REFEREED PAPER

CONVERSION OF A COAL FIRED BOILER TO BAGASSE FIRED USING COMPUTATIONAL FLUID DYNAMICS

VAN DER MERWE SW AND DU TOIT P

John Thompson, Sacks Circle, Bellville South, 7530, South Africa

schalkv@johnthompson.co.za

Abstract

The availability of good quality coals are found to be decreasing while its demand is increasing. The deterioration of coal quality has an adverse effect on combustion in boilers and their efficiency. Coupled with an abundant supply of a biomass such as bagasse, there is an ever increasing demand to convert traditional coal fired boilers to dual fuel boilers.

This paper investigates the conversion process of a traditional three pass mainbank, coal fired boiler to a bagasse fired boiler with the aid of computational fluid dynamics (CFD). Since the original design of the furnace was for coal firing only, concerns of inadequate residence time as well as bagasse related erosion problems were raised. Various design alterations were evaluated using CFD combustion - and erosion modelling.

A creative and cost effective heated secondary air system was proposed to achieve the required evaporation rate without increasing the furnace volume. Erosion modelling suggested alterations to the main bank, air heater and ducting to reduce the increased erosion associated with bagasse firing.

Keywords: coal conversion, boiler, bagasse, erosion, CFD

Introduction

The objective of this study was to determine whether a 100 TPH coal fired boiler can be converted to a 100 TPH bagasse fired boiler without increasing the furnace volume, and avoiding common erosion problems associated with bagasse firing. The approach was to simulate combustion and erosion using a commercial CFD package. The CFD model accounts for all the physics related to combustion and erosion and are an extension of the model used by Du Toit and Van Der Merwe (2014).

The methodology was to simulate combustion and erosion independently and investigate various configurations against a datum or “as is” case. The combustion simulations were solved for various permutations on undergrate temperature and secondary air settings. Fuel conversion, O_2, CO and temperatures were used as parameters to determine the effectiveness of combustion solutions. The erosion simulations were divided into three sections, i.e. furnace, main bank and airheater.

Common problems in both combustion and erosion were highlighted by the CFD modelling. This paper presents a series of solutions for both the combustion and erosion problems which would be encountered while firing this boiler on bagasse.

General

The geometry and dimensions of the boiler were known and were created in the three-dimensional volume depicted in Figure 1(a). The model included a travelling grate, bagasse spreaders, furnace, secondary air nozzles and superheater elements. The geometry and mesh was identical for the combustion and the erosion models.

