Power Generation and Superheater Upgrade Project at the Burnaby MSW Plant

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1. Abstract

Montenay Inc. operates a municipal solid waste (MSW) incinerator plant located in Burnaby, British Columbia. The facility operates three essentially identical boilers that were designed to generate slightly superheated steam at 248°C (478°F) and 3,140 kPa (455 psig).

The plant was originally sized to supply process steam for export to an adjacent industrial plant. The fraction of steam that was exported decreased in recent years to about 35% of the production with the remainder being condensed. This has caused Montenay Inc. to initiate a power generation project with the goal to improve the plant’s energy efficiency and generate additional revenues by purchasing and operating a steam turbine generator.

A superheater upgrade was required to raise the final steam temperature to a level that was suitable for use in an efficient steam turbine-generator. Jansen Combustion and Boiler Technologies Inc. (JANSEN) was contracted to perform the process and design engineering for the required boiler modifications.

The project work included defining target process conditions, deriving conceptual design options, sizing the new superheater, deciding on material selection, preparing equipment specifications, and supplying the fabrication and installation drawings.

The boiler modifications have been implemented in all three units in spring 2003. Power production will start in early summer 2003.

2. Background

The Greater Vancouver Regional District (GVRD) is a partnership of all municipalities in the Vancouver area. The GVRD owns a MSW incinerator plant located in South Burnaby, British Columbia, that is operated and maintained by Montenay Inc. (a CGEA/Onyx company). The facility burns about 17% of the district’s garbage [1, 2], and produces steam that is used internally as well as exported to an adjacent industrial plant.

The facility consists of three essentially identical Babcock & Wilcox (B&W) boilers that were commissioned in 1987 (Fig. 1). The original B&W design was to process 242 metric tons/day (267 tons/day) of MSW each, and generate 36,300 kg/hr (79,900 lb/hr) of slightly superheated steam at 248°C (478°F) and 3,140 kPa (455 psig).

The units are balanced draft boilers equipped with a reciprocating grate that was supplied by Martin GmbH, Munich. The boilers consist of a two-pass water wall furnace, a two-pass evaporator or generating bank, and a small superheater in the 5th pass followed by a multi stage economizer. The cleanup equipment includes a spray cooling conditioning tower, a scrubber with carbon and lime injection, and a fabric filter.

3. Overall Project Goals

The incinerator and its boilers were originally sized and designed to supply suitable steam to an adjacent paper mill. The overall size of the plant was consistent with the ability to provide the adjacent paper mill with 100% of their required capacity, with two out of three boiler lines...
operational. The pressure and temperature of steam produced were consistent with the paper mill's own boilers, which were removed from service after the incinerator commenced operation and then were eventually de-commissioned.

Over time, the paper mill has also decommissioned two out of its three paper machines and the demand for steam has consequently dropped to almost 50% of historical maximum levels. With the decommissioning of the paper mill boilers, the highest pressure in active use at the paper mill has dropped from 2.75 MPa (400 psig) to 0.9 MPa (130 psig).

Since the Burnaby Incinerator Plant was originally designed, Martin GmbH has improved their grate and combustion control systems and revised their expectations on maximum grate heat release rates. These new controls systems will be installed at the plant coincident with the boiler modifications. These new controls systems will allow for more stable operation, higher throughputs, operation at lower excess air and reduced emissions.

The overall project goals were:

- To redesign the boilers to produce steam more suitable for use in a new turbine generator than the present slightly superheater steam.
- To direct all of this steam to the inlet of this new turbine and to provide any process steam, including that required by the paper mill, from one of three turbine extractions.
- To ensure that the redesigned boilers are capable of taking advantage of the improved grate and combustion controls systems and revised maximum grate heat release rates.
- To arrive at a suitable final boiler steam temperature that is the best compromise between the conflicting requirements of:
  - Electrical power output
  - Capital cost
  - Operational and maintenance cost
  - Good boiler design practice
  - Other process considerations

4. Scope of Boiler Hardware Modifications

The boilers were originally designed to generate slightly superheated steam. A superheater upgrade was required to raise the final steam temperature to a level that was suitable for use in an efficient steam turbine-generator. The locations that were considered to install additional superheater surface area were in the second and fifth furnace passes.

JANSEN performed the process and design engineering for the required boiler modifications, including new superheater sections and other boiler pressure part modifications. Design options were evaluated with a performance and heat transfer computer model that was tuned using collected operating data. The model allowed the evaluation of design options to optimize performance and reduce maintenance cost.

