Minor Design Changes for Controlling Reactor Inlet Header Temperatures in CANDU Reactors

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Abstract

Most CANDU operators are dealing with increasing Reactor Inlet Header (RIH) Temperatures. Expensive Steam Generator (SG) tube cleaning campaigns have been executed on a number of units with varying degrees of success. Other operators have resorted to boiler pressure reductions, which in some cases is leading to unit deratings and lost production. Several minor design changes were evaluated as an alternative means for controlling RIH temperature. The general conclusion of the study is that in the right circumstances, minor design changes can provide a cost effective means of controlling RIH temperatures by avoiding or deferring repeated Inner Diameter (ID) SG tube cleanings and/or additional power deratings.

1. Introduction

The Reactor Inlet Header (RIH) temperatures have risen more rapidly in CANDU units in general, compared to the original aging predictions. A typical example of the RIH temperature behaviour in recent years is shown in Figure 1. In this example, the RIH temperature increases by approximately 0.3°C/year. Thus, RIH temperatures are monitored and high temperature alarms are required to prevent operation outside the safe operating envelope as supported by the safety analysis.

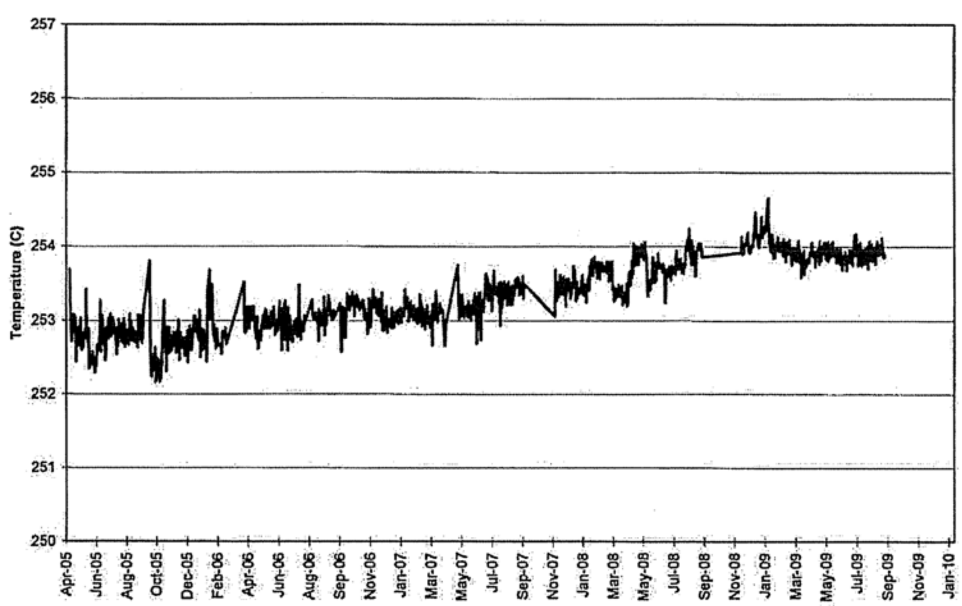

Figure 1 Typical RIH Temperature Trend with Time

To prevent RIH temperature alarms, increasing RIH temperatures are being mitigated through changes in unit operating conditions. Boiler secondary side pressures have been lowered and high pressure (HP) feedwater (FW) heater steam supply has been isolated, often leading to electrical output loss.

The main contributor to the RIH temperature increase is the ongoing accumulation of magnetite deposits on the Inner Diameter (ID) surfaces of both the boiler and preheater tubes. The increasing RIH temperature trends are reviewed annually, and corrective actions such as ID cleaning of the boiler and preheater tubes can be performed to recover lost heat transfer efficiency. However, the execution of ID boiler tube cleaning has not always been successful in providing long-term relief from high RIH temperature alarms. In some cases, RIH temperatures have returned to pre-cleaning levels within as little as three years of operation. Repeat ID boiler tube cleaning is a very expensive means for controlling RIH temperatures. Minor design changes may provide a cost effective means of controlling RIH temperatures as an alternative to ID boiler tube cleaning, and it may also be a cost effective approach to maximize production prior to refurbishment outages. The objective of the work presented in this paper was to evaluate two potential minor design changes in the high pressure feedwater system for the purpose of achieving lower RIH temperatures by reducing preheater / steam generator feedwater inlet temperatures.

