Abstract

The boilers' generating bank (convective) section began suffering repeated random failures at the Miami-Dade County Resources Recovery Facility. The plant embarked on an optimization program to better identify and target the failures using non-destructive ultrasonic Internal Rotary Inspection Services (IRIS) testing.

Through the use of the IRIS non-destructive testing method, the plant was able to identify 3 major contributors to tube failures by mapping out the locations of the tube wastage across all 4 boilers at the facility. The testing allowed optimizing the use of resources allocated to this area of the boiler and resulted in a considerable drop of unscheduled downtime and increase in generating bank tube reliability.

The IRIS testing method involves an ultrasonic probe that is lowered down the inside of the tubes. The tubes are flooded with water in order to get a full 360-degree thickness survey of the tubes from top to bottom, (steam drum to mud drum). The data for over 4.7 miles (7.5 Km) of linear tube per boiler is recorded digitally and presented on a CD.

By pinpointing the location and severity of tube wastage across the entire generating bank section, the root cause of the failures could be identified. An integrated solution was developed involving a combination of tube replacements, shielding, tube plugging, and soot blower optimization.

This paper summarizes the results of the testing and optimization program.

Background

The Miami-Dade County Resources Recovery Facility is 4,200 tons (3,810 tonnes) per day combined waste to energy and waste processing plant. The plant services the greater Miami – Dade County Florida area by processing approximately one third of the 3.5 million tons (3.2 million tonnes) of waste generated.

The 40-acre (16.2 hectares) site began operations in 1979 and has been retrofitted three times. The first retrofit...
was completed in 1989, which involved changing the waste processing system from a wet to a dry process. This retrofit also included a total rebuild of all 4 boilers, re-using only the existing steam and mud drums and most of the existing structural steel. [1]

The second retrofit completed in 1997 involved upgrading the trash processing system. This retrofit allowed commercial and wood waste including yard waste to be processed into a biomass fuel and a high-grade soil for recycling. This retrofit boosted the facility processing capabilities to over 1.2 million tons (1.1 million tonnes) per year, making it the largest in the world. [2]

The third retrofit completed in 2000 involved complying with the Clean Air Act Amendments (CAA) of 1990 and meeting more stringent air emissions limits. It involved upgrading the air quality control system by replacing the existing Electro Static Precipitators (ESP’s) with Spray Dryer Absorbers (SDA’s) and Fabric Filters (FF) as well as retrofiling the boilers. The boiler retrofit work included a new Over Fire Air (OFA) system, a new Selective Non Catalytic Reduction (SNCR) DeNOx system, and a new propane gas startup burner. See Fig. 1 for a site plan.

Soon after the third retrofit, the boiler availability began suffering from increasing generating bank tube failures reaching an excess of 600 hours across 4 boilers. See Fig. 2 for a graph of the increasing downtime. Typical failures were thin wall ruptures repaired under emergency conditions and resolved by tubes being plugged at both ends, (steam drum / mud drum) and abandoned in place. This method of repair was chosen due to lack of access to the tubes in this section of the boiler. The plant embarked on a reliability improvement program, with a non destructive Internal Rotary Inspection System (IRIS) testing method at the heart of the program.

**Boiler Description**

The facility has 4 identical boilers, originally supplied by Fives-Cail Babcock in 1977. They were demolished, re-designed and rebuilt by Zurn Industries during the first retrofit in 1989 [1]. They are Refuse Derived Fuel (RDF) fired, balanced draft, natural circulation boilers. They incorporate a welded membrane waterwall construction, screen tubes, generating bank section and two stage pendant type superheaters. They are top supported, two-drum, bent tube, single gas pass boilers with a two-section bare tube economizer and a tubular air heater.

The original stoker supplied by Detroit Stoker Company was replaced with a Zurn Industry traveling grate stoker during the 1989 boiler rebuild. The maximum continuous rating is 28 tph (25.4 tonnes per hour) per unit producing 180,000 PPH (81,648-kg/hr) steam at 732 Psig (50.5 bar) and 721 °F (383 Deg C) outlet conditions. For a boiler side view section see Fig. 3.

