SUPERHEATER LIFE WITH STAINLESS, INCONEL, AND CARBON STEEL ALLOYS AT THE MAINE ENERGY RECOVERY COMPANY

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Abstract

The Maine Energy Recovery Company is a refuse derived fuel (RDF) waste to energy facility that began commercial operation in 1987. The facility consists of an RDF production operation, two B&W boilers (A and B Boilers) which produce a total of 210,000 lb/hr of steam at 650 psig/750°F with a design Furnace Exit Gas Temperature of 1700 °F, and a 22 MW steam turbine generator.

Since startup, the facility has suffered fireside erosion/corrosion of the waterwalls, superheater, and generator bank hot side sections.

Through the years, Maine Energy has made various operational and design changes in order to improve combustion and overall boiler availability. While combustion has improved as evidenced by improved emissions, reduced supplemental fuel usage, and lower ash production, superheater availability has suffered. At the same time reliability of the waterwall and generating bank components have improved.

This paper will present a history of Maine Energy’s efforts to improve its superheater availability including a summary of the tube wastage rates for various superheater alloys, as well as Maine Energy’s plans for its superheaters.

Background

The Maine Energy Recovery facility processes approximately 285,000 tons per year of MSW, producing approximately 8,000 tons per year of recyclable ferrous and nonferrous metals and about 165,000 MWHR per year of power.

Significant Historical Events

Over the years, several operational changes have taken place that may have contributed to reduced superheater life expectancy.

Fuel Mix Change

From 1987 to 1995, the fuel usage consisted of approximately 86% RDF, 9% demolition debris woodchips, and 5% natural gas/oil. During this period of time, gas or oil was used to supplement combustion during periods of poor quality fuel thereby maximizing power generation.

In 1996, the facility negotiated a new power purchase contract with the local utility which altered the economics such that it was no longer economical to pay for supplemental fuels such as woodchips or natural gas. As a result, poor quality fuel will reduce steam production. Since 1996, Maine Energy’s fuel mix consists of 98% RDF and 2% natural gas.
Superheater wear may have been exacerbated by increased RDF combustion and because of boiler oxygen fluctuations caused when the boilers swing through periods of changing fuel quality.

Combustion Enhancements

In 2000, combustion enhancements targeted towards reducing ash production were implemented. "Ski jumps" were installed where the feeder chutes enter the furnace and the pulsation air dampers were fixed in the open position in order to project RDF further into the furnace. These changes were responsible for reducing ash production by 25%.

A consequence of the combustion enhancements may be higher flue gas temperatures entering the superheater which would tend to increase the corrosion rate.

Explosive Fireside Cleaning Implemented

In 1997, explosive cleaning techniques were implemented for fireside cleaning. Prior to 1997, labor intensive mechanical means supplemented with sandblast cleaning were utilized. Suffice it to say, explosive cleaning has dramatically improved the cleanliness of the fireside superheater and generator bank sections.

Even with explosive cleaning, Maine Energy would begin to lose superheat temperature and power generation due to slagging after about 6 weeks of operation. Generally, the boilers would be brought down for explosive cleaning somewhere after 6 to 12 weeks of operation; more towards the 12 week interval.

Fuel Tech Product Introduced

With a goal of eliminating the 12 week cleaning shutdown as well as to maintain a more uniform flow pattern across and through the convective pass, the Fuel Tech flue gas treatment system was installed in 1998. This system injects magnesium based slurry into the furnace through a proprietary injection technology. Ash becomes less tenacious and is therefore more easily removed from the tube by sootblowing. This system has been quite successful in keeping the superheater lanes clear and allowing the boilers to run a full 6 months without loss of superheat temperature and without explosive cleaning. Recently, because of furnace draft problems, the operating parameters of this system have been modified to target the generating bank for cleaning. The generating bank is now being effectively cleaned, but at a loss of superheat cleanliness. Currently, along with Fuel Tech, quarterly explosive blast cleaning is being used to ensure proper draft and to maintain superheat temperature.

