OPPORTUNITIES FOR IMPROVING THE PERFORMANCE AND REDUCING THE COSTS OF BAGASSE-FIRED BOILERS

By

A.P. MANN, T.F. DIXON, F. PLAZA and J.A. JOYCE

Sugar Research Institute
a.mann@sri.org.au

KEYWORDS: Boilers, Bagasse, CFD, Erosion, Corrosion.

Abstract

The challenges faced by bagasse boiler designers mean that significant compromise and conservatism are present in the design of most bagasse fired boilers. This paper describes a number of recent developments that have allowed factories to capitalise on some of the conservatism in both new and old boiler designs, to increase steam output, improve combustion stability and reduce maintenance costs, through low cost retrofits. The recently developed swirl spreader combustion system has overcome some of the limitations of conventional spreader firing technology. The steam generating capacity of a boiler in Australia has been successfully increased without any combustion stability problems and reduced grate deposition. Computational fluid dynamics (CFD) has been successfully used in a number of cases to reduce the operating and maintenance costs associated with erosion of convection bank tubes and erosion and corrosion of air heater tubes. CFD has also been used to improve boiler efficiency by correcting gas and air flow non uniformities that have occurred in a number of boilers. More recently CFD has been extensively used in the design of a new generation, low capital cost improved performance bagasse-fired boiler.

Introduction

Many bagasse-fired boilers around the world (especially the older ones) are conservatively designed and were often intended to operate at low efficiency to reduce the costs of stockpiling and transporting bagasse. Over time many factories expand their crushing capability, thereby increasing steam demand. Factory expansion is in many cases limited by the high capital cost of new steam generating plant. Consequently, there are significant advantages if the capacity of existing boilers can be increased or if the capital cost of new boilers can be reduced. The conservative design of many older boilers makes retrofitting changes to increase capacity a feasible option in many cases.

Cogeneration is becoming an increasingly important source of income for sugar factories. Boiler efficiency improvements will maximise income from cogeneration. Boiler operating and maintenance costs are a large proportion of factory running costs. Some of the major operating and maintenance issues are erosion and corrosion of boiler tubes, carryover of unburnt fuel and combustion instability. This paper summarises some of the work that the Sugar Research Institute has carried out over the last 10 years to address these issues. The recently developed swirl spreader combustion system, which reduces the capital cost of new boilers and overcomes some of the limitations that restrict steam capacity expansion, is discussed. The extensive advances in CFD modelling of bagasse-fired boilers developed by SRI are also described. These advances have enabled CFD modelling to reach the stage where it can be routinely used to design baffles for reducing tube erosion and corrosion, and increasing the efficiency of bagasse-fired boilers. CFD modelling has also been extensively used in the design of a new generation reduced capital cost, improved performance bagasse-fired boiler.

Swirl spreader combustion system

SRI has been investigating options for upgrading the performance of bagasse-fired boilers for several years. Dixon and Plaza (1995b) used the CFD code FURNACE to predict the effect of excess air, bagasse moisture, fuel firing rate and grate air flow distribution on the heat fluxes, gas temperatures and unburnt fuel levels in a bagasse-fired boiler. Alternative conventional spreader and secondary air arrangements were also investigated. Dixon et al. (1998) used the lumped parameter model BLRDSN to predict how performance parameters, such as the furnace residence time, would change when a boiler is
fired above its Maximum Continuous Rating (MCR). They found that, for the boiler under investigation (Pleystowe No. 2, Australia), the boiler could operate at over 120% MCR before the furnace residence time reduced to a level that would give rise to excessive carryover of unburnt fuel. Similar conclusions have been made about other boilers in the Australian industry. In practice, however, it has been found that for many boilers, when the bagasse feed rate is increased to above MCR levels, grate deposition and combustion instability increases. Part of this deterioration in performance arises from limitations with the design of current conventional spreaders. The swirl spreader combustion system was developed to address performance issues that limit the performance of conventional spreaders.