**Generating Bank Details**

The generating bank section utilizes 1248 2.5” (63.5 mm) O.D. x 0.165 (4.2 mm) MWT, SA-210 A1 tubes swaged to 2” (50.8 mm) at the ends to fit the old Fives-Cail Babcock Steam and Mud Drums. The bank has 15,922 square feet (1,480 m²) of heating surface area. It consists of 48 tube rows wide of which
the two outer rows are incorporated into the walls. The bank is 26 tube rows deep in the direction of gas flow. There are two built in sootblower/ manway access lanes included in the design with the first one occurring between tube rows 6 and 7 from the front and the second one between tube rows 18 and 19 from the front. The center line distance from drum to drum is 20 feet (6.1m). This yields the approximate total running length of all tubes in each boiler at 25,000 linear feet or close to 4.7 miles (7.6 Km). See Fig. 4 for a generating bank side view section.

As is typical in most generating banks for these type of boilers, the spacing is not conducive to allow normal non destructive ultrasonic thickness (UT) testing to monitor tube wear. Conventional UT testing is normally conducted from the outside of the tubes.

**IRIS Testing Method**

Non destructive Internal Rotary Inspection System (IRIS) testing is an ultrasonic test system used generally for the measurement of heat exchanger and steam generator tubes and pipe lines for measurement of wall thinning and pitting. The system has the capability to indicate the reduction in wall thickness taking place either from the fire or water side of the tube. In IRIS, the ultrasonic transducer is supported on a “probe carrier” that keeps it centered in the tube. The ultrasonic pulses are emitted along a path parallel to the tube axis. These pulses are reflected by a 45° mirror, mounted on a water driven turbine which makes the point of impingement of successive ultrasonic pulses along the internal circumference of the tube wall. See Fig. 5 for a diagram of a typical IRIS probe head arrangement.

This arrangement enables the probe to cover the whole circumference of the tube wall with each revolution of the mirror. All the wall thickness measurements made during a scan around the circumference of the tube are displayed on a computer screen and stored digitally. The image produced is a stationary rectilinear picture of the circumferential cross section (B scan) of the tube. See Fig. 6 for an example of the 360 degree scan on CD.

All gathered data is stored on a CD-ROM and reviewed immediately. The sensitivity achievable for reliable assessment of wall loss by IRIS is of the order of 0.002” (50μm). [3]

To carry out the testing, the boiler tubes (or pressure parts) are filled with water and then drained to the point that the generating bank tubes are still full with water just to the bottom of the steam drum. One technician handles the probe inserting and retrieving it from the flooded tubes. He works inside the drum. The other technician operates a laptop personal computer (PC) data recorder just outside the drum and also serves as hole watch for the first technician.

The testing can be done fairly rapidly, with testing of each 20-foot (6.1 m) long tube in less than a minute. At that rate, approximately 16 hours are required to test the 1248 tubes in each boiler.
IRIS Results

The results summary of a typical test is illustrated in Fig. 7. Usually given in color for better clarity and ease of analysis, this graph has been converted to symbols as noted for one-color reproduction purposes in this report.

From the analysis of the results, over a 3-year period on each boiler, 3 main mechanisms for wall loss were found to be predominant.

1. Soot blower erosion. The detailed wall thickness readings in the 360 degree plane, and the severity and localized nature indicated wear along the centerline of the soot blower path. The IRIS scan showed the tube thickness at nominal levels within 12 inches (305 mm) on either side of the centerline of the sootblower path.

2. Flue gas particle erosion. This method of wall loss presented itself in the data as more generalized and not as specific or localized to one particular elevation in line with other boiler auxiliary equipment. Together with past inspections and recorded fouling patterns, IRIS was able to identify where gas flow channeling had occurred.

In past inspections, certain areas had shown fouling with up to 85% of the gas pass area blocked. The remaining small open area experienced increased velocity and accelerated particle erosion and resultant accelerated thinning on the tubes that are adjacent to or in the open area. For flue gas particle erosion, the data showed a four to five foot length of wall loss slowly tapering back to nominal wall thickness.

3. Corrosion. To a much lesser extent but nevertheless occurring in a few areas, corrosion was indicated and attributed to ash and moisture in the furnace. The sources for this ash and moisture came from upstream tube leaks introducing moisture into the area and/or past failed attempts to clean the boiler by water washing. This was attributed again due to past inspections as well as the detailed pattern of thinning shown by IRIS. Occurrences of this method of failure were minimal but exclusively seen down low near the mud drum where ash and moisture had been known to accumulate. Again, the data showed the tube thickness close to nominal, further away from the mud drum.