5. Boiler Process Engineering Evaluation

The superheater upgrade project was started with a detailed process engineering evaluation. The purpose of this process evaluation was to: (1) characterize the pre-upgrade performance conditions, (2) predict boiler performance at the upgraded conditions based on current data, (3) determine feasible targets for the final superheater steam temperature and pressure, and (4) verify adequate natural circulation conditions in the boiler tubes to prevent tube overheating at the upgrade conditions. In addition, the evaluation results were used to derive conceptual options, and size the superheater.

5.1 Field Evaluation

Engineers from JANSEN traveled on-site to observe the boiler operations, collect operating data from the DCS, and measure additional parameters with hand held instruments. Measurements with hand held instruments on the No. 1 unit included: (a) flue gas temperatures at the outlet of the first pass, in the second pass, at the inlet to the evaporator, at the evaporator outlet, and at the economizer outlet; (b) flue gas oxygen concentrations at the economizer outlet, and (c) water velocities in all the feeder pipes that supply the furnace wall headers.

The purpose of the hand held measurements was to verify the plant instrumentation, and to measure data that was not available from boiler instruments. All the collected information was used to construct a spreadsheet based computer model of the Burnaby boilers. Performance calculations were based on ASME Test Codes.

Table 1 summarizes average collected and calculated performance data on a per unit basis. Each unit was burning an average of 269 metric tons/day (295 tons/day) of waste, and generating 38 metric tons/hr (83,900 lb/hr) of steam at 246°C (474°F) and 3.17MPa (460 psig).

5.2 Target Conditions for Future Operation

At the time of the superheater upgrade, the boilers will be upgraded with an improved grate and combustion control system that will allow for a revised maximum grate heat release rate, and lead to operation with less excess air. The performance and heat transfer computer model was used to
The calculated flow rates were verified by velocity measurements in all the feeder pipes of the No. 1 Boiler that supply the furnace wall headers with water. An ultrasonic flow monitoring (UFM) technique was applied [3]. The UFM data was used to baseline the calculation at the pre-upgrade conditions.

The program was then used to project natural circulation at the future upgrade conditions. Factors that were evaluated included flow velocity, circulation ratio, and circuit stability. Calculated properties were compared to recommended industry values to assure sufficient cooling, and avoid potential wall tube overheating.

6. Superheater Sizing

Installing superheater tubes in the second furnace pass at a location where the entrance flue gas temperatures were expected to reach 960°C (1,760°F) added uncertainty to the design process. For example, it was difficult to estimate how much deposit would accumulate on the tube surface over time, how effectively sootblowers or rappers could clean the tubes, and how much these deposits would reduce the overall heat transfer rates.

To limit these uncertainties, performance data from other MSW boilers with similar superheater applications was collected and evaluated. In addition, air cooled tube samples were inserted into one of the boilers to evaluate the amount of deposit build-up over time, to measure the stickiness of the deposit, and to collect information on cleanability. Furthermore, it was decided that some of the new superheater surface area should be installed in the 5th pass where tube fouling rates are better understood, thereby limiting the risk of under-sizing the superheater.

The installation of a low-temperature primary superheater section in the 5th pass required the removal of one of the five economizer tube banks in addition to removing the existing superheater section.

A boiler side view with the new superheater arrangement is shown in Figure 2. Steam from the steam drum flows first through a new low-temperature primary superheater in the 5th pass, then through a high-temperature primary section in the 2nd pass, and finally through a secondary section also in the 2nd pass. An attemperator for final steam temperature control is located between the high-temperature primary and the secondary superheater sections. The new superheater was sized to achieve a final steam temperature of 350°C (662°F).

Sizing of the superheater was severely constrained by the geometry of the 2nd pass cavity, and the allowable steam side pressure loss. Due to limitations in steam drum operating pressure and the steam turbine design pressure, the allowable pressure loss between the steam drum and the stop valve
outlet was restricted to 366 kPa (53 psi). The pressure loss allocated to the 2nd pass superheater sections was 152 kPa (22 psi).

Based on these constraints, several sizes and arrangement options were considered with a heat transfer model. The final design was chosen based on cost and installation related considerations. Sizing data is included in Table 2.

7. **Material Selection**

The low-temperature superheater material selection was straightforward. Due to the low temperature of both the steam and flue gas, and the service record of the existing superheater in this area, the selected material was identical to the existing superheater (SA 178).

