Assessment of Operating Margin Recovered by the Steam Generator Tube Inside Cleaning for CANDU6

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1. Introduction

Since Wolsong-1 started its commercial operation in 1983. The plant has experienced aging behavior in many aspects. Specifically, aging in primary heat transport system, caused by CANDU-6's inherent design, can affect the cooling of the fuel. This may reduce the margin to Onset of Intermittent Dryout (OID), similar concept to Departure from Nucleate Boiling in Pressurized Light Water Reactor. The magnetite dissolved from the carbon steel feeders and Deposited on the relatively low temperature part of heat transport system degrades the heat transfer efficiency. Steam generator primary side cleaning was implemented for Wolsong-1 in the year 2003 and the benefit of it was assessed.

2. Heat transport system degradation

The core of CANDU6 is subdivided into two symmetrically located figure of eight loops. Each loop consists of two core passes of 95 channels each. Each pass contains a pump feeding an inlet header connected to 95 inlet feeders connected to the channels as described above. The 95 outlet feeders connect to an outlet header. Two riser pipes connect the outlet header to the hot leg side of a steam generator. Coolant flows through the vertical steam generator U-tubes to the steam generator outlet where it flows to the pump suction line of the pump in the other core pass in the loop.

Dissolution of iron and flow accelerated corrosion (FAC) is occurring in the outlet feeders. Iron is being dissolved from the outlet feeders and being re-deposited in the cold part of the circuit, including the cold leg of the steam generators, the inlet feeders, and possibly the first section of the channel. Figure 1 shows the concentration of magnetite through the PHTS. The magnetite layers cause both a fouling of the inside of the steam generator tubes, leading to reduced heat transfer, and also an increase in hydraulic resistance in the steam generator tubes and inlet feeders. This has a negative effect on core flow, on inlet header temperature and, consequently, on Critical Channel Power [1].

3. Steam generator tube cleaning

Siemens developed special equipment, SIVABLAST^{TM} , blowing small steel balls into the tube to wear the deposits away from the tube wall. Mechanically cleaned tube has less hydraulic resistance and better heat transfer efficiency. Reduced hydraulic resistance in the steam generator tubes increases the steam generator outlet pressure and inlet header pressure. If the flow resistance of below header components remains the same, increased inlet header pressure means more driving force of flow through the core. More efficient heat transfer from primary side to secondary side through steam generator tubes decreases the temperature of primary coolant at steam generator outlet plenum and reactor inlet header. Coolant having a little lower temperature at inlet feeder has more margin to dryout at the same reactor power level.

4. Operating condition changes

During the 16th planned overhaul of Wolsong-1 in the year of 2003, all the steam generators were cleaned by SIVABLAST^{TM}. Operating data acquired at Jan. 31 and Oct. 22, 2003 are used to observe the changes in operating condition. Wolsong-1 had experienced a transient in operating condition for 8 months right after the steam generator cleaning. After waiting for the heat transport system find an equilibrium condition, operating data were acquired at Oct. 22. Table 1 shows the changes in the major operating parameters. The reactor inlet header temperature decreased by 1.6°C and differential pressure between headers increased by 53kPa in average. The flow rate increased by 2% than the value before cleaning. Gentilly-2 in Canada, reference plant of Wolsong, had cleaned its steam generators in 1999, and resulted in inlet header temperature decrease by 3°C and flow rate increase by 5% [2]. The less effect in Wolsong-1 is judged by the less total mass of gathered magnetite. However, these changes result in more margin to dryout.

5. Assessment of operating margin recovery

Results of ROP analysis at 5726 EFPD (Nov. 2001) was used as the reference case before steam generator cleaning. The prediction curve of ROPT set point considering pressure tube creep only was used to estimate the ROPT set point after steam generator cleaning condition. And an assumption that the PHT operating condition degrades with the trend at that point (i.e. at 5726 EFPD) and none remedial measures are applied. Full scope of ROP analysis was done at 6382 EFPD (Oct. 2003) with applicable operating condition and creep data at that point.

Comparing the analyzed ROPT set points before and after the steam generator primary side cleaning, ROPT set point has increased by 4.26%. For the reference, Gentilly-2 had margin recovery by 4.9% through steam generator primary side cleaning.