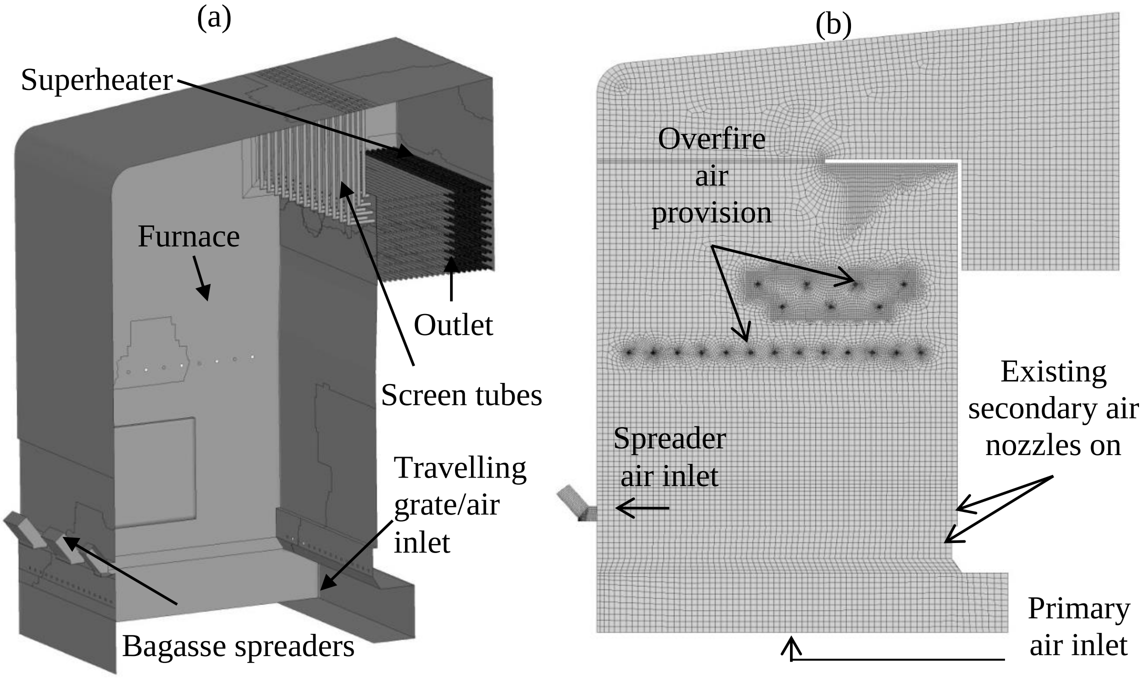


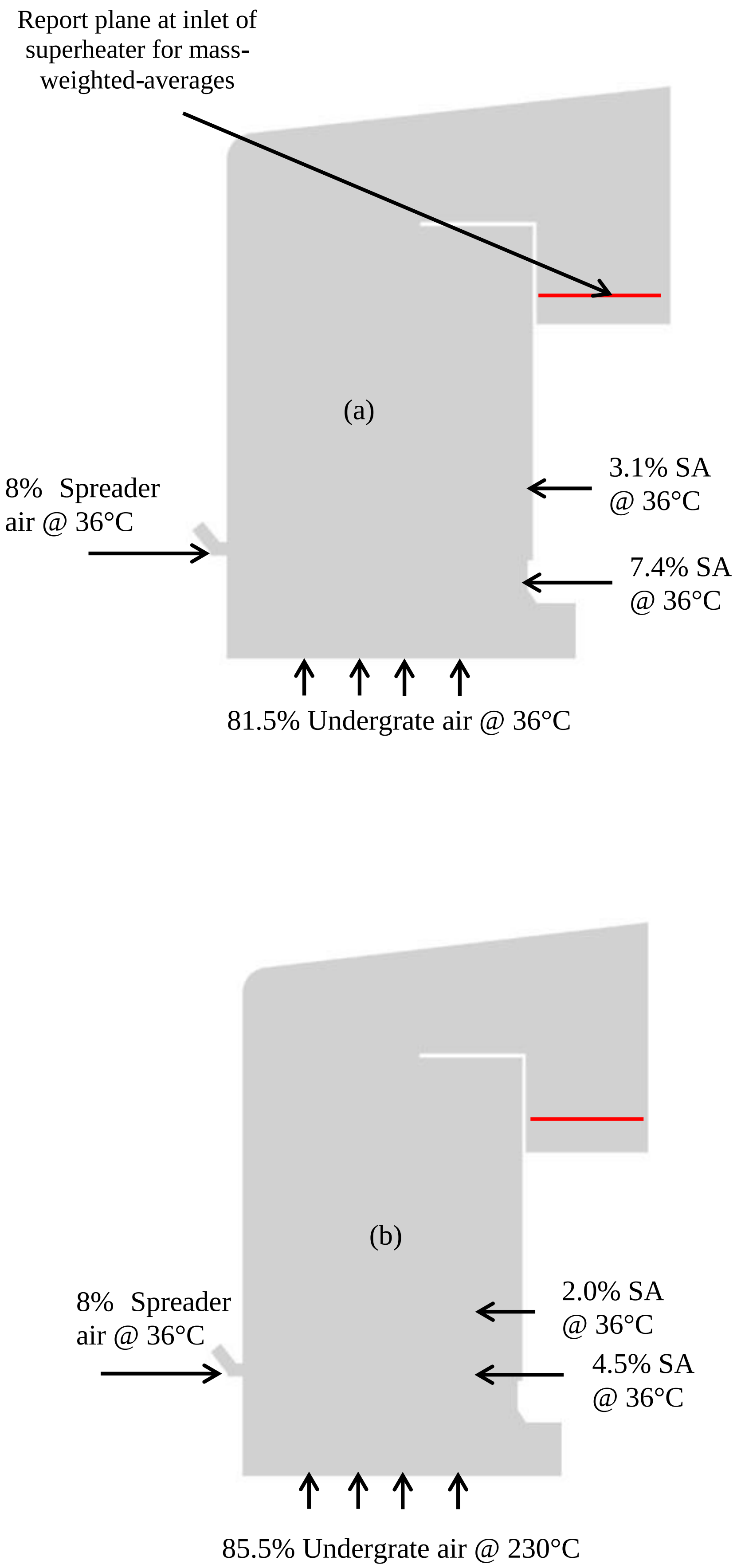
Figure 1(a) Sectional view of a three-dimensional model of the boiler and (b) a side view of the mesh as utilised in the combustion simulations.

