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THE EFFECTS OF GAS AND AIR FLOW DISTRIBUTIONS ON THE PERFORMANCE OF THE FARLEIGH NO. 3 BOILER

By

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Abstract

As more raw sugar factories become involved in the manufacture of by-products and cogeneration, bagasse is becoming an increasingly valuable commodity. However, in most factories, most of the bagasse produced is used to generate steam in relatively old and inefficient boilers. Efficient bagasse fired boilers are a high capital cost item and the cost of supplying the steam required to run a sugar factory by other means is prohibitive. For many factories a more realistic way to reduce bagasse consumption is to increase the efficiency of existing boilers. The Farleigh No. 3 boiler is a relatively old low efficiency boiler. Like many in the industry, the performance of this boiler has been adversely affected by uneven gas and air flow distributions and air heater leaks. The combustion performance and efficiency of this boiler have been significantly improved by making the gas and air flow distributions through the boiler more uniform and repairing the air heater. The estimated bagasse savings easily justify the cost of the boiler improvements.

Introduction

Bagasse is becoming increasingly valuable to sugar factories engaged in cogeneration and by-product manufacture. Mill steam demand and boiler efficiency have, in the past, been controlled to ensure that all the bagasse produced in the milling process was consumed. Factory bagasse consumption can be reduced by reducing the factory steam demand and by increasing the efficiency of the boilers. Most sugar factory boilers in Australia are over 20 years old and many of them were not designed for high efficiency operation. A low efficiency boiler station was one way to minimise the costs associated with the storage and transport of bagasse. With age, the efficiency of these older boilers has decreased even further due to deterioration of the boiler heat transfer surfaces and external casings.

Given that most of the steam used by the sugar industry is produced in these older low efficiency boilers, there is considerable scope for increasing the amount of surplus bagasse the industry is able to generate by improving boiler efficiency. The Farleigh No. 3 boiler is over 30 years old and like many boilers of similar vintage is relatively inefficient. This paper summarises some of the work that has been carried out to improve the combustion performance and efficiency of this boiler.
Background

Boiler efficiency is determined primarily by the size of the boiler heat transfer components. The most efficient bagasse fired boilers in the Australian industry are able to achieve gross boiler efficiencies of over 70% by reducing the final flue gas temperature to below 150°C with air heaters and economisers. Many of the older boilers in the industry have final flue gas temperatures well over 200°C. The most effective way to increase the efficiency of these boilers is to increase the available heat transfer surface area. However this usually requires significant capital expenditure so other options such as reducing the losses due to incomplete combustion should be considered.

The measured concentrations of carbon monoxide (CO) are often used to assess the efficiency of the combustion process (Dixon, 1983). Provided there is good mixing between the air and fuel streams, CO concentrations in the flue gas leaving the boiler should be low (Ormerod and Read, 1979). At typical furnace temperatures, CO should be converted to carbon dioxide (CO₂) if adequate oxygen (O₂) is available. High CO concentrations have been measured in oxygen deficient regions of bagasse furnaces (Dixon, 1984) but as long as this CO can subsequently react with oxygen in the furnace, CO concentrations at the furnace exit will be low. Any CO that remains in the flue gas entering the convection bank is unlikely to react to form CO₂ because gas temperatures are too low.

The Farleigh No. 3 Babcock and Wilcox boiler has a Maximum Continuous Rating (MCR) steam output of 68 t/h (150 000 lb/h). It has a dumping grate, multi-pass convection bank, a dry multiclone dust collector and a tubular air heater (1 528 tubes). The air heater has a single gas pass and single air pass and is supplied with ambient air from a forced draft fan on the right (looking from the front) side of the boiler. Hot air leaves the air heater through two ducts (one on each side of the boiler) that join a common duct at the rear of the furnace. Air is supplied from this common duct to the four undergrate sections through four smaller ducts. Hot secondary air is taken off from the air heater air outlet duct on the right hand side of the boiler.

Measurements carried out by SRI in 1996 and 2004 indicated there was an air flow bias towards the left side of the boiler. Measured oxygen (O₂) concentrations at the convection bank exit were much higher on the left side of the boiler. Carbon monoxide (CO) concentrations measured at the convection bank exit were much higher on the right side of the boiler. At the inlet to the induced draft fan, CO concentrations over 4 000 ppm (dry basis) were consistently recorded. Figure 1 shows the calculated relationship between efficiency loss due to unburnt CO and measured CO concentration (dry basis). From Figure 1 the measured CO concentrations correspond to a loss of boiler efficiency of more than 1.5 percentage points. When CO concentrations are high, losses due to unburnt solid fuel are usually also high (due to the poor combustion performance); this further reduces boiler efficiency.

In many cases a non-uniform air flow distribution into a boiler becomes a non-uniform gas flow distribution across the width of the boiler. Previous investigations (Dixon et al., 2000) identified that low gas flow through air heater tubes could lead to condensation of boiler flue and therefore dew point corrosion. Water condensing on
the inside walls of air heater tubes can start dust building up on the walls causing tube blockages. Worse corrosion and more blockages occurred in tubes on the right hand side of the boiler, which is consistent with there being a gas flow bias towards the left side of the boiler.

![Graph showing the relationship between CO concentration and gross boiler efficiency loss due to unburnt CO](image)

**Fig 1 – Calculated relationship between gross boiler efficiency loss due to unburnt CO and CO concentration for a constant excess air of 45%**.

