GENTILLY-2 MODERATOR HEAT EXCHANGER REPAIR

Prepared by

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1- Summary

At the time of an unscheduled outage for a problem with the fuelling machine, an operator noted a sound coming from the inlet moderator heat exchanger 3211-HX1. The noise was reported as a loose object knocking around between the tubesheet and the inlet piping.

Upon separating the tubesheet from the Heat Exchanger, the tubesheet overlay and tubes extensions were found severely damaged. The repair work would be required to be performed insitu in a highly contaminated environment during end of the year where obtaining manpower resources were difficult. The team work between Hydro-Quebec and Babcock & Wilcox Canada Nuclear Services and use of non-conventional tooling was a big part of the success for this project.

The repair started on December 21st, 2007 and the vessel was turned over to HQ on January 24, 2008.

2- Introduction

On November 9, 2007, while the plant was encountering an unscheduled outage, an operator heard a sound coming from the inlet moderator heat exchanger 3211-HX1.

After recording a video capturing the peculiar sound, HQ forwarded it to B&W to analyze and to estimate what the potential damage / cause could be. Shortly after, the B&W project manager sent this answer to HQ: *"Our acoustics expert seems to think the part is long (approximately 2") flat and approximately ½ "in diameter."*.

The area of concern at the moderator heat exchanger system was isolated permitting radiographic inspection of the inlet/outlet piping to be performed. The purpose was to determine the size and shape of the loose part and prepare potential repair scenarios. The radiography discovered two foreign material (FM) objects shown on Figure 1. After opening the exchanger, two pieces were retrieved from the moderator system. The first was spherical and a little less than 1 in. of diameter. The second was a cylindrical piece, approximately 2 in. long with a diameter of ¾ in. The acoustic expert was right.

After metallurgical analysis, we found that the material was a 304 stainless steel. What was the original size? Where they come from?? We still don't know yet. X-Rays were performed on majority of the valves on the moderator system providing no additional data. Reviewing moderator's chemistry over the months leading up to outage, we may have had a sign that something was going on because we found a high concentration of Cr-51 between July and November. So we think the parts might have been there for at least 5-6 months.

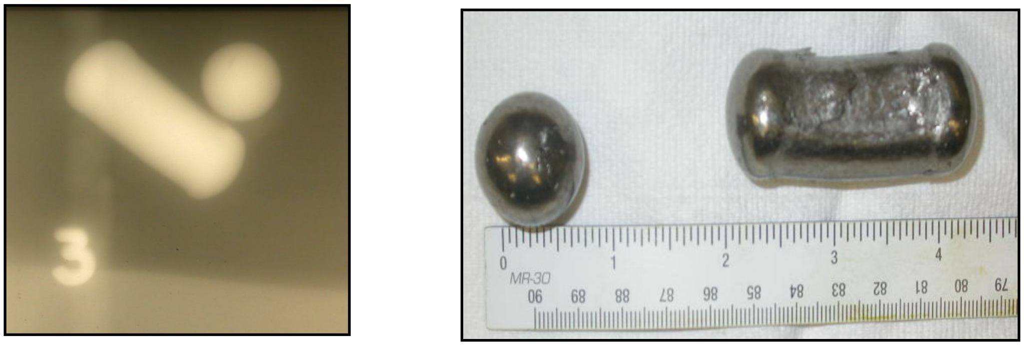

Figure 1 : X-ray from the inlet piping of the heat exchanger and loose parts found

3- 3211-HX1 as found

We had three weeks to prepare for different scenarios (only tube recess, some seal welds, part of the overlay, etc.) because the system was not ready to be drained. The extent of the damage was unknown.

Original tube to tubesheet fabrication consisted of carbon steel plate with a stainless steel overlay and a tube extension of 0.215” with a tube to tubesheet fillet seal weld (Figure 2).

Figure 2 : Original exchanger tubesheet illustrating fillet seal weld

A couple of minutes after the opening of the exchanger, we finally got the extent of the damage.