2. Feedwater Flow Bypass of High Pressure FW Heater Tube Bundle

2.1 Methodology and assumptions

In a typical CANDU turbine cycle, the HP FW heaters increases the FW temperature from around 150°C after leaving the boiler feed pumps to about 175°C before entering the shell side of the preheaters / steam generators. The RIH temperature is sensitive to FW temperature. For example, a 10°C drop in FW temperatue will result in a RIH temperature drop ranging from 0.5 to 1°C, depending on the preheater/steam generator design. The heating supply to the HP FW heaters is a normally a combination of extraction steam from the HP turbine outlet and drain flows from the moisture separator/reheaters (MSR). A path for the MSR drains must be maintained at high power operation and therefore if the HP heaters are not available to accept the drains, the flow must be diverted to the condenser resulting in high thermal losses. The extraction steam flow to HP heater, however, can be reduced or isolated in such a way that the steam remains in the steam path minimizing thermal losses. Therefore, in order to reduce HP FW heating with the least impact on overall cycle efficiency, normal MSR drain paths must be maintained while reducing the extraction flow to the heaters. In some plants, isolating extraction steam to the HP heaters while maintaining normal drain paths is possible but not in all plant. In the later case, minor design changes could be a better approach for controlling RIH temperatures.

The first minor design change considered was to provide a means of bypassing a portion of the FW flow around the tube side of the HP FW heater, as shown in Figure 2. The objective is to manage high RIH temperatures by reducing FW temperatures while minimizing trade-off in lower cycle efficiency.