The SRI measurements also showed that there was significant air leakage into the Farleigh No. 3 boiler air heater. Air leakage into the air heater tubes will reduce boiler efficiency and will also increase the load on the forced and induced draft fans and therefore limit the steam generating capacity of the boiler.

**Boiler modifications**

To address the issue of air heater leaks, all the air heater tubes were replaced during the 2007 maintenance season.

Based on experience with other boilers, it was likely that the duct work arrangement between the forced draft fan and the air heater was the main cause of the air flow bias. SRI carried out Computational Fluid Dynamics (CFD) modelling, of the air flow patterns from the forced draft fan through the air heater and into the undergrate sections using the FURNACE code. The three dimensional model used 779 000 cells and a plan view of the predicted air velocity distribution into the air heater is shown in Figure 2.
Figure 2 shows that most of the air flow is directed towards the left side of the boiler (top of Figure 1) and therefore more air flows over the tubes on the left side of the boiler. As more air flows over the left air heater tubes, the temperature of the air in the left air heater air outlet duct will be lower than the temperature of the air in the right air heater air outlet duct. This has been confirmed by previous SRI measurements.

Further CFD simulations were carried out to design a turning vane configuration that would produce a more uniform air flow distribution across the width of the air heater. Turning vanes were subsequently installed in the air heater inlet plenum during the 2007 maintenance season.

**Boiler performance comparisons**

To assess the effect of the air heater modifications, gas composition and temperatures measurements were taken at different locations around the Farleigh No. 3 boiler during the 2007 crushing season. These measurements are compared with the earlier measurements (before the air heater repairs and installation of the turning vanes) in Table 1.

The measured oxygen concentration at the inlet of the induced draft fan in 2007 was significantly lower than that measured in 2004; this reduction is almost certainly due to repair work done on the air heater. Note also that the oxygen concentration measured at the inlet to the induced draft fan in 2004 was much higher than the
oxygen concentration measured at the same location in 1996. This shows that the air heater leaks had become significantly worse.

Table 1 – Gas compositions and temperatures measured around the Farleigh No. 3 boiler

<table>
<thead>
<tr>
<th></th>
<th>Convection bank outlet</th>
<th>Induced draft fan inlet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left side</td>
<td>Right side</td>
</tr>
<tr>
<td>O₂ (% dry basis)</td>
<td>2007</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>7.1&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>T (°C)</td>
<td>2007</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>339</td>
</tr>
<tr>
<td>CO (ppm dry basis)</td>
<td>2007</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td>1996</td>
<td>3 250</td>
</tr>
</tbody>
</table>

<sup>a</sup> Oxygen concentrations varied from 1.5 to 6.8%, possibly due to grate combustion cycling.

<sup>b</sup> CO concentrations in excess of 15 000 ppm were recorded at times.

<sup>c</sup> Taken at a different time to other 1996 measurements.

CO concentrations measured in 2007 at the induced draft fan inlet are much lower than those measured in previous years. This indicates that the repairs to the air heater and the installation of the air heater turning vanes have improved combustion performance. However the measured CO concentrations in 2007 are still high and gas temperatures are still higher and oxygen concentrations lower on the right hand side of the boiler. CO concentrations are still very high on the right hand side of the boiler outlet. It appears that the air heater turning vanes have not been able to completely correct the flow bias towards the left side of the boiler. It was though at the time that too much of the air flow from the air heater outlet duct on the right side of the boiler was going to the secondary air duct. However the static pressure measured from a point on the right side air heater outlet duct downstream of the secondary air take off duct was very similar to the static pressure measured from the corresponding point on the left side air heater air outlet duct. If the static pressures are very similar then, provided the flow resistances of the left and right sides of the grate are the same, the air flow distribution into the grate should be reasonable uniform across the width of the furnace.

The possibility of a non uniform bagasse distribution causing the variation in gas composition across the width of the boiler was also investigated. However the speeds of all four bagasse feeders were measured and found to be identical. This makes it very likely that the non uniform combustion conditions are due to an air distribution, rather than a bagasse distribution problem.

Given that all the secondary air supplied to the furnace is supplied from the duct on the right side of the boiler, it is possible that the secondary air flow into the furnace is biased towards the left side of the boiler. This and other possible causes of the poor combustion on the right hand side of the boiler are currently being investigated.
Approximate efficiency calculations based on the 2004 and 2007 measurements in Table 1 show that boiler bagasse consumption of the boiler when operating at MCR steam load has been reduced by more than 3.5 t/h. The approximate cost of the air heater modifications (replacement of all tubes and installation of turning vanes) was $300 000. If the net (coal replacement value – transport costs) value of bagasse to Mackay Sugar is $20 /t then a bagasse saving of 3.5 t/h corresponds to a payback period of approximately 30 weeks.

With increased boiler efficiency there is less gas flow through the boiler and consequently wear of the convection bank tubes, dust collector components and the induced draft fan should reduce.

Conclusions

The efficiency and combustion performance of the Farleigh No. 3 boiler has been adversely affected by air heater leaks and a flow bias towards the left side of the boiler for several years. With the replacement of the air heater tubes and the installation of turning vanes at the air inlet of the air heater, boiler performance has improved significantly. The estimated bagasse savings from the improved boiler performance easily justify the cost of the air heater modifications. However, combustion performance, while much better than before the modifications, still needs to be improved.

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REFERENCES