The full swirl spreader combustion system was installed on the Proserpine No.4 boiler (200 t/h MCR) prior to the 2002 crushing season. This installation was the culmination of technology development over several years. The development sequence progressed through stages of (i) concept development on a single full-scale spreader under cold flow conditions in a test facility at SRI during 1999, (ii) hot testing of two Mark I small-capacity spreader units on the No.1 boiler (18 t/h MCR) at Farleigh mill during 2000, and (iii) hot testing of an intermediate size boiler retrofit (Marian No.2 boiler, 113 t/h MCR) utilising three Mark II spreader units during 2001. The Proserpine No.4 boiler was retrofitted with four swirl spreaders (Mark III design) that were located in positions 2, 3, 4 and 5. The outer two conventional spreaders (positions 1 and 6) were not altered. Figure 1 shows a front view of the new swirl spreaders in positions 2 and 3.

Overall combustion performance of the boiler with the swirl spreaders in operation was generally very good. Modifications to the scrubber modules in the maintenance season to reduce pressure drop, and thus recover some performance margin on the ID fan, made it possible for the boiler to achieve steam loads in excess of 230 t/h (MCR 200 t/h) when bagasse quality was good (< 49% moisture). This output was achieved with only minimal bagasse flow (5% feeder speed) through the two outer conventional spreaders.

This small flow was necessary to prevent radiant overheating of the bagasse feed chutes to these conventional spreaders. Even when the bagasse quality was poor, there was only localised grate deposition (near the front and in the rear corners of the furnace) with most of the grate remaining free of deposits. This is especially encouraging because with the current set-up on the Proserpine No. 4 boiler, a large proportion of the hot grate combustion air (between one third and one half of the original grate air flow) is replaced by cold swirl spreader air. It is planned that for future installations hot air may be used for the swirl spreaders. Testing showed that overall furnace performance was relatively unaffected by the settings of the swirl spreaders. Unburnt fuel measurements showed that the efficiency loss due to unburnt fuel with the boiler operating at an average steam load of 215 t/h was not much higher than the unburnt fuel efficiency loss measured by the boiler manufacturer shortly after boiler commissioning at the much lower steam load of 174 t/h.

Fig. 1—Front view of the spreaders in positions 2 and 3 on the Proserpine No. 4 boiler.
The demonstrated ability of the Præserpine No. 4 boiler to generate steam loads in excess of MCR with four swirl spreaders (while six standard spreaders were required previously) means that there are significant capital cost savings associated with installing swirl spreaders on new boilers. By increasing combustion stability with high moisture bagasse and reducing grate deposition when the boiler is operated at steam loads above the boiler MCR, the swirl spreader combustion system will also assist with upgrading the capacity of existing boilers.

**Advances in CFD modelling of bagasse fired boilers**

**The FURNACE CFD code**

Most of the CFD modelling work carried out by SRI in the boiler field has used the FURNACE code, which was originally developed for pulverised coal fired boilers by the University of Sydney (Boyd and Kent, 1986). FURNACE is a three dimensional, structured grid CFD code that can predict the standard gas and particle flow patterns, combustion and radiation in utility and industrial boilers firing a range of fuels. The code also has time stepping capability. It has been modified over a number of years to model the flow and combustion processes in bagasse fired boilers (Luo, 1993; Woodfield et al., 1998; Mann et al., 2001).

**Tube erosion modelling**

Erosion of boiler tubes is a significant contributor to the maintenance costs of sugar mills. In some severe cases, boiler convection banks have required a complete re-tube, a major capital cost. The problem can be particularly severe in boilers with baffled convection banks. Tube wear rates are the highest where there are high local gas velocities and high local particle concentrations. Wear rates also depend strongly on the impact angle.

The FURNACE code was first applied to the problem of convection bank tube erosion in 1994 (Dixon and Plaza, 1995a) and since then the code has been successfully used to redesign a number of convection banks in Australia (Plaza et al., 1999) and overseas. Figure 2 shows the predicted gas velocity distribution through a baffled convection bank that experienced wear at the inlet of the convection bank and near the convection bank outlet baffle.

![Fig. 2—Side elevation view of the predicted gas velocity (m/s) distribution through a boiler convection bank experiencing tube wear problems.](image)

Figure 3 shows the corresponding gas velocity distribution through the bank after modifications to reduce tube wear rates. The success of the investigations has been noted, for example, by Muchow and Wallis (2002). Modifications have been made to the FURNACE code to enable it to better predict convection bank heat transfer performance with different baffle configurations (Mann et al., 2003). This will allow boiler engineers to make more informed decisions about how to balance the sometimes
competing concerns of reducing tube erosion and improving convection bank heat transfer. Small modifications, that allow the boiler to carry on for a few more years, can also be made, after which a re-tube, with major changes to the geometry, is recommended.

