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# COMPUTATIONAL FLUID DYNAMIC COMBUSTION MODELLING OF A BAGASSE BOILER

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## Abstract

As our demand for energy increases, so does the urgency for increased efficiency and versatility from boilers. Current demand is shifting towards higher pressure and temperature boilers for co-generation, consequently complicating current design procedures. Computational fluid dynamics (CFD) has been widely used to predict flow fields and heat transfer.

This paper presents the CFD modelling of a bagasse boiler to predict the final steam temperature and flame profile in the furnace. Site measurements of the flame temperature were taken with a suction pyrometer and a thermal camera to validate the CFD model. Good correlations were found for the flame temperature and the final steam temperature, demonstrating the capability of the software as an accurate and feasible design tool.

*Keywords:* computational fluid dynamics, validation, suction pyrometer, thermal camera, heat transfer

## Introduction

The objective of this study was to develop a physically consistent model that can predict the steam temperature of an industrial watertube boiler reliably. The model accounts for all the physics, radiation, convection, turbulence and combustion that influence the resulting steam temperature.

Traditional boiler design methods are well established, and are irreplaceable as rapid coarse models. They provide useful information on a lumped system analysis, but fail to provide details on complex areas such as combustion and heat transfer in a three dimensional space. CFD has become the tool of choice to provide the detail in these areas and aid the design process with a high level of detail in areas of interest. Other applications of CFD in boilers include erosion modelling, fouling modelling, assessment of new fuels and general improvements relating to flow optimisation.

CFD modelling is computationally intensive, as the software solves multiple equations iteratively. Recent advances in both hardware and software have made numerical modelling more feasible to all industries. These improvements were essential for CFD modelling, as often the amount of detail required in a model exceeded the hardware capability of the time.

This paper presents a 3-D model of a bagasse boiler consisting of 20 million cells in the computational domain and is solved with commercial CFD code FLUENT R15. Results obtained with the CFD were validated with site measurements. Temperature measurements of the flue gas were taken with a suction pyrometer and flame temperatures were taken with a thermal camera. The suction pyrometer makes it possible to measure true gas temperature in the combustion zone.

## General

The geometry and dimensions of the boiler were known and were created in the three-dimensional volume depicted in Figure 1. The model included a pin-hole grate, bagasse spreaders, furnace, secondary air nozzles and superheater elements.

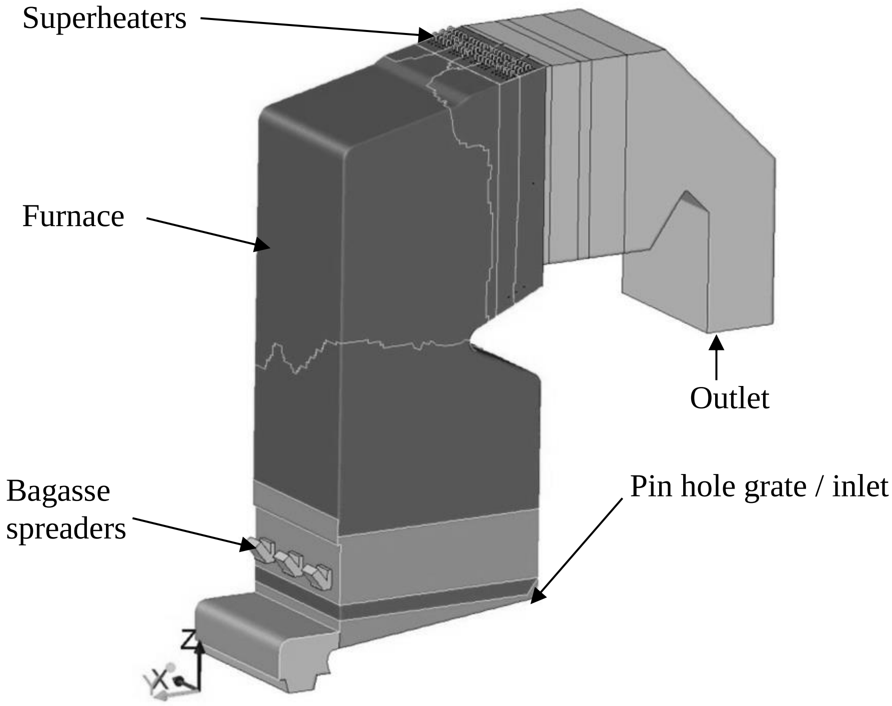


**Figure 1. Diagrammatic view of three-dimensional model of boiler.**

The mesh was constructed with a resolution fine enough to capture and resolve all the physics. Figure 2 depicts the mesh at a bagasse spreader.