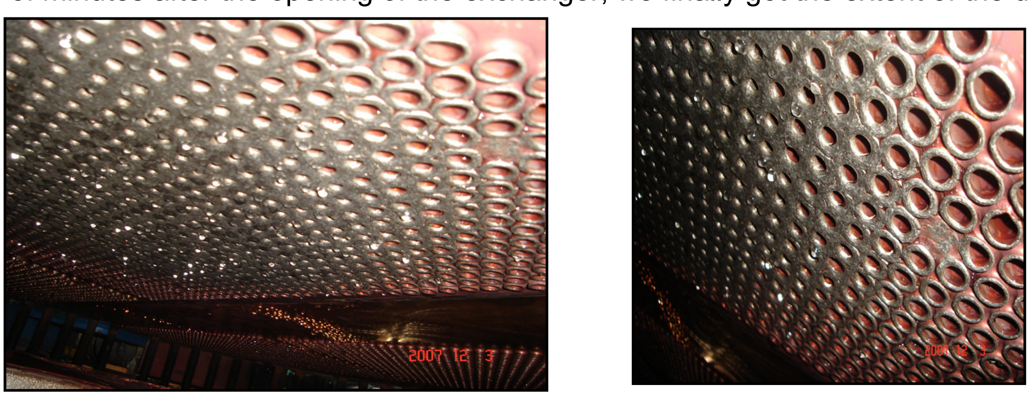

Figure 3 : First view of the damaged tubesheet

Figure 4 is showing the inlet (damaged on the right) and the outlet (untouched on the left) of the exchanger. Almost all of the inlet tubesheet was severely damaged, excepted for some areas on the periphery (lower corners on Figure 4).

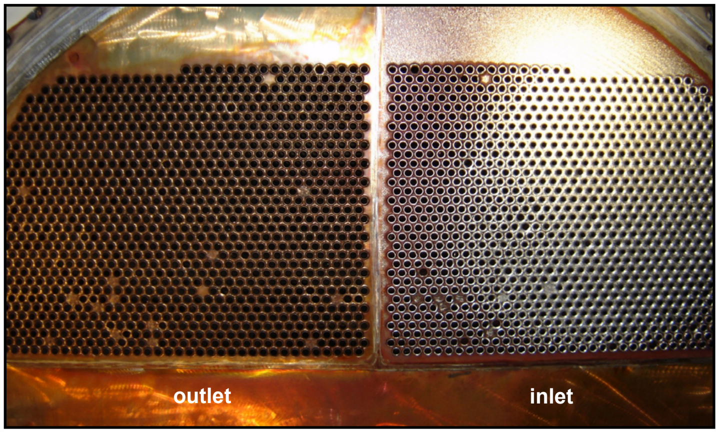

Figure 4 : Underneath view of the tubesheet

Figure 5 is showing a closer look at some of the most damaged areas of the tube sheet. In the most damaged zone, material coming from the tube extension and the seal weld were pushed into the tube ID bore. And the area right over the inlet piping was so damaged that approximately 50% of the damaged tube ends were subsurface of the tube sheet face.