The three-dimensional combustion model was solved for a single geometry as depicted by Figure 1(b), with the following case permutations:

- Datum case – with geometry and combustion controls as is in the current state as depicted by Figure 2(a).
- Air heater case – all settings kept the same as the datum case with the exception of the undergrate temperature, which was raised to simulate the effect of an airheater as depicted by Figure 2(b).
- Cold overfire case – The effect of cold secondary air is simulated on the air heater case as depicted by Figure 2(d).
- Hot overfire case – The effect of heated secondary air is simulated on the air heater case as depicted by Figure 2(c).

The erosion model was solved for the following cases:

- Datum case – with screen and superheater as is in their current state as depicted by Figure 3(a).
- Moved superheater case – kept the superheater size the same and moved it towards the furnace as depicted by Figure 3(b).
- Extended screen case – kept superheater the same and split the screen into two screens as depicted by Figure 3(c).
- Extended screen case with less superheater – screen identical to the extended nose case and removed the last five rows of superheater elements as depicted by Figure 3(d).


Report plane at inlet of superheater for mass-weighted-averages
(a)
8% Spreader air @ 36°C
3.1% SA @ 36°C
7.4% SA @ 36°C
81.5% Undergrate air @ 36°C
(b)
8% Spreader air @ 36°C
2.0% SA @ 36°C
4.5% SA @ 36°C
85.5% Undergrate air @ 230°C