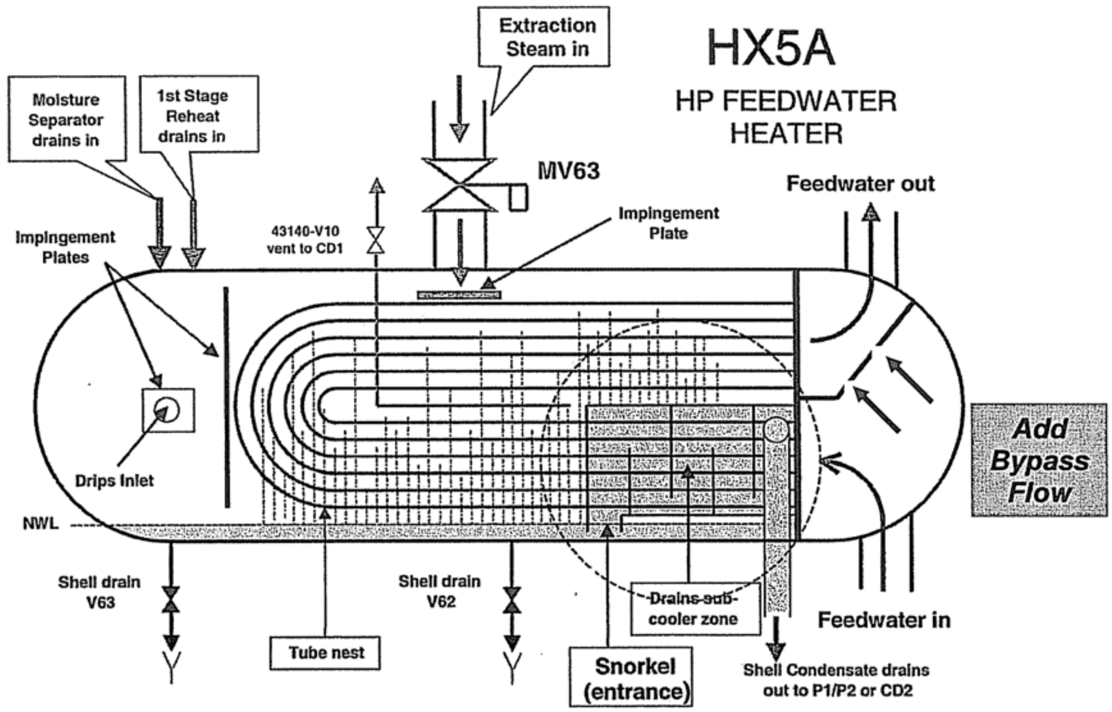

Figure 2 FW bypass flow of HP FW heater tube bundle

The feasibility of the design change was studied using the Performance Evaluation of Power System Efficiencies (PEPSE) turbine cycle modelling software [1] to simulate this minor design change. Due to the complexity of modeling moisture separator drain piping, two bounding cases were simulated with respect to drain flow response to changing conditions in the HP FW heater and impact on cycle efficiency as Best Case and Worst Case. The Best Case assumes that drain flows remain unchanged either by control action or compensating changes in the drain line water column. The Worst Case assumes no control action or change in the drain line water column. In this case, reheating steam load is expected to increase and super heat to the LP turbines is expected to drop resulting in increased cycle efficiency losses. Two sensitivity studies were therefore carried out with varying degrees of FW bypass flow from 0% to 50% of the total FW flow under Worst Case and Best Case conditions.

2.2 Key results

For one case studied, the trends of the RIH temperature drop and MW output loss due to increased FW bypass flow are shown in Figures 3 and 4. If there is 50% FW flow bypassing the HP heater tube bundle, the RIH temperature will drop by about 1.1°C. However, the gross electrical output will also be reduced by between 5.5 MW and 12.8 MW, depending on the overall impact on cycle efficiency as discussed in Section 2.1.