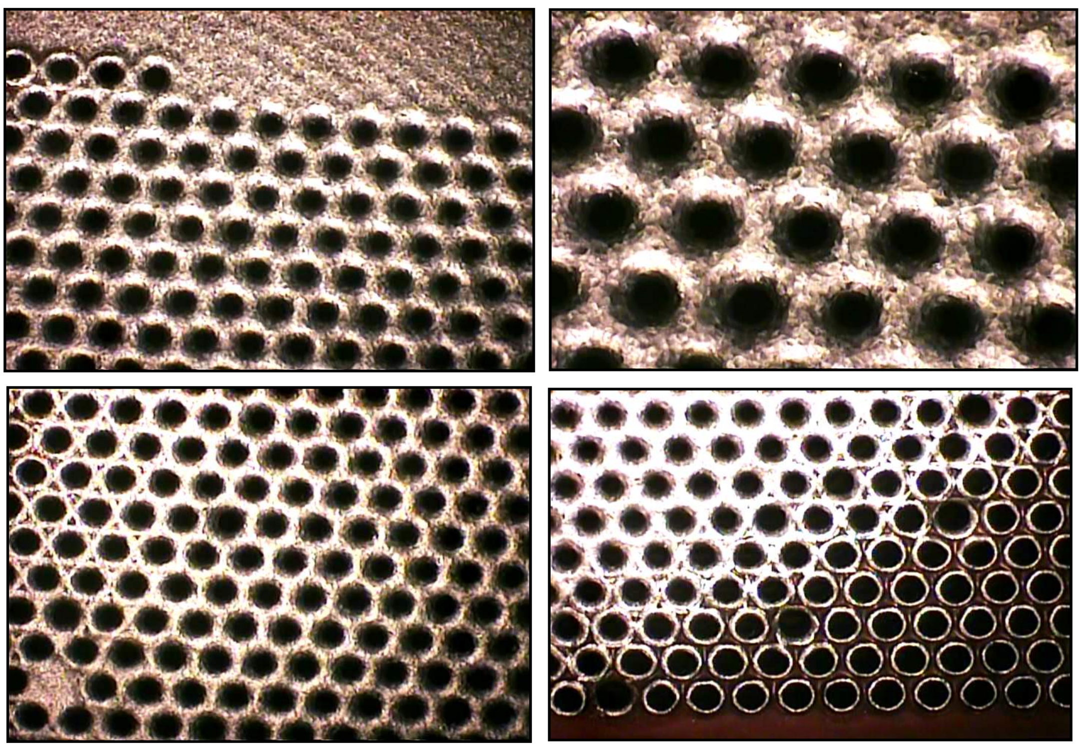

Figure 5 : Pictures of some damaged areas

4- First Stage of Preparing the Tube sheet for repair

The preparation for the repair started well before getting the first pictures of the tube sheet. A replica of the exchanger stand was built to simulate the room under the vessel and a mocked tube sheet was peened. As you can see on Figure 6, the as-found tubesheet was a lot worst than the mock-up.

Figure 6 : Mock-up to test machining

The first step consisted of employing a portable milling machine positioned under the stand as shown in Figure 6. The cutters used are shown in Figure 7.

The zone where the foreign material created the most severe damaged consisted of approximately 50% of the entire tubesheet damaged. This zone consisted of fillet welds peened subsurface into the tubesheet face. The milling machine was only able to work on the tubes on the periphery.

Prior to proceeding further with repairing the damaged tube ends that did not clean up with the milling machine process, engineering was required to determine remaining tubesheet overlay thickness. This value was required to control the maximum overlay material permitted to be removed with the semi-auto process for each individual tube end.