Optimization Plan for Improved Reliability

With the help of IRIS testing and frequent furnace inspections the target areas needing attention were identified. Once identified, an optimization plan was developed to improve generating bank tube reliability. The integrated approach involved steps to be taken immediately and then steps for future improved reliability and cost controls.
First Steps / Immediate actions taken:

1. Since the IRIS testing is typically done at the start of the outage, tubes exhibiting excessive thinning especially tubes below code minimum thickness are plugged and removed from service, (if they are located in the middle of the bundle and no access can be gained).

2. Partial tube replacement were identified and performed also at the start of the outage, immediately following IRIS testing. These, when warranted, involved cutting out only the thinned area (usually the lower third of the tube), making one field weld and then rolling in the new end of the tube into the mud drum. Most of these partial tube change outs occur where they are accessible, (in the sootblower lanes).

3. In most cases, the outage plan had already been set for replacements of a certain group of tubes in a specified location and the IRIS testing confirmed or allowed us to slightly adjust the number or location of the group to be changed.

Future steps/ Long range planning:

The Facility plans to continue IRIS testing on an annual basis. This frequency may be reduced as the program ages, if wear patterns stabilize or become predictable. The IRIS maps when considered across all 4 boilers will allow prioritizing future replacements and give the ability to direct resources to the areas most in need. Typically a 100 to 300 block of tubes would be selected for replacement in the boiler indicated. To date, this allocation of resources was not necessarily evenly distributed across all 4 boilers. See Table 1 for the distribution of tubes changed.

The number and location of tubes requiring replacement was found to vary from boiler to boiler and from year to year as the program moved forward. Tracking the progress of the tubes replaced is done in a simple spread sheet format. See Fig. 8 for a sample of the tube mapping on Boiler 4.

<table>
<thead>
<tr>
<th>Boiler No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<tbody>
<tr>
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<td>80</td>
<td>0</td>
<td>428</td>
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<td>Tubes Replaced in 2002</td>
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<td>Tubes Replaced in 2003</td>
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<td>202</td>
<td>0</td>
<td>0</td>
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<td>Total 2001 – 2003</td>
<td>372</td>
<td>390</td>
<td>91</td>
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Table 1 – History of Tube Replacements

Combating tube erosion related to soot blowers:

Installation of cast, flat-faced shields is planned in the sootblower lanes. The stainless steel curved, thin gage type shields used in the past did not prove long lasting. They also posed other problems such as blocking gas lanes or ash hoppers as they deteriorated and came loose from the tubes. As an alternative, the cast flat faced shields were installed and appeared to have no measurable wear after one full year of service. See Fig. 9 for a comparison picture. Field applied Inconel overlay
was also tested in the past as a guard against sootblower erosion, but the economics did not favor continuing with that method.

Based on inspections and fouling patterns, an optimized soot blower sequencing was developed. This involved adjusting the soot blower programming to match the frequency of blowing to the amount of fouling observed. By reducing blowing frequency in many areas, wear will undoubtedly be reduced.

**Combating erosion from gas channeling:**

Water washing of the boilers during outages will be completed using a rotary Cable Swivel Tool (CST) that effectively cleans from drum to drum, leaving no residue. [4] By opening up all gas lanes, the original gas pass area is restored and velocities are reduced slowing damage from flue gas particles.

Soot blower programming optimization is also included here for more frequent blowing in areas shown to be prone to fouling in an attempt to keep gas lanes clearer, longer. Periodic draft loss readings across the boiler will also help monitor fouling.

**Combating corrosion:**

Employing the water wash technique mentioned above with the rotary CST will also ensure the boiler-generating bank to be 100% clean once water is introduced. This will help reduce ash and moisture accumulations causing corrosion.

Having the boiler warm so the tubes are thoroughly dried after cleaning from water washing may also help inhibit corrosion. South Florida’s humidity frequently runs high and boiler tubes have been found to have moisture condensing on them during shutdowns.

Optimizing tube reliability in upstream areas, (superheater, bull nose, and screen tube) will also help to limit moisture introduced to the section. Identifying and addressing leaking sootblower poppet valves in the area will also help minimize moisture entering the boiler. Improving our ability to identify tube leaks and limiting run time once a tube leak is detected should also be included in the factors that will help combat corrosion.