6. Conclusion

Reactor inlet header temperature, inlet header and outlet header differential pressure and outlet header pressure are not only the most representative parameters of HTS condition but also the index of aging. Due to the CANDU-6's unique design, magnetite is dissolved from outlet feeders made of carbon steel and deposits on the steam generator tube inside. This results in increase of hydraulic resistance through the primary coolant pass flow and reactor inlet header temperature due to less heat transfer efficiency. By the mechanical cleaning of steam generator tube inside wall, thermal hydraulic condition of PHTS has been improved and margin to dryout has been recovered by some amount. It can be concluded that steam generator primary side cleaning has some effect on thermal hydraulic condition improvement and other measures such as steam drum pressure reduction can also be considered to reduce reactor inlet header temperature.

References

[1] W.J. Hartmann and M. Cormier, "Plant Aging Adjustments to Maintain Reactor Power at The Point Lepreau Generating Station", The 5th International Conference on CANDU Maintenance, 2000 Nov.

[2] Rene Pageau et al., "Gentilly-2 Full Power Operation History and Future Challenges", The 21st Annual Conference of CNS, 2000 June.

Table 1 Operating parameter changes after S/G cleaning

Operating data	Before cleaning	After cleaning	Difference	%
RIH Pressure(MPa(a))				
RIH2	11.145	11.266	0.121	1.08
RIH4	11.126	11.253	0.127	1.15
RIH6	11.153	11.272	0.119	1.07
RIH8	11.159	11.287	0.128	1.15
RIH Temperature(°C)				
RIH2	263.83	262.59	-1.24	-0.47
RIH4	263.72	262.34	-1.38	-0.52
RIH6	264.07	262.10	-1.97	-0.75
RIH8	264.09	262.27	-1.82	-0.69
RIH-ROH Δ P (kPa(d))				
Pass23	1247.44	1295.87	48.42	3.88
Pass41	1198.52	1257.57	59.05	4.93
Pass67	1217.26	1264.14	46.88	3.85
Pass85	1206.52	1264.61	58.09	4.81
ROH Pressure (Mpa(a))				
ROH1	9.876	9.939	0.063	0.63
ROH3	9.884	9.943	0.059	0.60
ROH5	9.895	9.959	0.064	0.65
ROH7	9.873	9.930	0.057	0.58
Pump Suction Pressre (Mpa(a))				
HTP1	9.360	9.501	0.141	1.51
HTP2	9.340	9.498	0.158	1.69
HTP3	9.380	9.527	0.147	1.56
HTP4	9.371	9.527	0.156	1.67

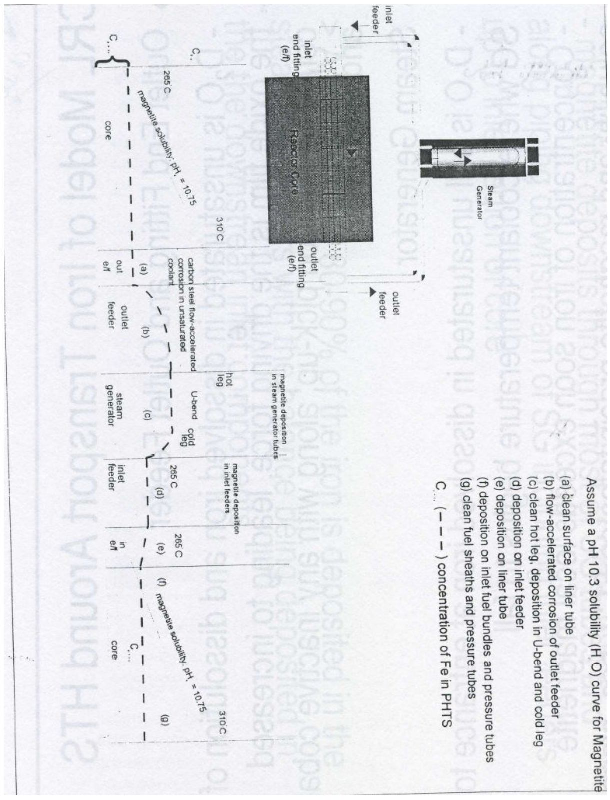

Figure 1 Concentration of Magnetite in PHTS