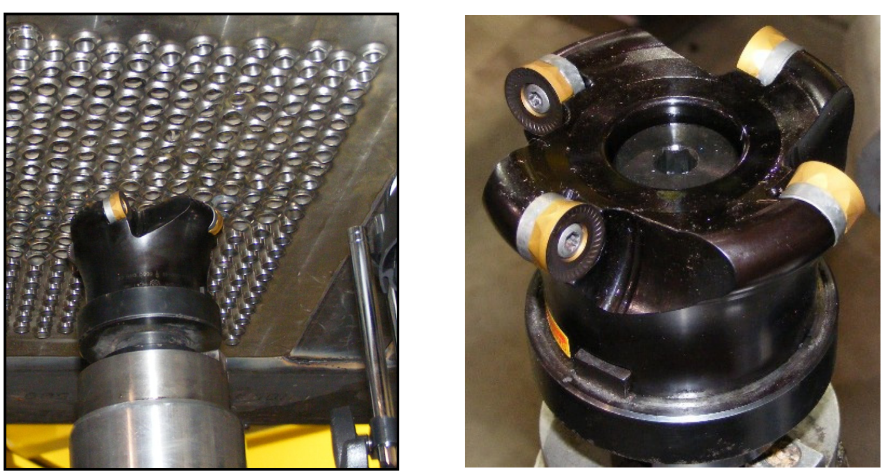

Figure 7 : Cutters used on the portable milling machine

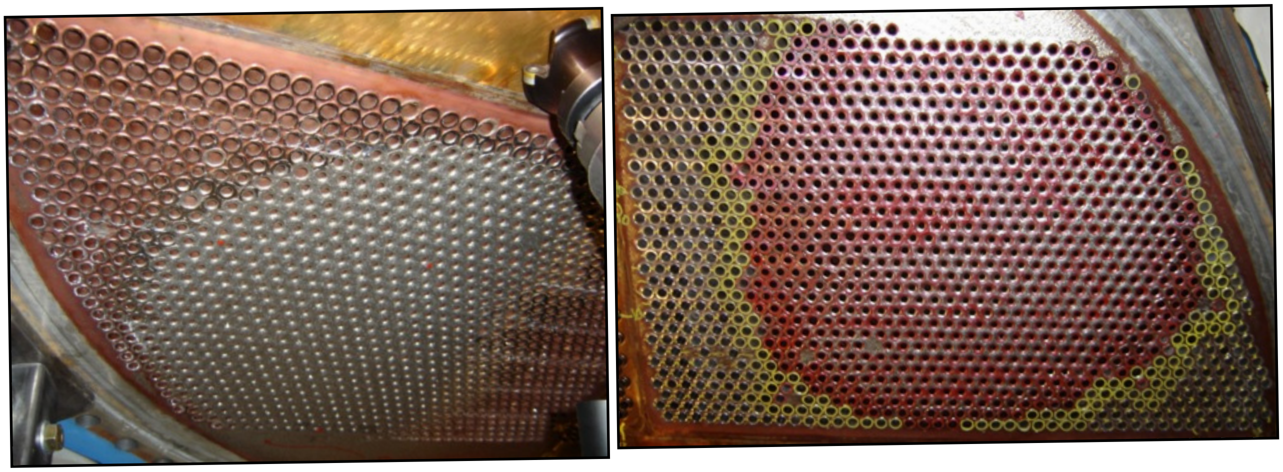

Figure 8 : Tubes machined with the portable milling machine

5- Second Stage of Preparing the Tube sheet for repair

The initial machining process was not capable of reaching this more severely damaged area as the damage surface was dished into the tube sheet surface requiring an isolated cutter to be employed. The isolated cutter was required to remove the peened material out of the tube openings but was compounded due to work hardening of the stainless steel from the foreign material peening.

Using conventional tube end facing equipment, the cutters could not remove the damaged material and the grippers holding the end facing equipment could not remain static. Due to the manual labour required to operate the semi-auto device, the project was experiencing high man-dose exposures and loss of critical path schedule. The face of the tubesheet started off with radiation fields >200 milli-Rem/hr and were reduced to approximately 125 milli-Rem/hr after majority of the damaged tube ends were machined back.

A more robust tool developed by HQ and B&W at the station after a couple of HQ machinists suggested the idea. This setup was capable of facing the tube ends on a first pass and bore part of the tube ID on a second pass. A third step was then necessary using a boring tool to remove the remaining excess ID bore material without removing actual tube material.

The idea was to use a magnetic based drill mounted on a milling plate fixed on the stand and aligned on clean tubes. The plate had 108 holed drilled with the same pitch of the tubesheet with a cutter allowing to end-face the tubes. The depth of machining that was the critical parameter, was controlled with the use of a vernier and by zeroing the magnetic drill on an undamaged tube. The milling plate was aligned using brass bushings (see Figure 9).

The first sets of cutters used were only to machine the tube end. To machine the material pushed inside the tubes, a second pass was made using the same magnetic based drill and milling plate with another type of cutter. This permitted machining the rolled over material peened inside the tube without interfering with the original tube wall thickness. There was basically no margin for error even though the milling plate could not be confirmed to be 100% true to the tubesheet pitch.

To achieve the final boring of the tube, another idea came up from a Hydro-Quebec machinist. It consisted of an air grinder (rotary file) and a carbide cutter / bearing tool that was inserted into a similar tube hole pattern plate (deburring plate) and a brass bushing (Figure 10).

Figure 9 : Magnetic based drill on the mock-up in the shop and the brass bushings used for the alignment of the plate

Figure 10 : Boring tool with the deburring plate

The new setup was tested on a mock-up in the machine shop prior to applying it to the heat exchanger. It provided enough strength and stability to precisely machine the hardened stainless steel.

This setup created a substantial exposure reduction and accelerated the work compared to the conventional tube end facing equipment.

In a span of 8 days, the tooling was developed, tested in the shop and executed on the remaining damaged tubes.

Refer to Figure 11 for photographs of the semi-auto device used and examples of faced tube ends prepared for flush seal welding and to Figure 12 for the final machining result.