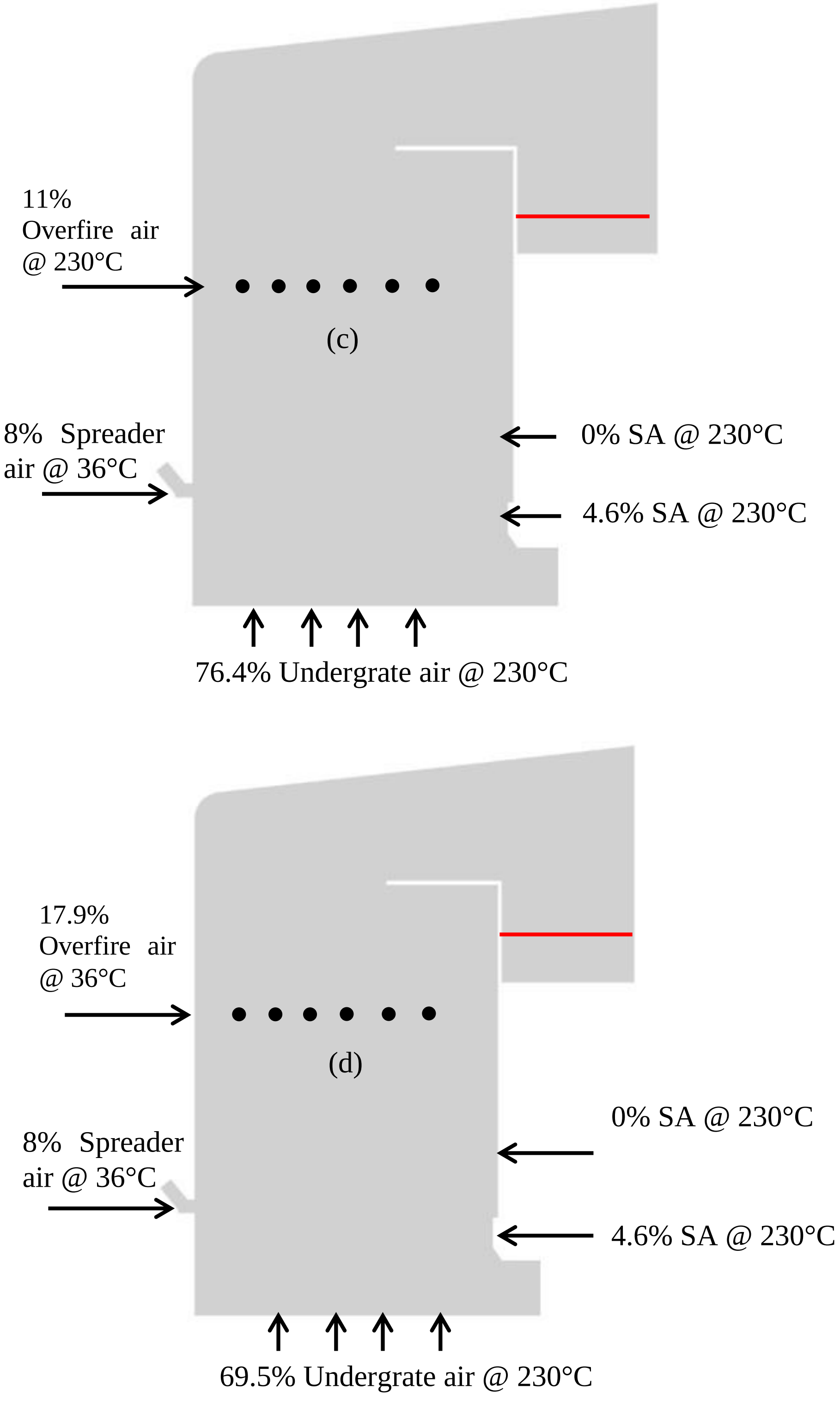


Figure 2. The various air distribution cases for the combustion modelling. (a) The datum case. (b) The datum case with the effect of an airheater added. (c) The case with hot overfire air. (d) The case with cold overfire air.