The process undertaken to finalize the material selection for the high-temperature, 2nd pass superheater included a general literature review of current practice and experience for superheaters in MSW, a company wide (CGEA/Onyx) review of superheater experiences were carried out in 2000 covering 30 facilities, and some specific discussions with several key facilities.

Two key factors that made for a difficult decision making process were that the expected flue gas temperature of 960°C (1,760°F) at the 2nd pass superheater inlet is higher than typically found in MSW units, and that the vast majority of superheater experience is with bare SA 213 T22 tubes only. The potential for high superheater corrosion rates was a major concern.

Several material selection options were considered for the high-temperature superheaters. These options included:

- Bare SA 213 T22 tubing
- SA 213 T22 tubing clad with refractory protection
- Inconel 625 spiral welded SA 213 T22
- Inconel 625 clad composite tubing
- Austenitic stainless steel tubing

The material selected was Inconel 625 spiral welded SA 213 T22. The decision making process that arrived at this final selection involved a number of considerations including:

- The expectation that the life of bare SA 213 T22 would be very low (<2 years) at the required inlet flue gas temperatures.
- The expectation that the service life would be significantly higher if Inconel 625 spiral weld overlay was applied to these same tubes.

8. **Superheater Design Engineering Considerations**

JANSEN provided Montenay Inc. with the design engineering, detailed fabrication drawings, and installation drawings for the new superheaters and all other required pressure part modifications within the ASME Boiler and Pressure Vessel Code Section I boundary. Montenay Inc. used these drawings to select contractors for the material supply, fabrication, and erection of the boiler modifications.

From the outset, a key objective in the superheater design was reasonable life and maintainability. Experience at other facilities suggested that maintainability would be dependent on accessibility for routine testing of tube wall thicknesses and for tube repairs within the 2nd pass superheater. For this reason, Montenay Inc. strongly felt that the optimum side-to-side spacing should be 16" or more. Additionally, ease and cost of field installation was an important design consideration.

The design concept of the high-temperature primary and secondary superheaters is a header and pendant type. Each superheater section consists of an inlet and outlet header with 11 three-tube pendants. The high-temperature primary section tubes have a four-pass arrangement, and the secondary section has a two-pass. The superheater pendants are hung from the headers, which are suspended from hanger rods. (See Fig. 2).

The 2nd pass furnace cavity was originally designed as an open gas path containing no convective heat transfer surfaces other than the water walls. This provided a clear space within the furnace boundary to install the new high-temperature and secondary superheater sections.
However, the original unit was not designed to accommodate the additional weight of large vertical pendant superheaters.

The boilers are bottom-supported at the level of the lower drum and thermal growth of the furnace is upward from that location. Support of the new 2nd pass superheater sections was one of the major design challenges of the project. There was no existing top-steel from which the new superheaters could be hung and the small size of (or complete lack of) the building columns made the addition of new building mounted top-steel impractical. Seismic load consideration was also a factor in the design of the new supports.

A superheater structural support system was designed to provide a top-steel hanger grid that is attached to the upper sidewall headers. This allows the support steel to move with the thermal growth of the furnace and minimizes the growth differential between the superheater sections and the furnace roof and water walls. Special consideration was required to minimize the stress in the sidewall headers due to the added support forces from the superheater weight. Modifications to the lower sidewall header supports were also required for the same reason.

The superheater pendants were designed to provide close-spaced tubes joined with flexible ties at several levels. The tube return bends were made with as large a bend radius as possible to avoid the need for hot-bending and to minimize inducing wall thinning and bending stresses that may result in cracking of the alloy 625 welded overlay.

For field erection, Montenay Inc. had determined that a tower crane would be erected at the jobsite for use in the installation of other equipment associated with the turbine-generator project. The tower crane availability allowed for the fabrication of the 2nd pass superheaters in large, shop-assembled modules (see Fig. 3); two modules each for the high-temperature primary and secondary superheaters. This concept allowed the superheaters to be installed from overhead and inserted vertically into position in a total of four lifts and required only four header butt welds to complete the superheater field assembly. No superheater tube pendant welds were required for the installation, greatly reducing the cost of erection.