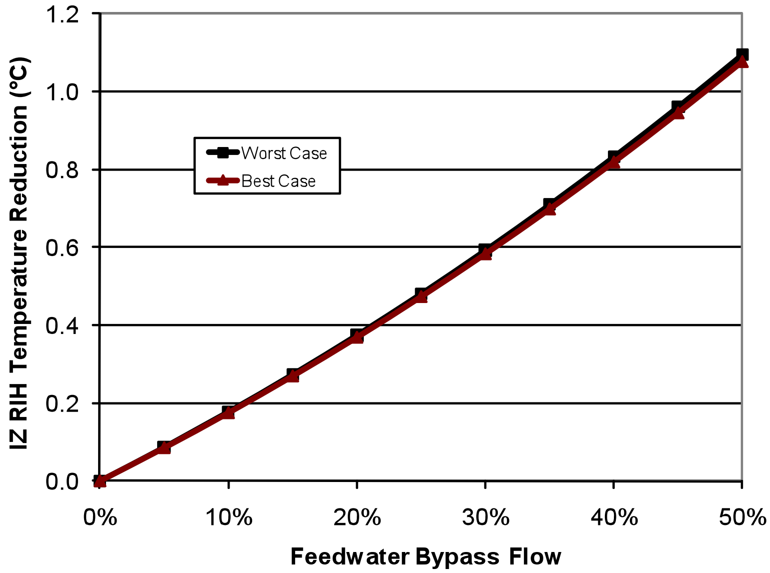

Figure 3   RIH temperature drop due to FW bypass flow

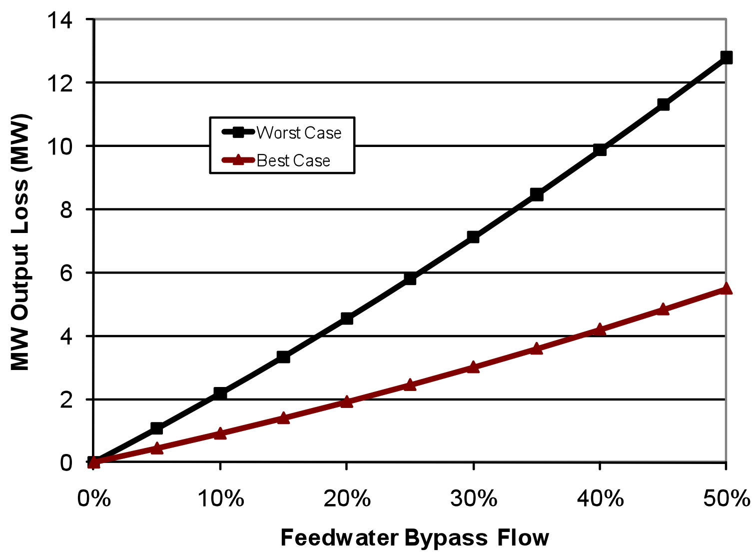

Figure 4   Gross electrical output loss due to FW bypass flow

On the other hand, units that are experiencing high RIH temperatures will often operate at reduced boiler pressures to the point where the turbine governor valves are close to fully open. A secondary consequence of reducing the FW temperature to the preheaters / steam generators is to reduce the steam flow from the boilers for the same reactor thermal power level and thus provide more operating margin for the turbine governor valves. This means that at the same reactor power, the boiler pressure (BP) could be dropped to gain additional RIH temperature margin without additional MW loss. If it is assumed that the BP can be reduced proportionally to the steam flow reduction, the steam flow reduction and the subsequent margin for additional BP reduction are shown in Figure 5. The comparison of MW output loss versus RIH temperature reduction with and without FW bypass flow is shown in Figure 6. Without FW bypass flow, the MW losses are based on the assumption that the main steam flow must be reduced by the amount corresponding to 1%FP for every 1% drop in BP to achieve the same RIH temperature reduction. With governor valves at maximum opening, the percentage change in HP turbine swallowing capacity and therefore MW generation can be considered directly proportional to percentage change in BP. The benefits of the minor design change are therefore more evident when considered in combination with additional boiler pressure reduction afforded by the lower steam flows.

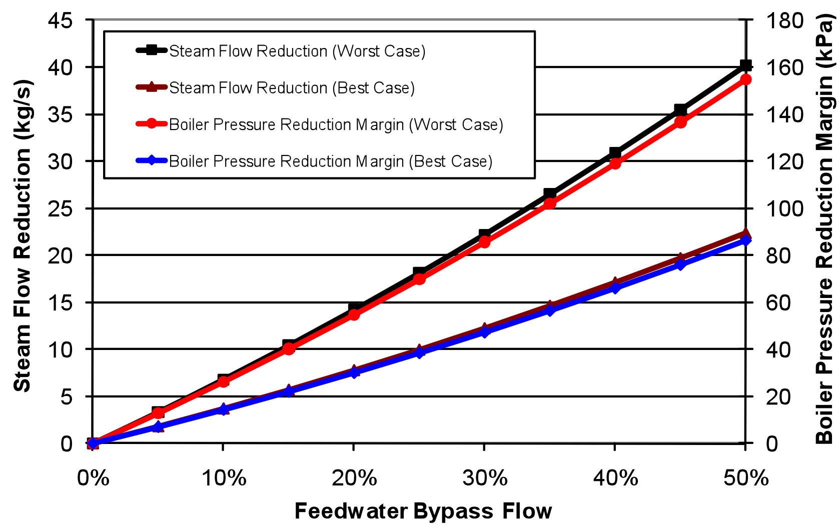

Figure 5 Steam flow reduction and subsequent BP reduction margin due to FW bypass flow