There is a question as to whether the Fuel Tech product, while successful in keeping the superheater lanes clear, may be causing portions of the tubes to be “too clean” thereby accelerating erosion/corrosion in local areas.

Carbon Monoxide Analyzer Changed

In January 2001, the CO gas analyzer was replaced. The range on the new unit was 0-2000 ppm whereas the range of the old unit was 0-500 ppm. Where instantaneous CO peaks previously would have been “capped” at 500 ppm, the peaks were now far higher, which increased reported average daily emissions. Periodically, load would need to be reduced to maintain compliance with CO emission limits. A number of potential causes for the inefficient combustion were investigated. The main problem was identified as insufficient draft through the boilers. The draft problem was caused by the condition of the baghouse bags and by problems with ductwork integrity through the pollution control train. New bags were installed in each baghouse and major ductwork repairs were completed in the pollution control train.

With the new bags and improved back end integrity, boiler draft was significantly improved. However,
the draft situation is tenuous requiring both periodic explosive blast cleaning and continuous application of the Fuel Tech product.

"Poor draft" may have had a detrimental effect on superheater life. A consequence of poor draft is that furnace pressure periodically goes positive. The fluctuation between a positive and negative operating pressure within the furnace may be indicative of a fluctuation between oxidizing and reducing atmospheres which can accelerate corrosion.

Oxygen Sensors Installed

In May 2001 COSA oxygen sensors were installed to measure flue gas oxygen levels at the entrance to the economizer. Data from these monitors are used in the combustion control O2 trim logic. Oxygen levels entering the economizer are approximately 4%.

Flue Gas Temperature Monitor Installed

In May 2003, an Infra-View Boiler Infrared Thermometer was installed in B Boiler. The purpose of this monitor was to measure average flue gas temperature entering the superheater and to determine how that temperature may be affected by changes in load setpoints.

Generally, the flue gas temperature entering the superheater was found to be approximately 1600 °F. Lowering load setpoints did reduce flue gas temperature but not substantially.

Historical Event Timeline:

1997 Explosive Blast Cleaning initiated
1998 Fuel Tech product introduced
2000 Furnace draft problems escalate
2000 Combustion Enhancements
2000 Rapid Increase in tube wastage
2001 Jan., new CO monitors installed, CO control problem discovered
2001 May, oxygen monitors installed for improved boiler control
2003 Flue gas temperature monitor installed

Combustion has significantly improved as evidenced by substantial reductions in supplemental fuel usage, significant reductions in ash production, and improved emissions. Generator bank and waterwall reliability has improved as well. Unfortunately, these improvements seem to have come at a cost of unprecedented wear rates in the superheater sections of the boilers.

Metallurgical Upgrades/Modifications

Many physical changes to the boiler components have taken place over the years which may have had the unintended consequence of negatively affecting superheater life. These changes have successfully improved reliability of every component except for the superheater. This section describes these changes.

Waterwalls

At startup in 1987, all boiler components were carbon steel. The first components which exhibited failure due to erosion/corrosion were the waterwalls. Since 1987, Inconel has been added to the waterwalls to the extent that more than 90% of the waterwalls have been overlaid with Inconel 625. Since 1998, only a small portion of new Inconel is added each year adjacent to the sides of the superheater. Most efforts now involve inspecting and touching up “old” Inconel.

Generator Bank

The generator bank consists of a “hot side” and a “cold side” with the hot side located directly behind the superheater and the cold side located behind the hot side.
The tube replacement history of the generator bank sections is as follows:

A Boiler Generating Bank

<table>
<thead>
<tr>
<th>Period</th>
<th>Hot Side Life</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987-1992</td>
<td>5 years; total replacement;</td>
<td>Cold side remains in service.</td>
</tr>
<tr>
<td>1992-?????</td>
<td>5 year hot side life; 1992 hot side comes with increased side spacing (2 ½” tubes reduced to 2”);</td>
<td></td>
</tr>
<tr>
<td>1992-1997</td>
<td>7 year hot side life; 1997 hot side comes with Inconel overlay in high wear areas. Hot side to be replaced in kind during May 2004 outage.</td>
<td></td>
</tr>
<tr>
<td>1997-2004</td>
<td>7 year hot side life; 1997 hot side comes with Inconel overlay in high wear areas. Hot side to be replaced in kind during May 2004 outage.</td>
<td></td>
</tr>
</tbody>
</table>