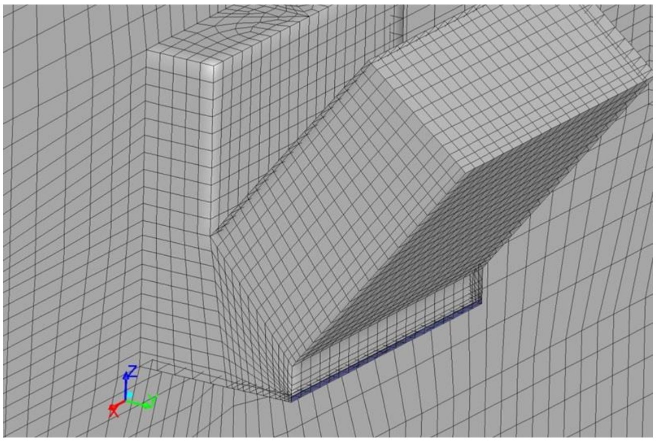

**Figure 2. Mesh at the bagasse spreader.**

The inputs to the CFD model were taken from site data and include fuel properties, fuel mass flow rate, volumetric air flow rate into boiler, steam flow rate.

## Results of CFD modelling

The velocity and temperature contours are depicted by Figure 3(a) and (b) respectively and shows how heat and velocity is distributed throughout the boiler.

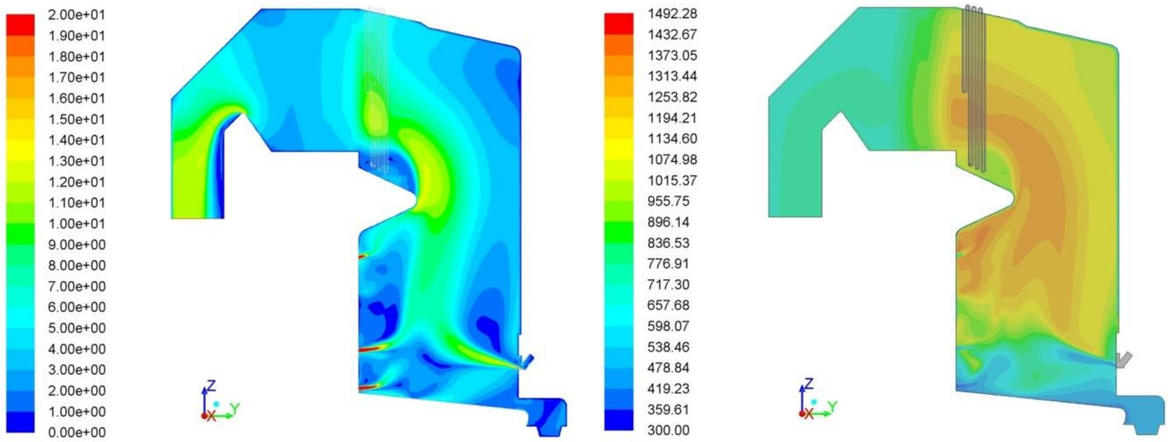


**Figure 3. (a) Velocity contours at the centre of the model (m/s), (b) temperature contours at centre of model (K).**

The flame profile and corresponding heat flux absorbed by the boiler walls are depicted by Figure 4(a) and (b) respectively.