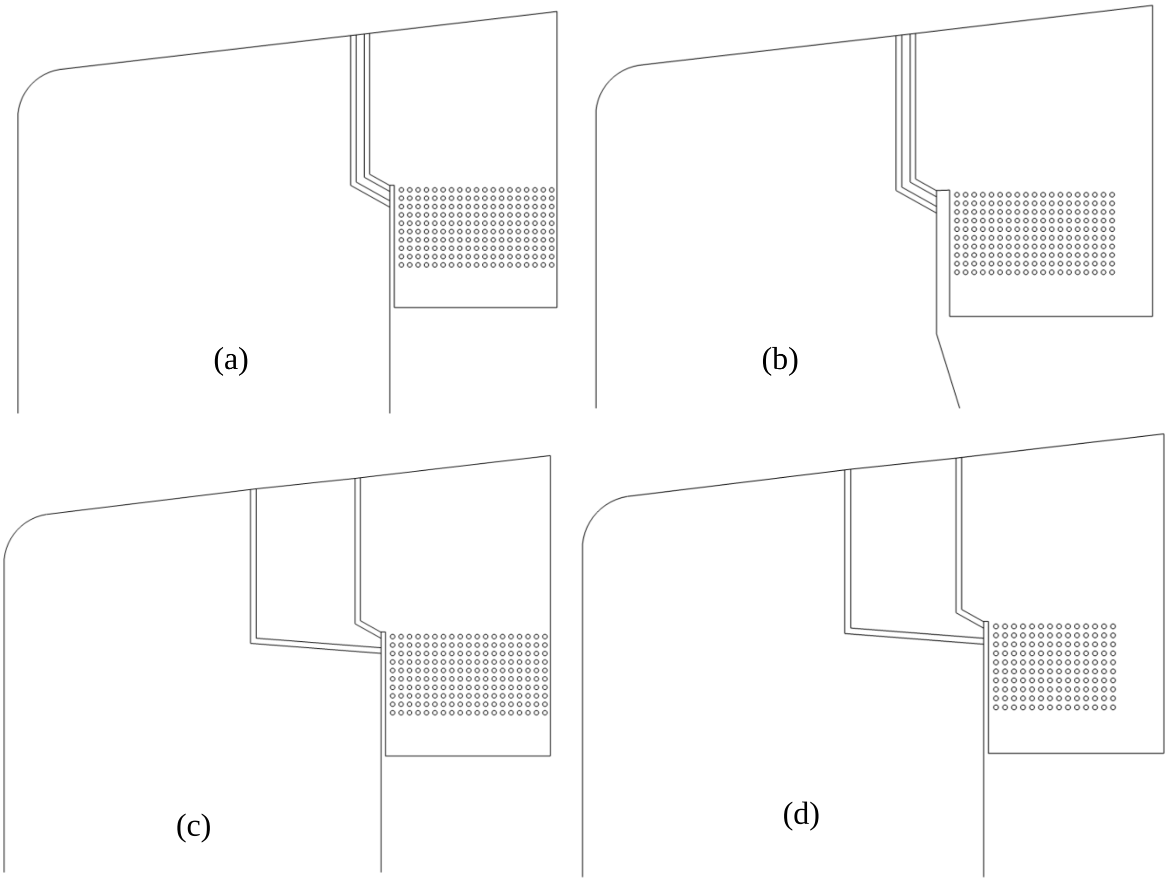


Figure 3. The various geometries for the furnace erosion. (a) Furnace geometry for the datum case. (b) Geometry for the case with the superheater moved toward the furnace. (c) Furnace geometry for the case with the screen spit and the nose extended. (d) Geometry for the case with the screen extended and the last five rows of superheater area removed.

Results of CFD modelling

The results are separated as combustion results and erosion results. Combustion parameters considered were O_2, CO, particulate matter carry-over and superheater gas inlet temperature. For the erosion the averaged erosion rate on the screens and the superheater tubes were reported to determine the effectiveness of the arrangement.

Combustion results
The combustion was cumbersome in the datum case with no airheater, as depicted by the low temperatures in Figure 4(a). The combustion was delayed and incomplete in this case, resulting in high CO concentrations at the superheater inlet report plane.

The effect of the airheater showed a vast improvement in combustion temperatures and fuel conversion. Although improved from the previous case, the CO concentration at the report plane was indicative of inadequate secondary air as depicted by Figure 4(b).

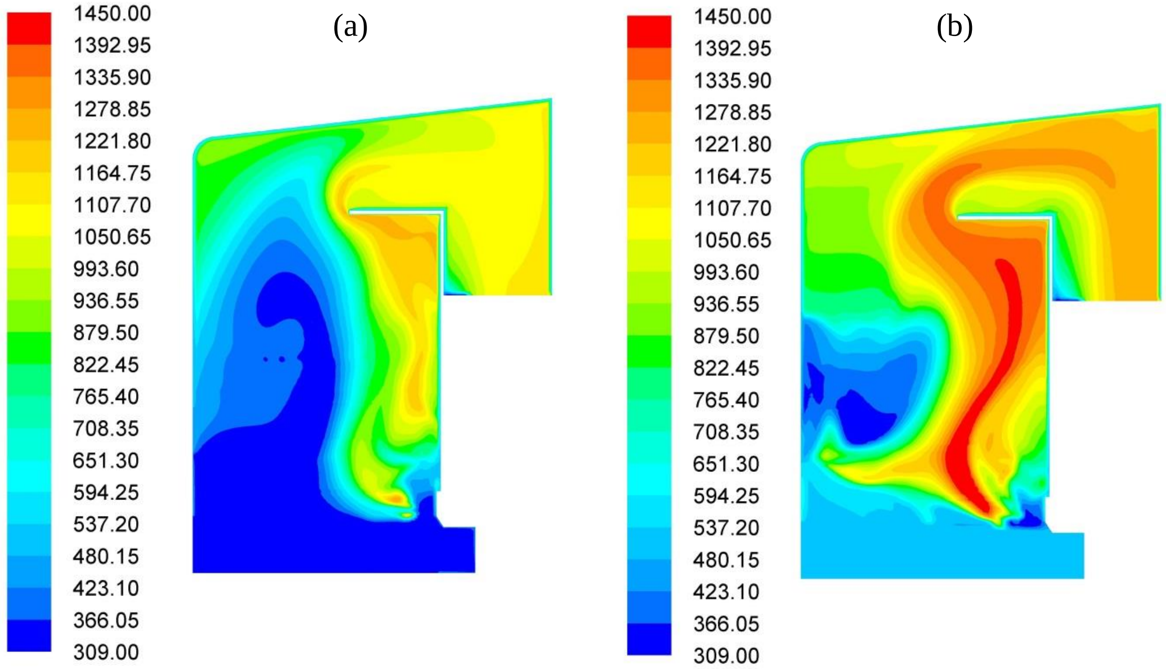


Figure 4(a) Temperature contours for the datum case in [K].
(b) Temperature contours for the case with the airheater in [K].