Small modifications, that allow the boiler to carry on for a few more years, can also be made, after which a re-tube, with major changes to the geometry, is recommended.

Fig. 3—Side elevation view of the predicted gas velocity (m/s) distribution through a boiler convection bank after baffle modifications to reduce tube wear rates.

Tube erosion can also be a problem at the gas side inlet of air heater tubes. The problem is particularly severe when the gas and particle flow distribution into the air heater tubes is non-uniform and when the flow into the air heater is not parallel to the longitudinal axes of the tubes. Tube wear rates have been reduced in several cases using FURNACE to design baffles that correct the flow non-uniformities and make the flow direction parallel to the longitudinal axes of the air heater tubes.

Air heater corrosion modelling

Air heater tube corrosion has been a major maintenance cost for many years for many boilers. Past research (Dixon et al., 2000) has demonstrated that the problem has its origin in gas and air flow distribution patterns and occurs while a boiler is operating.

Measurements of air heater tube temperatures have shown that wall temperatures close to 60°C, that is less than the flue gas dew point temperature, can occur in air heaters where the mean gas exit temperature is greater than 260°C. Negligible corrosion occurs during the start-up phase, which has been the traditional explanation for the problem.

It has been determined that the uniformity of the gas flow distribution at the air heater inlet is critical for preventing dew point condensation inside some air heater tubes. This is coupled with the matching air flow distribution, which can act to accentuate the gas flow deficiencies. The FURNACE CFD code has been used to design baffles upstream of the gas and air side inlets of air heaters with significant reductions in dew point corrosion.

In addition to reducing dew point corrosion, the air heater inlet baffles can make the gas and air flow distribution through an air heater considerably more uniform, improving heat transfer performance.

Global modelling of air heater performance has shown that the air heater heat transfer rates can be improved. In one case, where the original gas and air flow distributions into an air heater were highly non-uniform, making the flows more uniform using baffles was predicted to decrease the gas exit temperature from the air heater by more than 15°C. This will significantly improve boiler efficiency.

Further applications of CFD modelling to bagasse-fired boilers

With increasingly stringent limits on the emissions of particulates and gas phase pollutants such as NO and CO, the focus of CFD capability development is to predict and reduce pollutant emissions.
Concentrations of CO and NO in the furnace have been measured and the results analysed so that mathematical models for predicting NO and CO concentrations can be included in the FURNACE code.

SRI researchers also use FURNACE to investigate the effectiveness of equipment that has not been installed in Australian bagasse boilers but is operating in many overseas installations. Two examples are the use of spinning hot secondary air in some furnaces and the use of duct work that encourages the removal of particulates from the gas flow before entering the dry or wet scrubbers.

**Development of a new design bagasse-fired boiler**

SRI, in collaboration with the boiler manufacturer Clyde Babcock Hitachi (CBH) has been investigating new boiler designs for reduced capital cost and improved combustion performance. The FURNACE code was used to model the effect of various design changes on boiler performance. The design modifications included changing the aspect ratio of the furnace as well as the height, the size and placement of the superheaters and the size and the shape of the furnace bullnose.

The option of installing a new configuration of secondary air nozzles on the front wall of the furnace to enhance the furnace recirculation pattern (to increase furnace residence time and therefore improve burnout) was also investigated. Figure 4 shows a side elevation view of the predicted gas velocity distribution through a standard design high pressure boiler and Figure 5 shows the corresponding plot with some front wall secondary air added and swirl spreaders installed.

The flow from the front wall secondary air slots and swirl spreaders causes increased recirculation of furnace gases which should lead to improved combustion performance and reduced unburnt fuel losses. Furnace heat transfer was also predicted to increase due to higher temperatures lower down in the furnace. These, and other modelling results, were used with the design and costing information supplied by CBH to develop a new generation, low capital cost, improved performance bagasse fired boiler.

**Fig. 4**—Side elevation view of the predicted gas velocity (m/s) distribution through a standard design high pressure boiler.