The insertion of the superheater pendants through the furnace roof required multiple openings in the roof tube panel and a new roof seal design. Given the extent of the openings required and the condition of the original roof tubes, Montenay Inc. elected to replace the roof in its entirety with new panels extending from the front wall of the furnace to the steam drum. The new roof tubes were also supplied with alloy 625 welded overlay. The new roof was fabricated in two panels and expansion rolled into the original steam drum holes.

The placement of the new 2nd pass superheaters and headers above the furnace roof line required all 12 of the furnace upper sidewall reliever tubes to be rerouted. All new reliever tubes were designed, and four of the reliever tube relocations required new openings to be drilled into the steam drum.

Screen tube modifications were also required. The original unit had seven screen tubes. With the addition of the 11 superheater pendants and the desire to have a screen tube immediately ahead of each pendant for corrosion protection, four new screen tubes were added and the original seven screen tubes were modified. The four new screens required drilling new openings in the existing rear wall header to accept the new tubes.

All new steam piping services were required from the steam drum saturated steam outlet connection, interconnecting all three new superheater sections, and to the outlet of new superheated steam stop/check and stop valves. A steam attemperator section was installed between the high-temperature primary and the secondary superheater sections.

The 2nd pass superheater fouling rate, ash characteristics, and cleanability of the superheater tubes was largely unknown because of the unique application for the Burnaby units. The method of cleaning the new superheater pendants needed to be decided between rotary retractable sootblowers or mechanical rappers. Since there was no existing superheater in the 2nd pass there was no previous experience with the ash or corrosion rates. During the design phase, Montenay Inc. conducted ash accumulation and cleaning trials using a section of alloy 625 welded overlay tube inserted into the 2nd pass area and cooled by compressed air to simulate the tube metal temperatures expected for the new superheaters. Their trials indicated that the ash that accumulated on the tube was fairly easily removed with minimal rapping on the tube. Given this experience, the selection of rapper tube cleaning equipment was the most cost effective option.

A Neundorfer, Inc. rapping system was furnished consisting of two rappers for the high-temperature primary pendants and one for the secondary superheater. Each rapper system consists of a pneumatic rapper piston, transverse header shaft that extends from side-to-side through the lower loop of the pendant tube bends, and vertical tie bars at each pendant to grip the tubes and transmit the rapping force. The rapper system was designed such that no welding is required to the superheater tubes to mount or grip the rappers.
9. Installation Schedule and Initial Operation

The new superheater has been installed in the first boiler in February 2003. Figure 4 shows a photograph of a newly fabricated superheater element. Installation to the other two units will follow in the months after. Commissioning of the steam turbine is planned for May or June 2003.

10. Conclusions

The three boilers at the Burnaby MSW Incineration Plant were modified to produce steam at higher superheating temperature for use in a new steam turbine. The new superheater design consists of three main sections. The low-temperature primary section is located in the 5th pass where flue gas temperatures are relatively low and the reduction in heat transfer rate due to deposits is less significant. The two high-temperature sections were placed in the 2nd pass. Flue gas temperatures and the corrosive environment in the 2nd pass warranted a design with an alloy 625 welded overlay. Arapper system was installed in the 2nd pass to reduce deposit build-up, and its associated loss of heat transfer.

The installation of the modifications will be completed in May 2003. After commissioning of the steam turbine, the plant will generate approximately 15 MW of electricity from MSW, in addition to supplying process steam to the adjoining industrial plant from one of three turbine extractions.

In the future, Montenay Inc. is considering a further increase in the electrical power production by installing a waste heat recovery boiler between the existing economizers and the flue gas conditioning towers. First preliminary analysis by JANSEN indicated technical feasibility and promised a relatively good return on investment.

11. References:

[1.] “Solid Waste Burnaby Incinerator” Pamphlet by Greater Vancouver Regional District

[2.] “Greater Vancouver Regional District, Burnaby Incinerator – A Refuse to Energy Facility” Pamphlet by Montenay Inc.

Figure 1. Boiler Side View (Original Configuration)

Figure 2. Boiler Side View with the New Superheater Arrangement
Figure 3. Superheater Installation Schematic

Figure 4. Photo of a New Superheater Element Prior to Installation
Table 1. Pre-Upgrade and Predicted Post-Upgrade Performance Data (Per Unit).