**Program results**

Although the optimization program is still in progress, the results are very promising to date.

**Downtime Improvement:**

As best illustrated by Fig. 2, the downtime since the program inception (2001) has reduced dramatically. The only unit that incurred any downtime attributed to generating bank tube failures in 2003 was Boiler 2. These failures occurred in tubes that were not IRIS tested due to an interference baffle that was welded to the drum. Steps will be taken at the next opportunity to modify the baffle to allow 100% IRIS mapping in this boiler.
Cost Impact:

With the use of IRIS testing, we were able to significantly reduce maintenance costs associated with the generating bank section over the last 3 years. Employing the previously discussed life extension methods, gives a potential of further cost reduction in the future. Initially, when failures were increasing, a plan of changing one-fourth (312) of the generating bank tubes was developed. This would allow a step by step replacement of the entire Generating Bank of one unit in 4 years or 50% of the total facility generating bank section in 8 years. This annual cost was estimated at $400,000.

An analysis of the history of work showed an average replacement cost of $120,000 for a group of 100 tubes. This included $20,000 for material and $100,000 for labor with a time frame of 6 days in the outage. The cost for IRIS testing itself runs approximately $17,000 for 4 boilers when completed on one mobilization. Table 2 includes estimated costs associated with emergency repairs, which also dropped dramatically.

<table>
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<th>Year</th>
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<td>$275,000</td>
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<td>Actual - emergency</td>
<td>$156,000</td>
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Table 2 – Costs for Generating Bank Repairs

Practical Considerations/ Tips

In order to control the cost of the IRIS testing itself, the work was completed on several boilers back to back. Scheduling the IRIS technicians in this manner, when possible, helps reduce mobilization costs.

Success was also achieved in scheduling other conflicting boiler work at the same time as the IRIS testing. The probe used for IRIS testing requires water in the tubes, whereas other tube repair work may require the tubes drained. To resolve this conflict a series of rubber test plugs were used. By strategic placement of the plugs, water was isolated from tubes requiring work during the outage. The remainder of the boiler could be flooded with water in order to perform the IRIS testing. See Fig. 10 for a picture of typical test plugs.

Any bolted-in steam drum baffles usually need to be removed. The boiler contractor and not the IRIS technicians typically do this. Once the baffles are removed and the tubes are flooded, the IRIS technicians need relatively very little support. They typically require only a 110v-power supply to run the data acquisition unit and a 4 psig (281 g/cm²) water source to operate the probe. No scaffolding or special staging is required.

Summary

With the use of IRIS testing in the Generating Bank Section, boiler tube failure mechanisms could be identified and/or confirmed and a very targeted approach for improved reliability could be developed. When implemented, the plan for improved reliability resulted in a
reduction of unscheduled downtime hours from over 600 hours/year to less than 100 hours/year for the facility. The few tube failures that did occur to this point were in an area not IRIS tested due to a physical constraint. Since the plan is still in progress, this will be corrected over time.

By using this approach to improve reliability, emergency maintenance costs were greatly reduced. Also, planned maintenance costs dropped significantly over a three-year period. By the use of IRIS testing, the planned maintenance resources could be used for maximum effectiveness in reducing downtime and costs.

IRIS testing and tube mapping are the key elements of the continuing plan for improved reliability. By tracking tube wastage over time, trends will be developed and analyzed. Mapping will include past failures, replacements, targeted partial replacements and tube plugging. A sootblower optimization program and use of an alternative type cast tube shield will help with tube loss from sootblower erosion.

Acknowledgements
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References
Miami-Dade County Resources Recovery Facility
Site Plan

Figure 1 - Site Plan
Figure 2 – Downtime before and after Optimization Program Implementation (2001)
For: Dade County Resources Recovery
Miami, Florida

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Figure 3 - Boiler Side View Section
Figure 5 – Schematic of a typical IRIS probe head arrangement
Figure 6 - Example of a 360 IRIS scan on CD
Figure 7 - Summary page illustrating the results of a typical IRIS test
Figure 8 - Sample of the tube mapping on Boiler 4
Figure 9 - Pictures of the same Cast tube shield, new in 2001 and after 1 year of operation
Figure 10 – Typical Test Plugs