B Boiler Generating Bank

<table>
<thead>
<tr>
<th>Period</th>
<th>Hot Side Life</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987-1993</td>
<td>6 years; total replacement;</td>
<td>Cold side remains in service.</td>
</tr>
<tr>
<td>1993-?????</td>
<td>7 year hot side life; 1993 hot side comes with increased side spacing (2 ½” tubes reduced to 2”);</td>
<td></td>
</tr>
</tbody>
</table>

The generator bank replacement intervals show that design and operational changes have increased the life of the generator hot side sections by at least two years and the life expectancy of the cold side sections have at least doubled. The major reasons for these gains are (1) improved flow balance throughout the section achieved through increased side spacing and improved cleaning techniques and (2) improved metallurgy in the high wear sections.

Superheater

The pendant style superheaters produce steam at 750°F and 650 psig and hang 30 feet above the boiler grate. There are side by side primary and secondary sections. The secondary superheater runs hotter and has generally experienced more wear than the primary superheater. In general, the pendants near the waterwalls experience lower wear than the pendants in the center of the boiler. And, in general, the sootblower lanes experience higher rates of wastage than other portions of the superheater. Though superheater wear follows this general pattern, the variability within this pattern is very high, which makes it difficult to predict life expectancy or to predict success of various operational/metallurgical changes.

The tube replacement history for the superheater is as follows:

A Boiler Superheater

<table>
<thead>
<tr>
<th>Period</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987-1994</td>
<td>7 Years, carbon steel</td>
</tr>
<tr>
<td>1994-2000</td>
<td>6 Years, carbon steel. Changed front row tube diameter from 2.5” to 2.75”.</td>
</tr>
<tr>
<td>2004-?????</td>
<td>Superheater to be replaced with 0.300” min wall carbon steel in the primary section</td>
</tr>
</tbody>
</table>
and 0.400" min wall carbon steel in the secondary section.

B Boiler Superheater

1987-1995  8 Years; carbon steel
1996-2001  5 Years; carbon steel; changed front row tube diameter from 2.5" to 2.75".
2001-2004  First two rows Inconel overlaid; balance of rows is stainless steel. Added 4' of Inconel sootblowing protection on rows 3 to 5 for the top sootblower and on rows 3 to 6 for the bottom sootblower. Bottom bends Inconel overlaid. During spring 2003 outage, entire secondary superheater section replaced with stainless steel and carbon steel pendants.
2004-????  Superheater to be replaced with 0.300" min wall carbon steel in the primary section and 0.400" min wall carbon steel in the secondary section

Superheater Wear Rates

From 1999 through 2003, extensive UT examination of superheater tube thickness have been completed during each spring outage to assess overall superheater condition, complete necessary repairs, and to predict superheater life expectancy. As the wear rates escalated, so have the number of UT points. It should be pointed out that the average wear rates reported in this section represent a reduction of tens of thousands of UT data points which contained a considerable degree of variability.

In general, it can be stated that the problematic areas in the superheater comprise less than 5% of the overall superheater surface area.

A characteristic of the wear is that there is a significant "lane effect". That is, for a problem lane, the wear rates on the sides of adjacent tubes will be approximately twice the wear rate evidenced on the opposite side of the tube. Furthermore, there does not seem to be a pattern as to which lanes are affected.

Another observation of note is that, for the superheater configured with stainless steel for the first 6 rows and carbon steel for rows 7 through 18, there was no discernable differences in wear rates between the transition rows 6 and 7. In some instances, the carbon steel in row 7 experienced less wear than the stainless steel in row 6.

Carbon Steel

UT data for carbon steel taken over the last several outages shows that the maximum wear rate in the secondary superheater is approximately 0.020" per month. However, this rate is present only for an isolated portion of the secondary superheater. The average wear rate in the problematic portion of the secondary superheater (about 3% of the overall superheater area) is .013" per month. Based on outage UT measurements, the majority of the superheater (approximately 97%) appears to wear at a rate of .002" per month.