**Conclusions**

The developments summarised in this paper show that there is considerable scope for upgrading the performance of bagasse-fired boilers. The swirl spreader combustion system has successfully overcome some of the limitations associated with the conventional spreaders and enabled the steam generating capacity of a large Australian boiler to be increased to 115% of MCR. Combustion stability was good and grate deposition was minimised with swirl spreader firing.
CFD modelling has been used to minimise the operating and maintenance costs of a number of boilers, by reducing erosion of convection bank tubes and erosion and corrosion of air heater tubes. Further enhancements to the FURNACE code will allow boilers to operate with reduced emissions of gas phase pollutants. The code has also been an integral tool in the development of a new generation, low capital cost, improved performance bagasse-fired boiler.

Acknowledgements

The work described in this paper was funded by syndicates of Australian sugar factories, the Sugar Research and Development Corporation, the Australian Greenhouse Office and the Queensland Department of State Development. The authors would also like to acknowledge the assistance of the staff of Farleigh, Marian and Proserpine sugar mills with the installation and testing of the various swirl spreader systems.

REFERENCES


246
AMÉLIORATIONS DE LA PERFORMANCE ET RÉDUCTIONS DES COÛTS POUR DES CHAUDIÈRES A BAGASSE

A.P. MANN, T.F. DIXON, F. PLAZA et J.A. JOYCE
Sugar Research Institute
a.mann@sri.org.au

MOTS CLEFS: Chaudières, Bagasse, CFD, Érosion, Corrosion.

Résumé
La conception des chaudières à bagasse a toujours été difficile; ce problème a ralentit l’application d’idées nouvelles et demande souvent de nombreux compromis. Ce papier décrit des développements récents qui nous ont permis d’améliorer la performance de chaudières existantes, d’introduire de nouvelles idées, d’augmenter le débit de vapeur, de stabiliser l’opération et de réduire le coût de la maintenance. On a développé un nouveau système de combustion (swirl spreader) très performant. En Australie on a augmenté la capacité des chaudières et on a réduit le dépôt sur les grilles sans sacrifier la stabilité de la combustion. On s’est servi d’un logiciel (Computational Fluid Dynamics, CFD) pour optimiser l’opération des chaudières et pour réduire l’érosion sur les tubes. Le logiciel nous a aussi permis de corriger des erreurs trouvées dans les débits d’air et de gaz. Récemment le CFD a été utilise pour concevoir une nouvelle génération de chaudières offrant de bonnes performances à des coûts très intéressants.

OPORTUNIDADES PARA MEJORAR EL DESEMPEÑO Y REDUCIR LOS COSTOS DE CALDERAS OPERADAS CON BAGAZO

A.P. MANN, T.F. DIXON, F. PLAZA y J.A. JOYCE
Instituto de Investigación del Azúcar
a.mann@sri.org.au

PALABRAS CLAVE: Calderas, Bagazo, CFD, Erosión, Corrosión.

Resumen
El reto que enfrentan los diseñadores de calderas de bagazo hace patente la existencia de un importante compromiso y la búsqueda de un conservatismo en el diseño de la mayoría de las calderas operadas con bagazo. Esta ponencia describe algunos de los más recientes descubrimientos que han permitido a muchos ingenios capitalizar algo de dicho conservatismo, tanto en los nuevos como en los viejos diseños, cuyo objeto es incrementar la producción de vapor, mejorar la estabilidad en la combustión y reducir los costos de mantenimiento, a través de remodelaciones a bajo costo. El sistema de combustión de esparcidor de torbellino, recientemente desarrollado, ha superado algunas de las limitaciones de la tecnología tradicional de calentamiento por esparcidores. Se ha incrementado con éxito la capacidad de generación de vapor de una caldera en Australia, la cual no presenta ningún tipo de problema de estabilidad en la combustión y ha logrado reducir los depósitos en la parrilla. La dinámica de fluidos por computadora (DFC o CFD, por sus siglas en inglés) se ha utilizado con éxito en un cierto número de casos para reducir los costos de operación y mantenimiento asociados con la erosión del conjunto de tubos de conveción y la erosión y corrosión de los tubos de aire de la caldera. La DFC también se ha empleado para mejorar la eficiencia de la caldera, a través de la corrección de la falta de uniformidad en el flujo del gas y el aire que ocurren en un gran número de calderas. Más recientemente, se ha empleado ampliamente la DFC para el diseño de una nueva generación de calderas operadas con bagazo, las cuales cuentan con un desempeño mejorado y representan una baja inversión de capital.