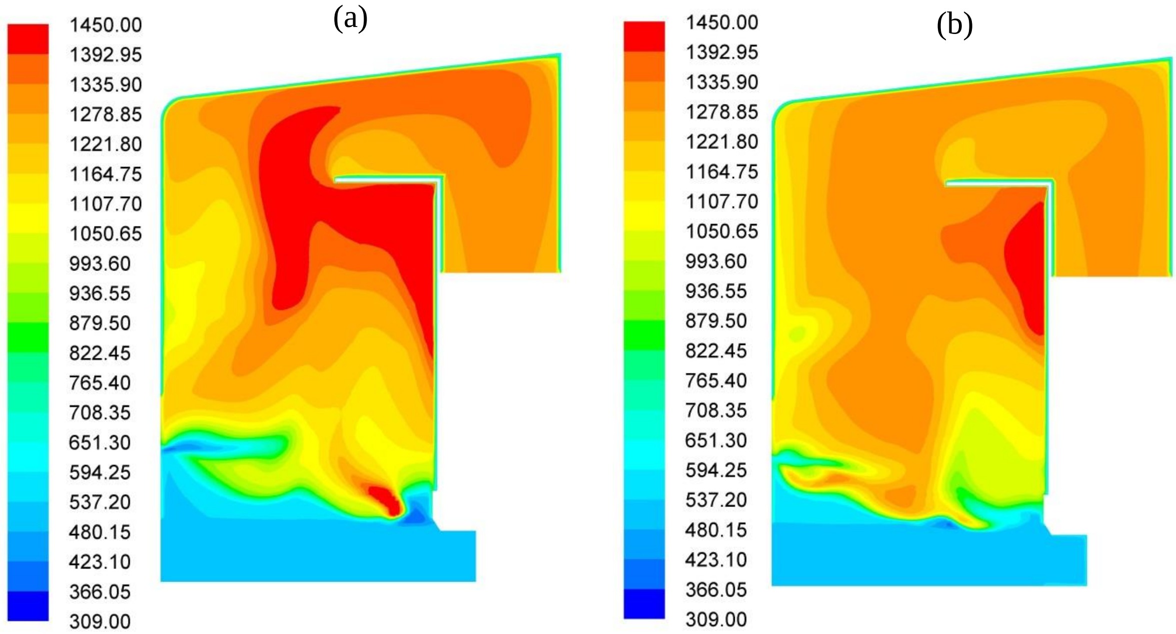


Figure 5(a) Temperature contours for the case with hot overfire air in [K].
(b) Temperature contours of the case with cold overfire air in [K].

The case with hot secondary air introduced from the sidewalls showed further improvement on the combustion temperature as depicted by Figure 5(a). The hot overfire case also presented a major improvement in reducing the CO concentration at the report plane.

The case with cold overfire air introduced showed less intense heat in the furnace as depicted by Figure 5 (b). Although the results in combustion parameters are similar to the case with hot overfire air, it is important to note that the mass of air required to achieve a similar result are considerably more, consequently reducing the amount of combustion air available for undergrate air as depicted by Figure 2(d). The summary of the combustion results are presented in Figure 6.