It needs to be noted that failures in the last couple of months indicate that some areas towards the back of the superheater may be wearing as much as 0.026" per month.

Stainless Steel

Failure data for the stainless steel pendants shows that the secondary superheater maximum wear rate is approximately 0.015" per month with an average wear rate of 0.013 in the failed pendants. The size
of the problem area for the stainless steel configuration was approximately the same as for carbon steel and is less than 5% of overall superheater area. Wear rates in the balance of the stainless steel secondary superheater are approximately 0.005" per month.

Inconel 625

The first two rows of the most recently installed superheaters in both A and B Boilers were completely overlaid with Inconel 625. The next four rows had 4 feet of Inconel overlaid in certain sootblower lanes. In addition, Inconel was overlaid on each bottom bend.

Though there is no definitive UT data on the overlaid sections of the superheater, the general experience is that it has held up well. The exception to this statement is the most recent experience with B Boiler in which there was significant wear in the secondary superheater after a single year of operation. However, it is believed that much of this wear may have been caused by an alignment problem associated with the D-link failure.

The Inconel does require annual inspection and touchup work each spring to ensure reliable operation for another year.

Flue Gas Temperature Study

In May of 2003, a flue gas temperature monitor was installed in B Boiler for the purposes of determining the relationship between flue gas temperature and various operating parameters. In addition, thermocouples were installed on selected tubes to determine tube metal temperature and how it might relate to flue gas temperature. Because the life expectancy of the thermocouples was expected to be short, the test was completed over a two day period.

Superheater Outlet Temperature

The table below shows that though flue gas temperature did decrease with reductions in superheater outlet temperature setpoint, the reductions were not significant and the flue gas temperature remains very high. Four runs of approximately 3 hours each were used for this analysis. Because much of the test data needed to be excluded from this analysis because of difficulties holding other variables constant, more testing is required to establish a relationship.

<table>
<thead>
<tr>
<th>Steam Outlet Temp. (°F)</th>
<th>Flue Gas Inlet Temp(°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>750 (Base)</td>
<td>1600</td>
</tr>
<tr>
<td>740</td>
<td>1586</td>
</tr>
<tr>
<td>730</td>
<td>1575</td>
</tr>
<tr>
<td>720</td>
<td>1575</td>
</tr>
</tbody>
</table>

Superheater Steam Flow

Normal steam flow is 105,000 lb/hr. The table below shows that flue gas temperature did decrease with a reduction in steam flow setpoint, but as with the steam temperature variant, the reductions were not substantial. Six runs of approximately 3 hours each were conducted. As with the first analysis, because much of the data needed to be discarded because of difficulty holding other control variables constant, more testing is required to establish a relationship.

<table>
<thead>
<tr>
<th>Massflow (lb/hr)</th>
<th>Flue Gas Temp. (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>105,000 (base)</td>
<td>1600</td>
</tr>
<tr>
<td>100,000</td>
<td>1571</td>
</tr>
<tr>
<td>95,000</td>
<td>1553</td>
</tr>
</tbody>
</table>

Tube Metal Temperature

Four tubes (2, 5, 9, and 13) in B Boiler superheater were fitted with thermocouples. Tubes 2, 5, and 9 are located in the secondary superheater and 13 is located in the primary superheater. The test data shows that metal temperature varied tube to tube and over the entire test duration. The fact that tube...
metal temperature dropped as the test progressed may be indicative of the insulating effect of slag or may be due to thermocouple problems associated with the harsh environment.

Tube Metal Temperatures (°F)

<table>
<thead>
<tr>
<th>Tube</th>
<th>2</th>
<th>5</th>
<th>9</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Test</td>
<td>801</td>
<td>854</td>
<td>851</td>
<td>844</td>
</tr>
<tr>
<td>Last Test</td>
<td>758</td>
<td>828</td>
<td>711</td>
<td>700</td>
</tr>
</tbody>
</table>

Superheater Outage and Tube Leak History

The following table shows the impact on power generation (MWHR) associated with scheduled outage time for superheater inspection, repair, and replacement. It also shows superheater forced outage power losses over the last few years.