<table>
<thead>
<tr>
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<th>Units</th>
<th>Site Visit Conditions (March 2002)</th>
<th>Predicted Future Maximum Performance after SH Upgrade</th>
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<tr>
<td><strong>Steam and Feedwater</strong></td>
<td></td>
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<tr>
<td>Total steam flow</td>
<td>t/hr</td>
<td>38.0 (83.9)</td>
<td>37.5 (82.7)</td>
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<td>Steam temperature</td>
<td>°C (°F)</td>
<td>246 (474)</td>
<td>350 (662)</td>
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<tr>
<td>Feedwater temperature to unit</td>
<td>°C (°F)</td>
<td>109 (229)</td>
<td>110 (230)</td>
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<td>Steam header pressure</td>
<td>kPa (psig)</td>
<td>3,170 (460)</td>
<td>3,070 (445)</td>
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<tr>
<td>Steam drum pressure</td>
<td>kPa (psig)</td>
<td>3,360 (487)</td>
<td>3,370 (488)</td>
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<td><strong>Fuel</strong></td>
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<tr>
<td>Waste feed rate (as received)</td>
<td>t/hr (1,000 lb/hr)</td>
<td>11.2 (24.6)</td>
<td>12.4 (27.3)</td>
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<td>Moisture</td>
<td>mass %</td>
<td>25</td>
<td>25</td>
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<tr>
<td>Higher heating value (dry)</td>
<td>MJ/kg (Btu/lb)</td>
<td>15.3 (6,570)</td>
<td>15.3 (6,570)</td>
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<td>Lower heating value (as received)</td>
<td>MJ/kg (Btu/lb)</td>
<td>10.0 (4,310)</td>
<td>10.0 (4,310)</td>
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<td><strong>Combustion Air</strong></td>
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<tr>
<td>Total flow to unit</td>
<td>t/hr</td>
<td>70 (154)</td>
<td>73 (161)</td>
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<td>Excess air</td>
<td>%</td>
<td>66</td>
<td>57</td>
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<td><strong>Flue Gas</strong></td>
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<td>Flow at economizer outlet</td>
<td>t/hr (1,000 lb/hr)</td>
<td>79 (173)</td>
<td>83 (182)</td>
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<td>Low-temperature superheater inlet temperature (5° Pass)</td>
<td>°C (°F)</td>
<td>341 (646)</td>
<td>346 (655)</td>
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<td>Economizer outlet temperature</td>
<td>°C (°F)</td>
<td>221 (429)</td>
<td>249 (481)</td>
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<td>O₂ at economizer outlet (wet)</td>
<td>volume %</td>
<td>7.2</td>
<td>6.5</td>
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<td><strong>Performance</strong></td>
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<td>Net steam heat output</td>
<td>MW (MM Btu/hr)</td>
<td>29.8 (101.9)</td>
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<td>Thermal efficiency (HHV basis)</td>
<td>%</td>
<td>68.9</td>
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Table 2. Summary of Superheater Design Data

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<th>Low-Temperature Primary</th>
<th>High-Temperature Primary</th>
<th>High-Temperature Secondary</th>
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<tr>
<td>Number of rows across</td>
<td>-</td>
<td>40</td>
<td>11</td>
</tr>
<tr>
<td>Tubes per row</td>
<td>-</td>
<td>17</td>
<td>12</td>
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<tr>
<td>Total number of tubes</td>
<td>-</td>
<td>680</td>
<td>132</td>
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<tr>
<td>Number of steam side inlets</td>
<td>-</td>
<td>40</td>
<td>33</td>
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<tr>
<td>Flow direction</td>
<td>-</td>
<td>Co-current</td>
<td>Co-current</td>
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<tr>
<td>Average heated tube length</td>
<td>m (ft)</td>
<td>2.6 (8.4)</td>
<td>7.8 (25.7)</td>
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<tr>
<td>Tube outside diameter</td>
<td>mm (in)</td>
<td>51 (2.0)</td>
<td>54 (2.14)</td>
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<tr>
<td>Minimum tube wall thickness</td>
<td>mm (in)</td>
<td>4.6 (0.18)</td>
<td>5.3 (0.21)</td>
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<td>Spacing (pitch) across</td>
<td>mm (in)</td>
<td>114 (4.5)</td>
<td>406 (16)</td>
</tr>
<tr>
<td>Spacing (pitch) in flue gas direction</td>
<td>mm (in)</td>
<td>114 (4.5)</td>
<td>92 (3.6)</td>
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<tr>
<td>Heated circumferential surface area</td>
<td>m² (ft²)</td>
<td>277 (2,984)</td>
<td>177 (1,900)</td>
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