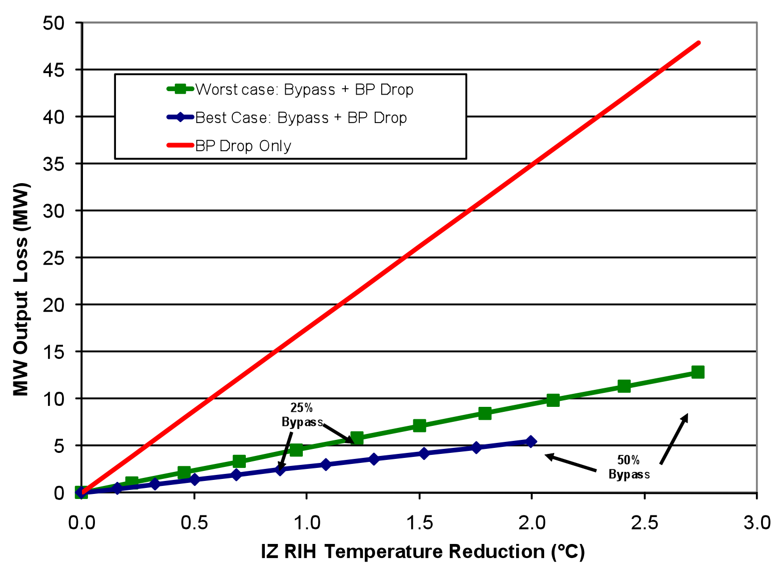

Figure 6 Gross electrical output loss versus RIH temperature reduction

The design envelope for the HP heaters must be considered as part of any design change in the plant. The HP heater shell pressure will be increased due to FW bypass flow, but is expected to be well within the shell design pressure. The FW temperature at the exit of the HP heater tube bundle will also increase and in one case studied the tube design temperature was exceeded if there is more than 30% bypass flow. The impact on the remaining cycle components must also be assessed. In one worst case study, the reheater drains flow increased beyond the reheater drains pump performance capacity with more than 40% bypass flow.

3. Partial flooding of HP FW heater shell side

3.1 Methodology and assumptions

Shell side flooding of the HP FW heaters is an undesirable condition from the thermal performance point of view, but it can provide another means of reducing final FW temperatures for controlling RIH temperatures. As more and more tubes are covered in the horizontal heaters, as shown in Figure 7, the condensing area of the tube bundle is reduced, resulting in less heat transfer and increasing shell side pressure. This option may be effective alone or in combination with a fixed FW bypass flow providing a means of fine tuning final FW temperatures through changes in the heater operating levels.

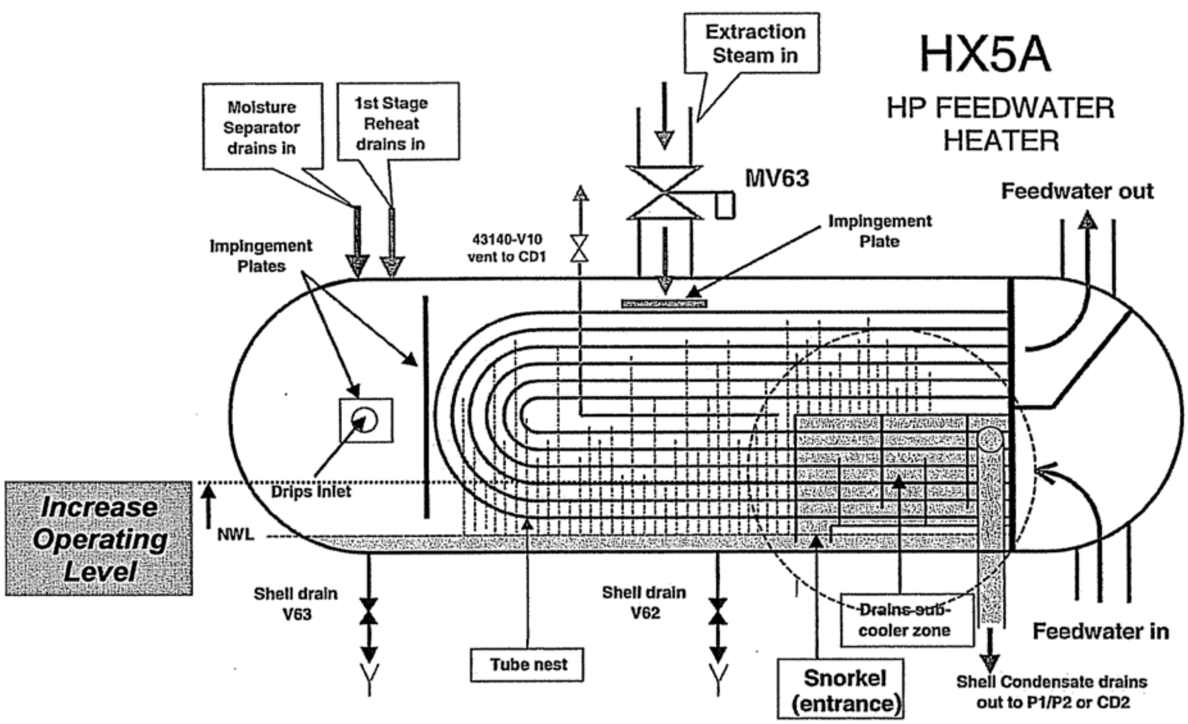

Figure 7 Partial flooding of HP FW heater shell side

The PEPSE turbine cycle model was used again to simulate this design changes and the aforementioned Worst Case and Best Case conditions were also applicable. Two sensitivity studies were carried out with varying amounts of tubing length assigned to the condensing section from

90% (normal operating state) to 70% of the total tubing length of the HP heaters under Worst Case and Best Case conditions, respectively. Structural considerations within the heater shell limited the reduction in condensing tube area to 70%.

