A NEW APPROACH TO SECONDARY AIR IN BAGASSE BOILERS

DU TOIT PC AND VAN DER MERWE S

John Thompson a division of Actom (Pty) Ltd, Sacks Circle, Bellville South, 7530, South Africa
philipd@johnthompson.co.za

Introduction

The combustion efficiency of the boilers at factories is becoming increasingly important due to more stringent pollution legislation. There is a larger financial impact on mills with off-crop refining or any downstream activity which utilises more costly fuels than bagasse.

Decreasing the excess air by improving the combustion also has the added benefit of reducing the erosion rates on the downstream equipment in the gas flow path. The lifetime of these components can therefore be extended and maintenance reduced.

The development of advanced secondary air (SA) systems in grate-fired boilers is seen as one of the real breakthroughs in this technology in the last few years (Yin et al., 2012). This is primarily due to the use of computational fluid dynamics (CFD) in order to determine the ideal locations and properties of the air streams.

A firing strategy was developed by Naude (2001) for wet biomass fuels based on reducing the under-grate airflow where the primary function of this air fraction is drying. Sub-stoichiometric conditions at grate level prevents the rapid combustion of the dried fuel pile and overcomes the batch type combustion phenomenon known as cycling or puffing. This approach of gasification in the bed and combustion in the freeboard is also utilised in modern biomass bubbling fluidised beds.

The two aforementioned methodologies were combined in this study by utilising CFD to design an advanced SA system for bagasse combustion with minimal under-grate air. The higher mass flow available to the SA system was leveraged by introducing the air into the lower bagasse chutes to create enough turbulence without the use of high velocity and a separate high pressure fan which is the conventional approach. It is therefore a more cost effective and compact solution. The main focus of the system was to improve combustion efficiency and stability.

Materials and Methods

Materials

The fuel used in this study was bagasse, furfural residue and a combination of the two. Therefore, there was a substantial variance in the particle size distribution. Bagasse contained the coarsest- and furfural residue consisted of the finest particles.

The moistures of the fuels also varied from 40 to 60%. This large variation in fuel quality proved challenging from the perspective of designing a static SA system to cater for the range of operating conditions. It also required careful setup during commissioning.

CFD analysis

The boiler was simulated with the commercial CFD software package, ANSYS Fluent following the approach of Du Toit and van der Merwe (2014). The physics modelled were the flow of air
to the combustion chamber and the mixing with the fuel in the form of solid particles. The heterogeneous particle reactions, homogenous combustion with species transport after chemical reaction and associated heat transfer were simulated in detail.

The solid and gas phases interact through the exchange of mass, momentum and energy. The governing equations were discretised by a finite volume method.

Testing

Prior to the experiments, the fuel spreaders of the boiler were set at the correct angles and air pressures to achieve an even fuel bed on the grate. The secondary air pressures were adjusted as per the boiler's original equipment manufacturer standards with the highest pressure at grate level.

The John Thompson three-pass mainbank boiler was maintained at a constant load and air-fuel ratio. The combination of steam flow, feed water flow, steam pressure and drum level were continuously monitored to anticipate upset conditions.

A thermal camera was used to obtain the temperatures in the flame by means of optical pyrometry. The images from the camera indicated the position of the flame, particle movement and combustion intensity.

The most important parameter monitored was the flue gas oxygen ($O_2$) content at the mainbank outlet by means of a Zirconian probe. The oxygen content and carbon monoxide (CO) were periodically verified with a chemical cell gas analyser. This indicated the correct fuel distribution and combustion stability in combination with the furnace pressure reading.

Blockages of fuel-feeding equipment, piling on the grate, plugging of measuring equipment due to high particle loading and process load swings were managed.

A team of people conducted the experiments in order to obtain the best quality data in this difficult and aggressive testing environment far from laboratory conditions.

Data analysis

Data from the distributed control system (DCS) of a crushing season without the new SA system was compared to the subsequent season after the system was commissioned. Both period lengths were similar. The condition of the equipment was checked prior to both seasons to ensure that no changes were made during the off-crop that could influence the results. The data included steam flow, fuel feeder speeds, oxygen content, fuel moisture, fuel density and final gas temperature. The data was filtered to remove start-ups, short and long stops.

The sampling frequency was one hour. Moving averages with a lookback of 100 data points were used in order to inspect smoother trends.

Results and Discussion

CFD analysis

Iso-surface plots of constant CO at a value of 20 000 ppm were used to depict the outer flame envelope in Figures 1 and 2. These plots were coloured with the temperature of the gas on the surfaces. Figure 1 indicates a tall, elongated flame with localised hot spots when the old SA system is used. A short, diffused flame with uniform temperature can be seen in Figure 2 with the new SA system.
The flame in Figure 1 extends into the primary superheater in the back pass compared to Figure 2 where the flame only touches the nose before the secondary superheater closest to the furnace.

The average flame temperature is also higher lower down with the new SA system in Figure 2. A higher more uniform furnace heat flux was reported from the CFD results. The increased turbulence due to the higher fraction of SA versus under-grate air results in a more effective utilisation of furnace volume. Reports of particle burnout from the CFD results confirmed higher combustion efficiency with less unburnt carbon.
Therefore time, turbulence and temperature of combustion were increased leading to lower unburnt gas (CO) and unburnt carbon losses. These results suggest an improved boiler efficiency. The higher turbulence and resulting improved mixing of air and fuel also implies that operation with lower excess air could be possible.

