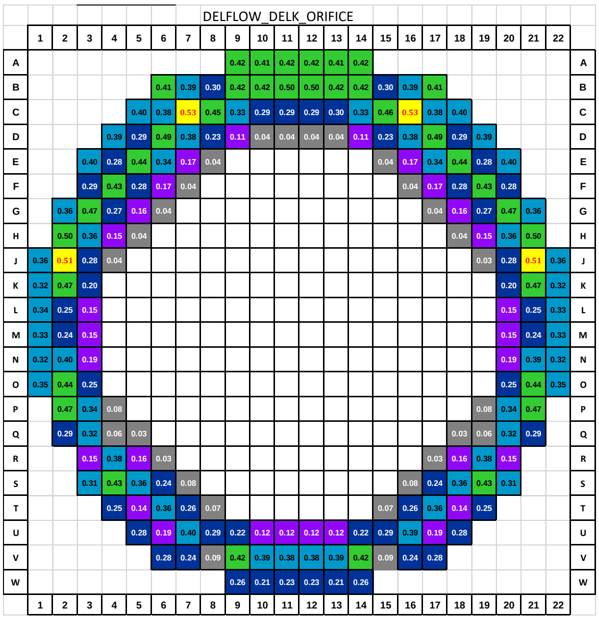

Fig. 7. Increase in flow (kg/s) due to a 10% degradation of flow orifice k factor.

Net effect of erosion is to reduce the value of effective K factor. Each orifice will be affected differently. A comprehensive analysis will also require consideration of effect of inlet flow velocity and effect of solid particle size.

4. Conclusions

200 out of 380 fuel channels include a flow reduction orifice. Effect of these orifices is to modulate the channel flow towards a desired constant flow to power ratio – also termed flow-power matching. Their net effect in actually creating a constant flow to power ratio has mixed results, i.e. is not very sharp, as summarized in Fig. 4. There are no data available on actual degradation of flow modulation orifices. The effect of degradation of these orifices as summarized above in a sample degradation of 10% is minor.

ACKNOWLEDGEMENTS

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