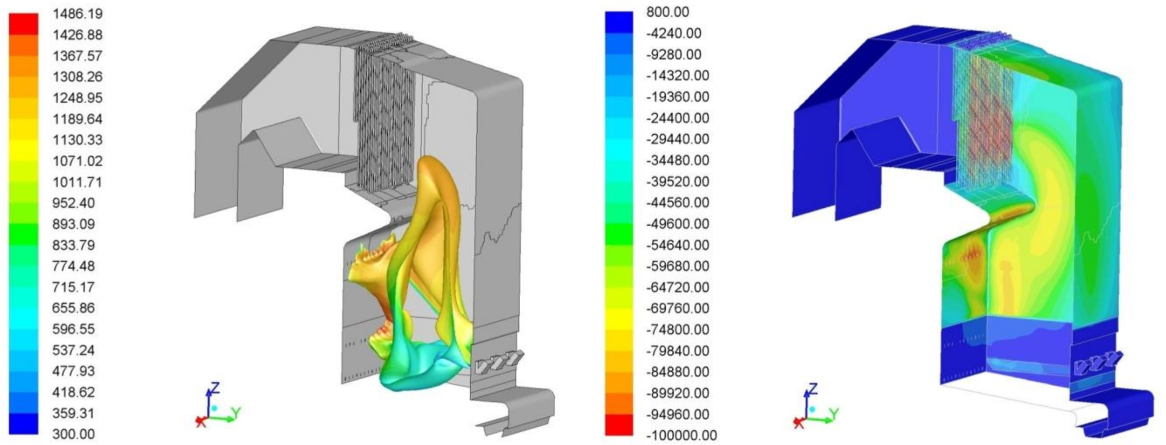


**Figure 4. (a) Iso-surface of the flame profile and temperature (K), (b) heat absorbed through walls ($W/m^2$).**

## Site temperature measurements

Two temperature measurement methods were selected to measure the temperature of the flue gas before and after the superheater. The first method was to use a calibrated suction pyrometer and the second method was to use a thermal camera.

The suction pyrometer utilises a suction device that draws warm flue gas at high speed over a thermocouple. This type of measurement is considered to be the most accurate for gasses at temperatures of ±1000°C (Rinaldi and Najafi, 2013). The suction pyrometer used in this study is capable of taking temperature measurements up to 6 m into the boiler.

The thermal camera used in this study utilises the visible spectrum of light to determine the temperature of the flame and has been proven in the boiler environment to be accurate to 1% of the actual flame temperature (Lu *et al*., 2005). Figure 5 depicts the area and direction in which the measurements were taken.