3.2 Key results

The trends of the RIH temperature drop and MW output loss due to increased flooding are shown in Figures 8 and 9. If the tubing length assigned to the condensing section is reduced from 90% (normal operating state) to 70%, i.e., the flooded tube length is increased from 10% to 30%, the RIH temperature will drop by about 0.17°C. However, the gross electrical output will also be reduced by between 0.8 MW and 2.3 MW.

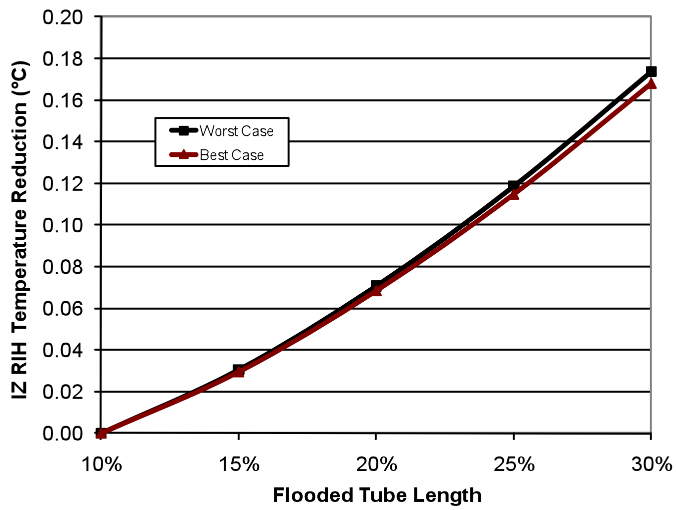

Figure 8 RIH temperature drop due to partial flooding

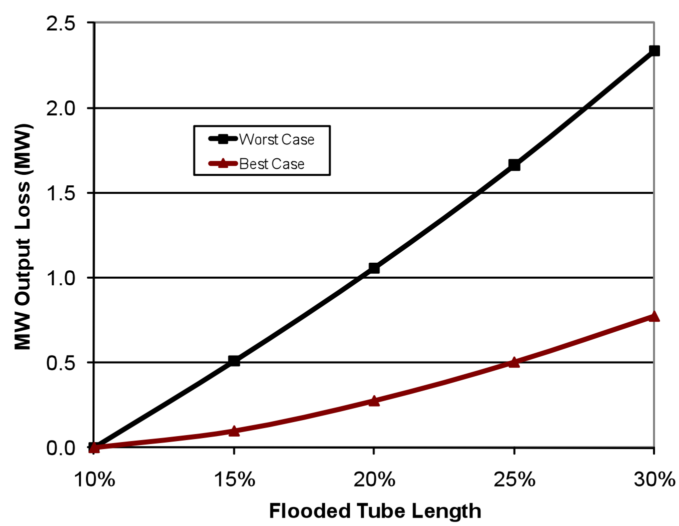

Figure 9 Gross electrical output loss due to partial flooding

Since the turbine inlet steam flow will also drop as the condensing tube length is reduced, as discussed previously, additional RIH temperature drop can be achieved for the same amount of flooding and MW loss. The steam flow reduction and subsequent margin for additional BP reduction are shown in Figure 10. The comparison of MW output loss versus RIH temperature reduction with and without partial flooding is shown in Figure 11.