**Testing on site**

A testing campaign proved challenging due to the large variance in fuel quality. The under-grate dampers in the 6 individual sections of the dump grate had to be set manually in order to divert the primary air to the lower bagasse chutes. Initially this caused piling of fuel on the sections of the grate closest to the side walls. The velocities in the ducts leading to the under-grate compartments were checked for even flow to ensure that the dampers were working correctly. The solution was to leave the under-grate dampers of the sections next to the side walls partially open and the rest of the dampers almost fully closed to compensate for the fuel particles hitting the sidewalls and piling on the sides.

A remarkable improvement of combustion stability was seen with the new SA system. Puffing reduced considerably with a more constant furnace pressure. The next notable improvement was a reduction of CO measured at the mainbank outlet from 2000 ppm to 900 ppm at a low O\textsubscript{2} content of 3% volume dry. A typical O\textsubscript{2} value for bagasse is 5% volume dry which is 4% volume wet as measured by a Zirconian probe at the mainbank outlet. The values were measured on average over the width of the duct during one hour indirect efficiency tests at constant load.

A thermal camera was inserted into the furnace at the middle of the front wall on fuel feeder level looking at the furnace rear wall just below the nose. The difference in shape, position and temperature of the flame comparing the old and new SA system corresponded to the CFD results qualitatively. Comparing Figure 3 with the old SA system to Figure 4 with the new SA system a shorter, more diffused flame with less and lower temperature peaks can be seen utilising the new SA system.

A reduction of fuel feeder speed was also seen comparing the trends displayed on the DCS before and after the new SA system was commissioned. The boiler was also more responsive to load changes with the new SA system.

![Figure 3. Thermal camera images (old SA system).](image-url)
Data analysis

The new SA system was commissioned in June 2017. The data in Figure 5 is with the old SA system and Figure 6 after June is with the new SA system. Comparing the average values over the period June - December 2016 with the old SA system to June - December 2017 with the new SA system the following was seen:

- Boiler load during 2017 after the overfire air modification was only 0.55% higher
- \( O_2 \) was 17% lower and more stable with the new SA system
- Final gas temperatures were comparable over the data with a 1.7% variance
- Fuel moistures are comparable with 2017 post modification since it is only 0.88% lower
- Chute densities are also comparable by being within 1% higher
- Fuel feeder speed was 5% lower with the new SA system.

The fuel feeder speed was the only parameter shown above that can give an indication of the efficiency gain over the crushing season with the new SA system compared to the old SA system. The boiler load, final gas temperature, fuel moistures and fuel densities will affect the fuel feeder speed, but since it was confirmed that these parameters were similar on average over the two periods, the average fuel feeder speed can be confidently used as an indication of a 5% efficiency gain.

The 5% efficiency gain is higher than the theoretical expected value of approximately 2% according to the indirect method when considering the lower excess air, unburnt gas loss and unburnt carbon loss. It is standard practice to use an assumed carbon loss for biomass fuels as it is extremely difficult to quantify accurately during a test. If the carbon loss was measured during the two indirect efficiency tests conducted it would not account for the transient effects during the crushing season since efficiency tests are conducted at constant load.

Since the unburnt carbon was not measured it is deduced that the associated loss on a dump grate over the crushing season is higher than the theoretical value with the old SA system on average due to transient conditions and varying fuel quality, accounting for the balance of the 5%. It ties up with the fact that the theoretical carbon loss is suitable for constant load and design fuel quality at contractual capacity and efficiency testing conditions.
Figure 5. 100h moving average plots of 2016 season (old SA system).

Figure 6. 100h moving average plots of 2016 season (new SA system from June)
Conclusions

A new SA system for bagasse combustion was designed using CFD by minimising the amount of air to the grate of the boiler. The higher mass flow available to the SA system was leveraged by introducing the air into the lower bagasse chutes to create enough turbulence without the use of high velocity and a separate high-pressure fan, making the system more cost effective.

Comparing CFD results of the old SA system to the new system indicated that the time, turbulence and temperature of combustion were increased leading to lower unburnt gas (CO) and unburnt carbon losses.

A testing campaign on site revealed an improvement of combustion stability with the new SA system. Puffing reduced considerably with a more constant furnace pressure. A reduction of CO measured at the mainbank outlet from 2000 to 900 ppm at a low O2 content of 3% volume dry was also seen. The difference in shape, position and temperature of the flame comparing the old and new SA system corresponded to the CFD results qualitatively. A shorter, more diffused flame with less and lower temperature peaks was observed when utilising the new SA system.

A data analysis comparing two crushing seasons with and without the new SA system indicates a 5% efficiency improvement with the new system on average. This value is higher than theoretically expected and it is deduced that is due to a higher reduction in unburnt carbon loss.

At the moment the air split between the grate and free-board is static requiring careful setup during commission. A dynamic modulating system is seen as the next step.

REFERENCES