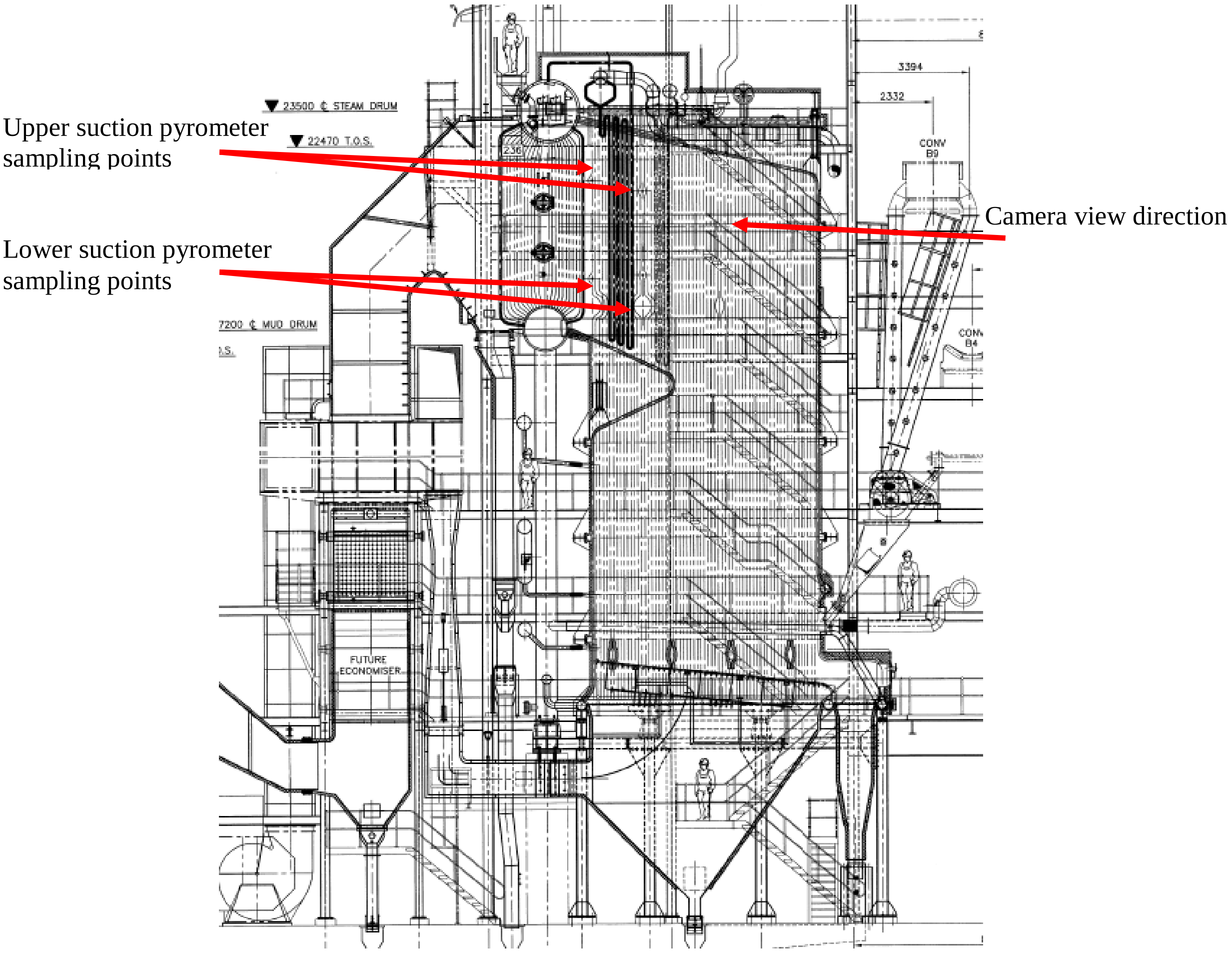


**Figure 5. Positions of suction pyrometer sampling points taken through the width of the boiler and the direction of the camera measurements.**

*Suction pyrometer data*

Figure 5 shows the positions where the 6 m suction pyrometer lance was inserted on four positions into the furnace. The lance of the suction pyrometer is water cooled to allow the thermocouple to be inserted deep into the furnace. Temperature measurements were made at 500 mm intervals, while the boiler was held at a steady operating condition. Figure 6(a) and (b) depicts the temperature measurements vs the calculated CFD temperatures at the upper elevation behind and before the superheater respectively.