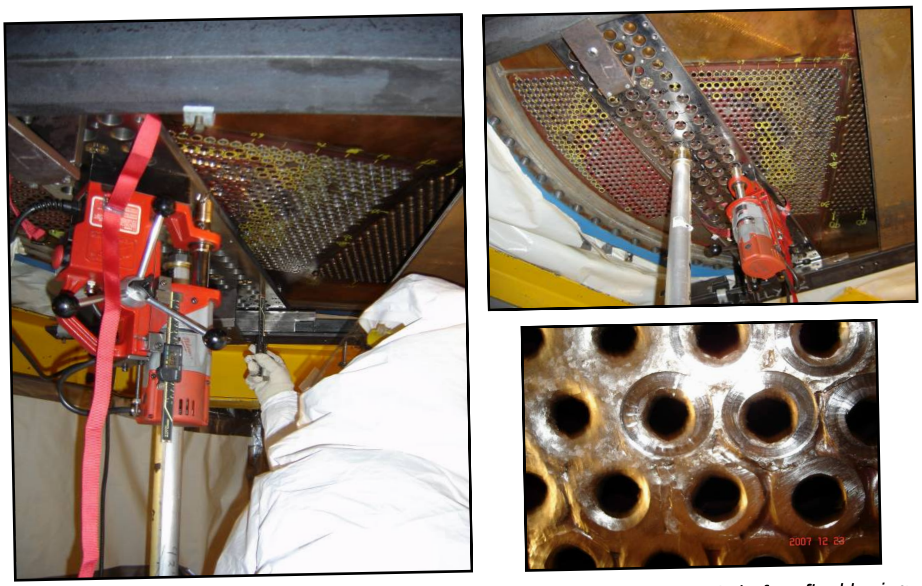

Figure 11 : Semi-Auto End Facing Tool and example of repaired tube ends before final boring

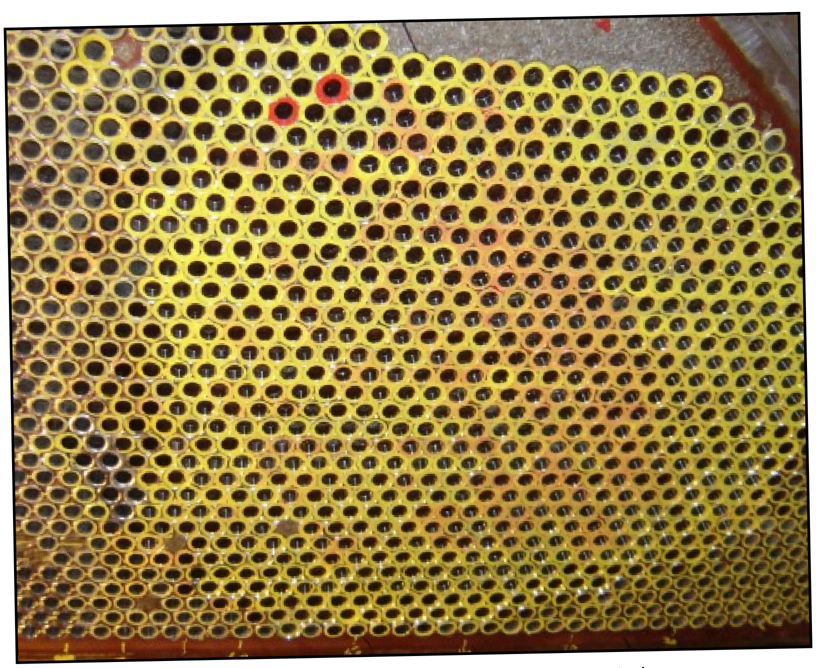

Figure 12 :Tubesheet after machining completed

6- Welding the seal welds

Of the 1200 hot leg quadrant tube ends, 781 of them were so severally damaged they required to be seal weld repaired to recapture minimum leak path requirements. The initial weld repair process consisted of using an automatic autogenous flush seal welding machine. This process also required the weld equipment to be manually manipulated into every tube opening creating the concern of high man-dose exposures and loss of critical path schedule. The option of using remote arm manipulators was not possible due to the limited time for development.