Superheater MWHR Impact

<table>
<thead>
<tr>
<th>Superheater</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;A&quot; Sched</td>
<td>2,852</td>
<td>950</td>
<td>3,326</td>
<td>2,376</td>
</tr>
<tr>
<td>&quot;A&quot; Forced</td>
<td>0</td>
<td>713</td>
<td>1,782</td>
<td>1,069</td>
</tr>
<tr>
<td>&quot;B&quot; Sched</td>
<td>-1,426</td>
<td>950</td>
<td>1,663</td>
<td></td>
</tr>
<tr>
<td>&quot;B&quot; Forced</td>
<td>-0</td>
<td>2,138</td>
<td>1,069</td>
<td></td>
</tr>
</tbody>
</table>

Note the reduction in scheduled outage time for A Boiler in 2001 and B Boiler in 2002. The time to install a new superheater has been significantly reduced. Also note the large increase in forced outage rate for B Boiler in 2002, which was only its second year of operation with the new 100% stainless steel/Inconel superheater. Much of this forced outage time was caused by tube leaks associated to a D-Link failure which allowed some pendants to shift into the gas lane. Lastly, the scheduled outage time increased drastically in the second year of operation because of the immense amount of time spent identifying the problem areas and taking corrective action.

Economic Analysis

Costs chargeable to the superheater include purchase costs, installation costs, inspection costs, cleaning costs, repair costs, and lost profit as measured by EBITDA associated with installation time and forced outage time.

A comparison was made between costs associated with continuing to operate with stainless steel superheaters and expected costs associated with switching to a heavy wall carbon steel tube with shorter replacement intervals.

By changing to a "disposable" carbon steel superheater, costs such as UT inspection, repair, and the time associated with that work will be significantly reduced. It is also expected that the rate of superheater forced outages will be significantly reduced.

The analysis shows that costs chargeable to the superheater will be reduced by 46% per year if the carbon steel superheater lasts 18 months and 60% if it lasts 24 months with reasonable reliability.

What has been learned?

First and foremost, there is a lot more to learn.

Approximately 5% of the superheater surface area is problematic. This area is predominately located in the secondary superheater and near the center of the boiler. Though damage is more pronounced in the sootblower lanes, there is substantial damage occurring well away from the sootblower lanes. There also is a somewhat random "lane effect" going on whereby by the sides of immediately adjacent tubes are suffering wastage rates twice the rate evidenced on the other side of the tube.

Stainless Steel/Inconel performs no better than carbon steel yet is far more costly.
It is very time consuming and expensive to locate the problematic wear area in the superheater and to take corrective action to maximize availability for the upcoming year.

The cost for the “Cadillac” Stainless Steel/Inconel pendants is nearly 6 times the cost for carbon steel pendants.

**Future Plans**

It is clear that the relationship between operating conditions and the primary mechanisms behind superheater tube wastage is not well understood.

It is important to find out whether the injection of the Fuel Tech product is helping to preserve the superheater by keeping lanes clear and minimizing erosion damage or whether it is keeping portions of tubes too clean thereby accelerating the erosion/corrosion cycle.

It is important to find out what is causing the “lane effect”. Is there an alignment issue (not evident)? Or is there a sootblower problem? Or is there a problem with the Fuel Tech product being concentrated in an area causing that area to be too clean?

Is the more pronounced wear in the sootblower lanes due primarily to erosion from the steam and flue gas, enhanced by corrosion? Or, is this wear predominately due to corrosion because the tube metal temperature is higher due to a thinner slag layer?

Is there an alloy that can cost effectively extend superheater life? Currently, proprietary alloys are being tested in the superheater.

While work is underway to answer these questions, Maine Energy is going to install 0.300 min wall carbon steel primary superheater sections, and 0.400" min wall secondary superheater sections. Substantial cost reductions will be attained by changing to the disposable superheater, but by no means is this expected to be the most cost effective long term solution.