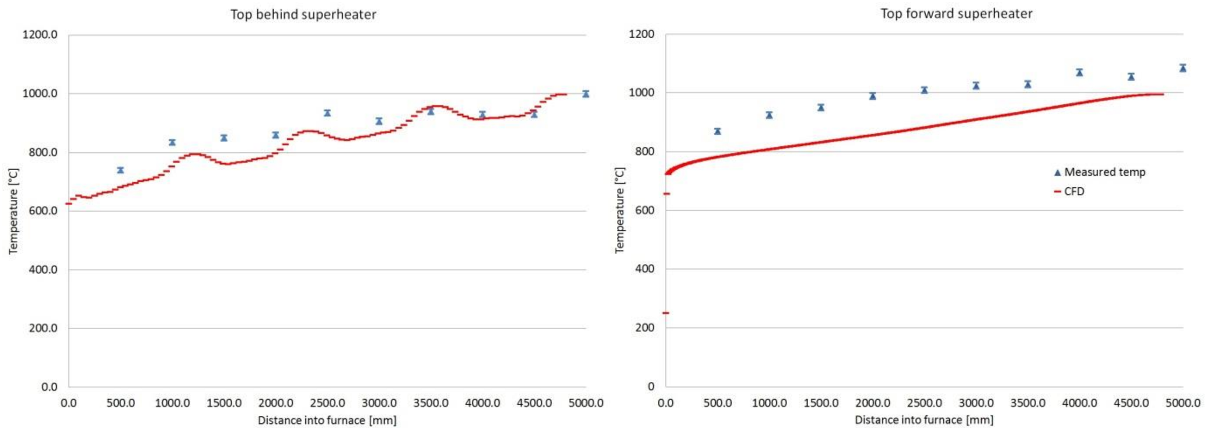


**Figure 6. (a) Measured vs CFD temperature at the upper level behind the superheater, (b) in front of the superheater.**

Figure 7(a) and (b) shows the temperature measurements vs the calculated CFD temperatures at the lower elevation behind and before the superheater respectively.

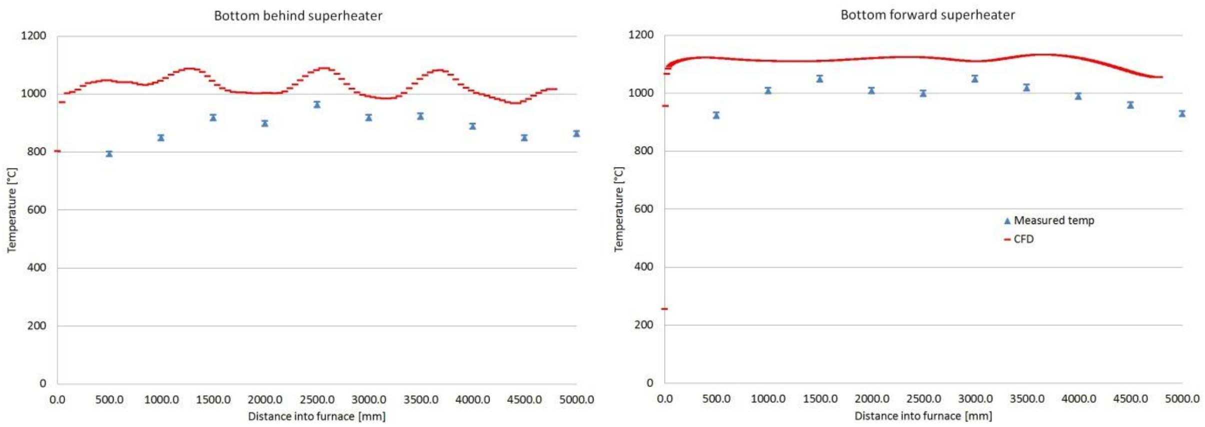


**Figure 7. Measured vs CFD temperature at the lower level behind the superheater, (b) in front of the superheater.**

*Thermal camera data*

Figure 5 shows the position and direction where the camera took temperature measurements from. The thermal camera temperature measurements are depicted by Figure 8.