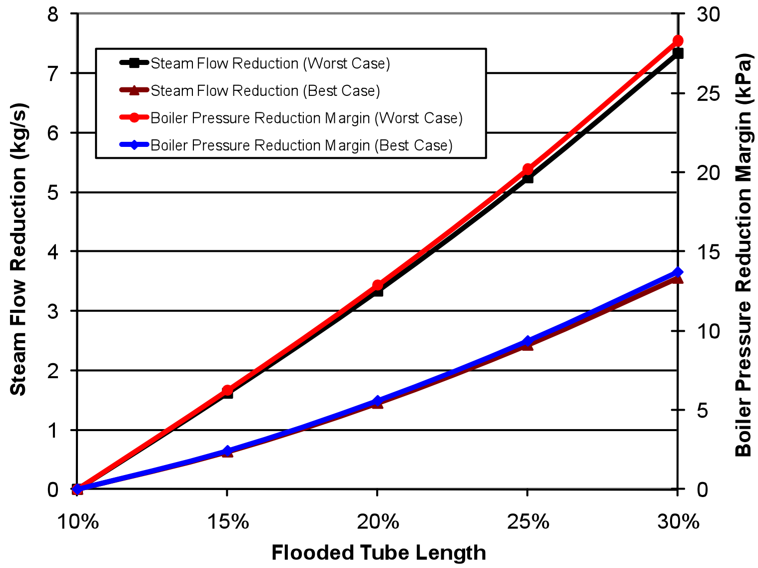

Figure 10 Steam flow reduction and subsequent BP reduction margin due to flooding

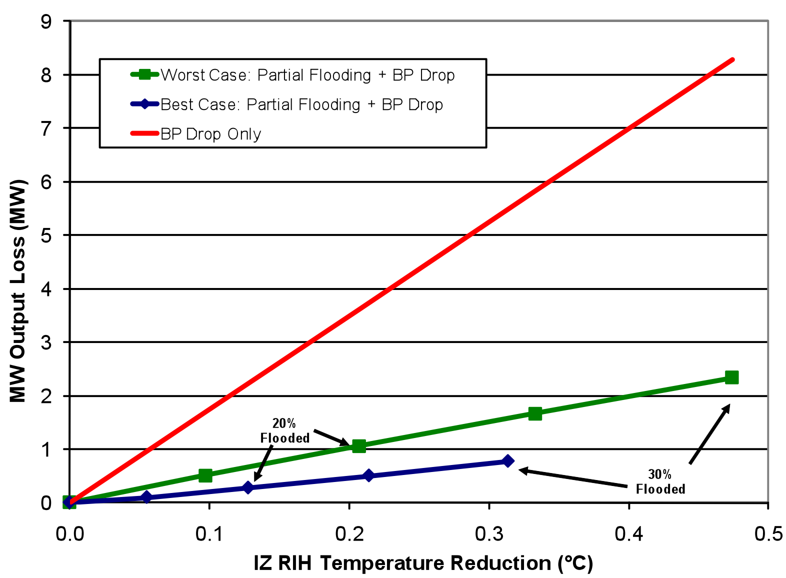

Figure 11 Gross electrical output loss versus RIH temperature reduction

The HP heater shell pressure and reheater drains flow will be increased due to flooding, but are still expected to be below the shell design pressure and the reheater drains pump performance capacity.

4. Conclusions

Based on the feasibility study findings, the design change feasibility is ranked high for HP FW heater bypass flow modification but marginal for HP FW heater level increase due to the significantly lower impact on RIH temperatures. The physical modification to the HP heater can be as simple as drilling holes in the channel partition plate to provide a bypass path for the flow or new bypass piping and valving could be installed around the HP heater to provide a means of adjusting the bypass flow for optimum RIH temperature control. Implementation of the minor design modification can provide significant increases in production over using boiler pressure reduction alone and can also be used to extend operating periods between steam generator cleanings for optimizing outage planning.

5. References

[1] G.L. Minner, et al, “PEPSE User Input Description, representing version 73 of PEPSE – Volume 1”, SCIENTECH a Curtiss Wright Flow Control Company, August , 2008.

6. Acknowledgements

This study was conducted with the assistance of Mr. S. Ho and Mr. L. Lee of AMEC NSS who provided valuable in-sight into the impact of the minor design changes on preheater and feedwater heater operation. Also thanks to the support and interest of Mr. I. Thompson of AMEC NSS, Mr. R. Blackwood, Mr. M. Upton, Mr. K. Sedman, Mr. K. Chuong and Ms. J. Stoklosa of Bruce Power.