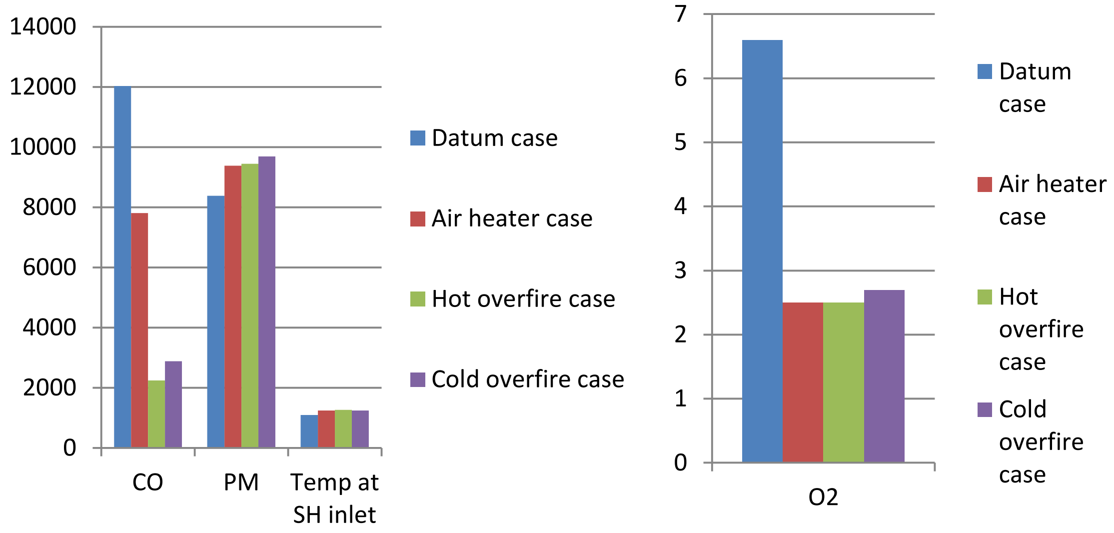


Figure 6. Comparison of O_2, CO, PM and superheater gas inlet temperature between the four cases.

Erosion results

The erosion rate in the datum case is depicted by Figure 7(a) and shows a typical wear pattern on both the screen and the superheater. The erosion rate on the superheater, in the case with the superheater moved, showed vast improvement when compared to the datum case. The erosion on the screen is slightly reduced in the case where the superheater is moved, as depicted by Figure 7(b).

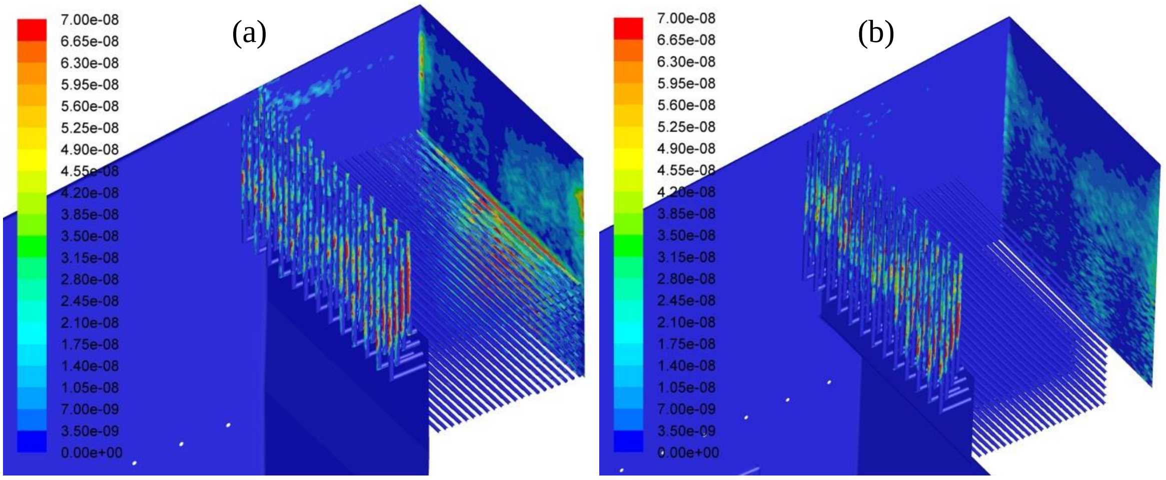


Figure 7. Erosion rate in [kg/m^2-s] on the screen and the superheater in (a). The datum case (b) with the superheater moved.

The erosion rate on the screen and superheater in the cases with the screen extended are depicted by Figure 8(a), (b). The extension of the screen into a nose has a positive influence on reducing the erosion on the superheater as depicted by Table 1. The erosion on the screen has, however, been aggravated when compared to the datum and the moved superheater case. This is a result of the flow curving around the nose and is then concentrated towards the top of the screen.