Upon completion of automatic Autogenous seal welding the entire repair area was Liquid Penetrate inspected (LPI). Of the 781 tubes repaired, 1/3rd of them encountered some form of repair after LPI. After another six LPI cycles and 35 tubes manually weld repaired, the repaired tube sheet face was found acceptable to both customer and ASME III & XI code/specifications. Refer to Figure 12 for a photograph taken in the severely damaged zone now repaired and LPI accepted. Only four tubes were required to be plugged, two due to loss of tube wall thickness and the other two due to un-repairable LPI defects.

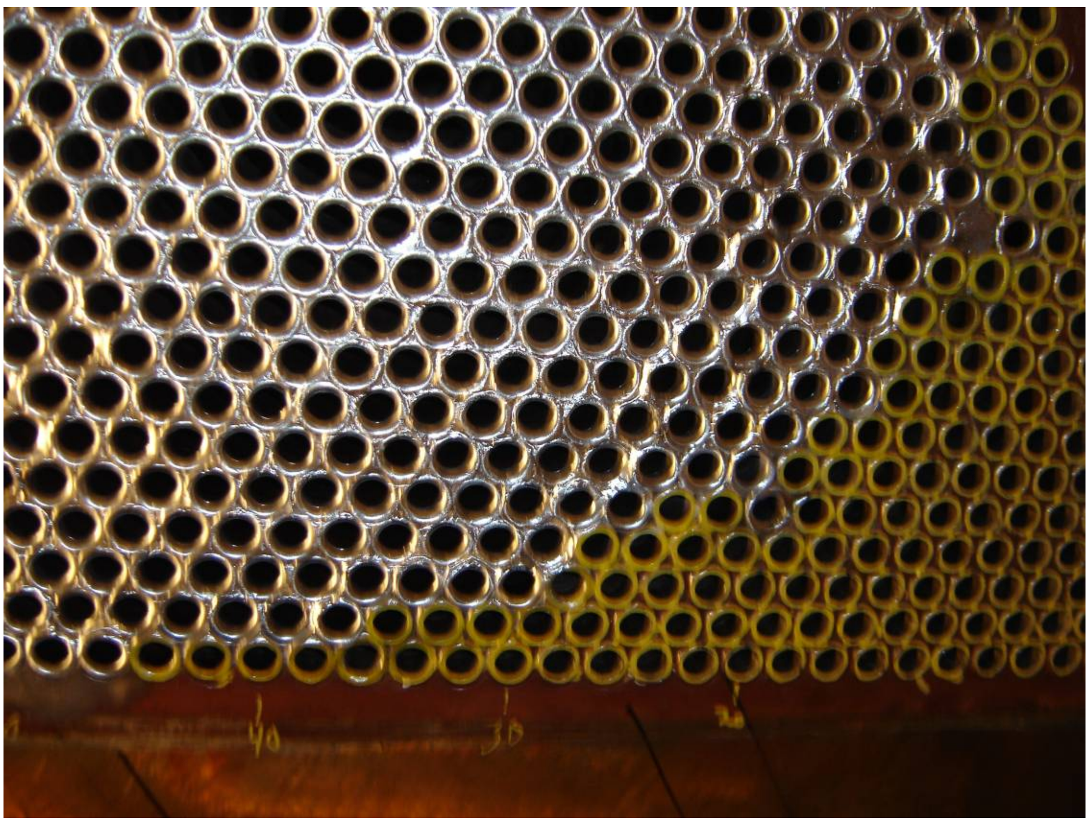

Figure 13 : Photograph of repaired tube ends that were in the severely damaged zone.

7- Conclusion

The Moderator Heat Exchanger with nearly 800 severely damaged tube ends was returned back to service with only four tubes being plugged in a 33 day time period from start of repair execution. No repair on the stainless steel overlay was required.

Without the attention of an operator, the Moderator HX damage and the foreign material itself may have been missed until the next scheduled outage (April 2008) if a failure did not occur before then. No moderator leak was detected in the re-circulated water system prior to the unscheduled outage but the probability of it occurring was likely not that far from happening.

The use of an “old school” machining approach showed to be very effective in the circumstances where schedule and dose exposures were critical.

The team work between the crews, even with the language barrier was a big part of the success.