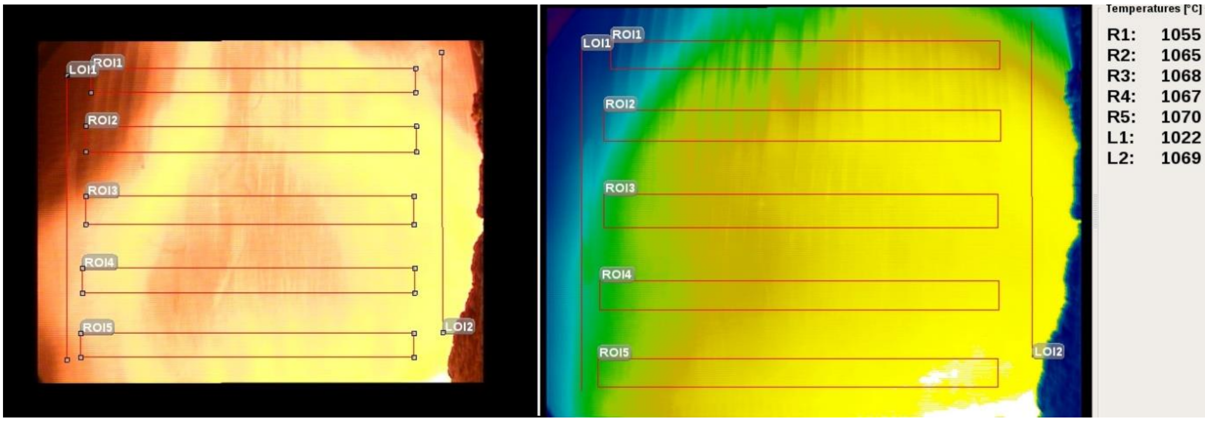


**Figure 8. The actual image of the flame and the superheater on the left and the calculated thermal camera image on the right.**

The thermal camera gives another dimension to the validation of the CFD calculation, as the contours of the temperature can be compared to that of the thermal camera, as depicted by Figure 9.

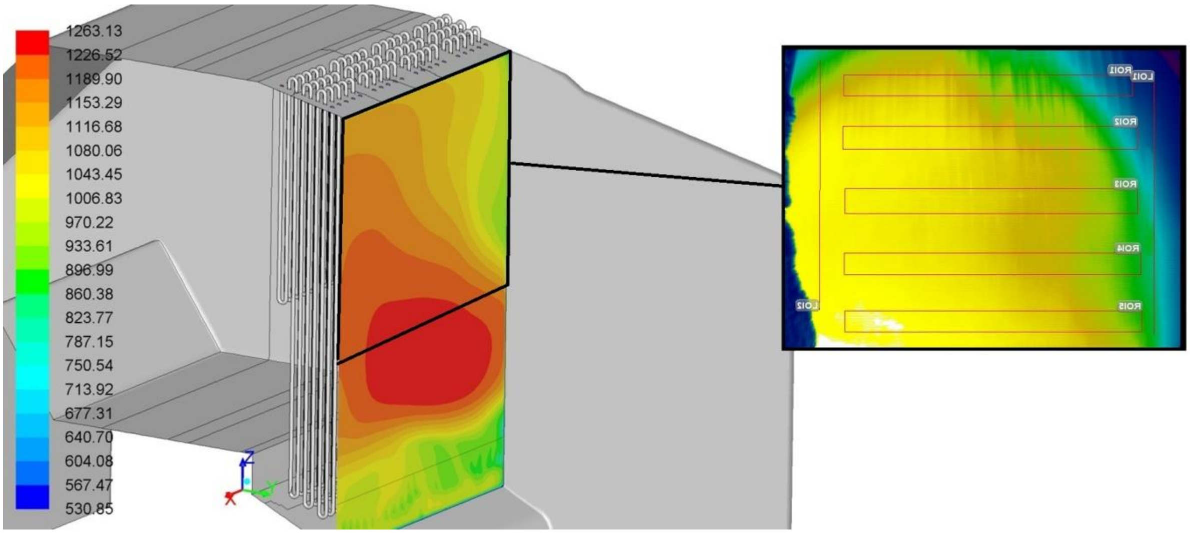


**Figure 9. Similarities in the temperature contours were observed in the CFD.**

*Comparison*

Table 1 list the maximum recorded temperatures on the upper level, in front of the superheater.

**Table 1. Summary of CFD and measurements.**

| | CFD | Suction pyrometer | Thermal camera (R1) |
|---|---|---|---|
| Upper level temperature in front of superheater (°C) | 1020 | 1040 | 1055 |

## Conclusion

A reliable CFD model of a bagasse boiler was developed. The model included complex combustion and turbulence models and all corresponding couplings. Inputs to the model were correlated with site conditions with little unknowns or assumptions.

The final steam temperature was calculated by the CFD within 3% of the actual boiler steam temperature. The CFD results showed good correlation with both the suction pyrometer data and the thermal camera, with an average deviation of 5% between suction pyrometer and CFD results.

Validation of CFD results remains the most important aspect of complex modelling of combustion and turbulence.

This study showed that CFD is a very capable design and analyses tool. The scope of CFD software is endless and is paramount to continue exploring the possibilities within boiler design.

## REFERENCES

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