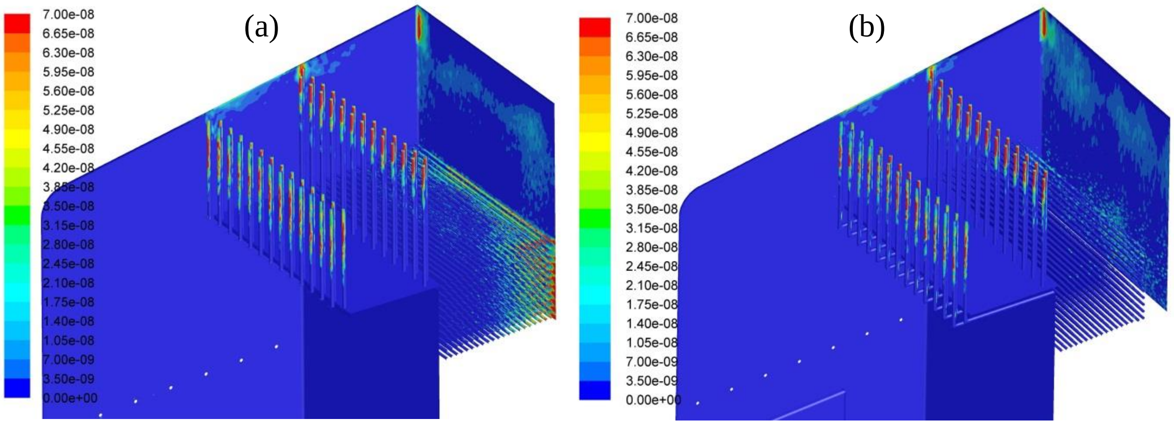


Figure 8. The erosion rate in [kg/m^2-s] for (a) the case with the screen extended into a nose and (b) the case with the screen extended and with less superheater rows.

Table 1 shows the overall results of the erosion modelling for the cases investigated.

Table 1. Summary of the erosion modelling results.

	Datum case	**Moved superheater case**	**Extended screen case**	**Extended screen/less superheater case**
Ave screen erosion (kg/m^2-s)	1.334e-8 (--)	0.845e-8 (-36.7%)	1.42e-8 (+6.45%)	1.4e-8 (+6.0 %)
Ave superheater erosion (kg/m^2-s)	4.323e-9 (--)	0.052e-9 (-98.8%)	2.9e-9 (-32.9%)	0.23e-9 (-94.6%)

Conclusions

This paper investigated the procedure involved in converting a traditional coal boiler into a bagasse fired boiler, without major modifications such as increasing the furnace volume.

The datum case with cold combustion air, had limitations in the amount of fuel that can be converted into heat. Only 65.7% of the bagasse could be converted, resulting in a steaming rate of 66 TPH. Another concern for this case was the low furnace utilisation, indicated by the temperature contours.

The addition of hot combustion air to the simulation made a significant difference in the combustion characteristics with lower O_2 and CO concentrations at the outlet of the furnace. It also resulted in more stable combustion. This case showed signs of poor furnace utilisation and can be identified, as with the previous case.

With the addition of hot overfire air the combustion efficiency can be further increased by lowering the CO concentrations leaving the furnace. This case also had improved furnace utilisation, visible in the temperature contours as depicted by Figure 5(a). Bagasse volatiles and CO gas were also better distributed throughout the furnace.

The overfire air system becomes vital to reduce CO concentrations and absorb fluctuations in boiler conditions such as load swings and fuel moistures.

The best combustion characteristics were found with hot overfire air. There is a small difference in combustion characteristics between the hot and cold overfire case, but since the hot overfire case requires 6% less mass through the overfire nozzles to achieve superior combustion, it is therefore the preferred option to introduce mixing in the furnace.

The CFD simulations presented in this report have detailed the combustion characteristics of the boiler and presented a solution to successfully and efficiently burn bagasse at a 100 TPH. Particulate matter carry over was within acceptable industry standards.

For the erosion in the furnace, two areas were identified from the datum case to be focuses of erosion, namely the screens and the superheater bank. The erosion rate on the superheater bank was successfully reduced in all four cases. The best case was reported where the superheater bank was moved by manipulating the furnace rear wall into the furnace and moving the superheater into the resulting cavity.

Other design alterations which improved the erosion rate on the superheater had the opposite effect on the screens, as shown by Table 1.

This paper showed that CFD modelling is an essential tool when considering industrial scale modifications to complex systems like boilers. By careful analysis and validation of the CFD software, excessive costs involved with rectifying faults can be avoided. Furthermore, although not in the scope of this paper, the effect of reduced heat transfer can be accurately quantified with the CFD, when considering erosion mitigation techniques as presented in this paper.

REFERENCE

Du Toit P and Van der Merwe, SW (2014). Computational fluid dynamic combustion modelling of a bagasse boiler. *Proc S Afr Sug Technol Ass.*