WORLD COAL®

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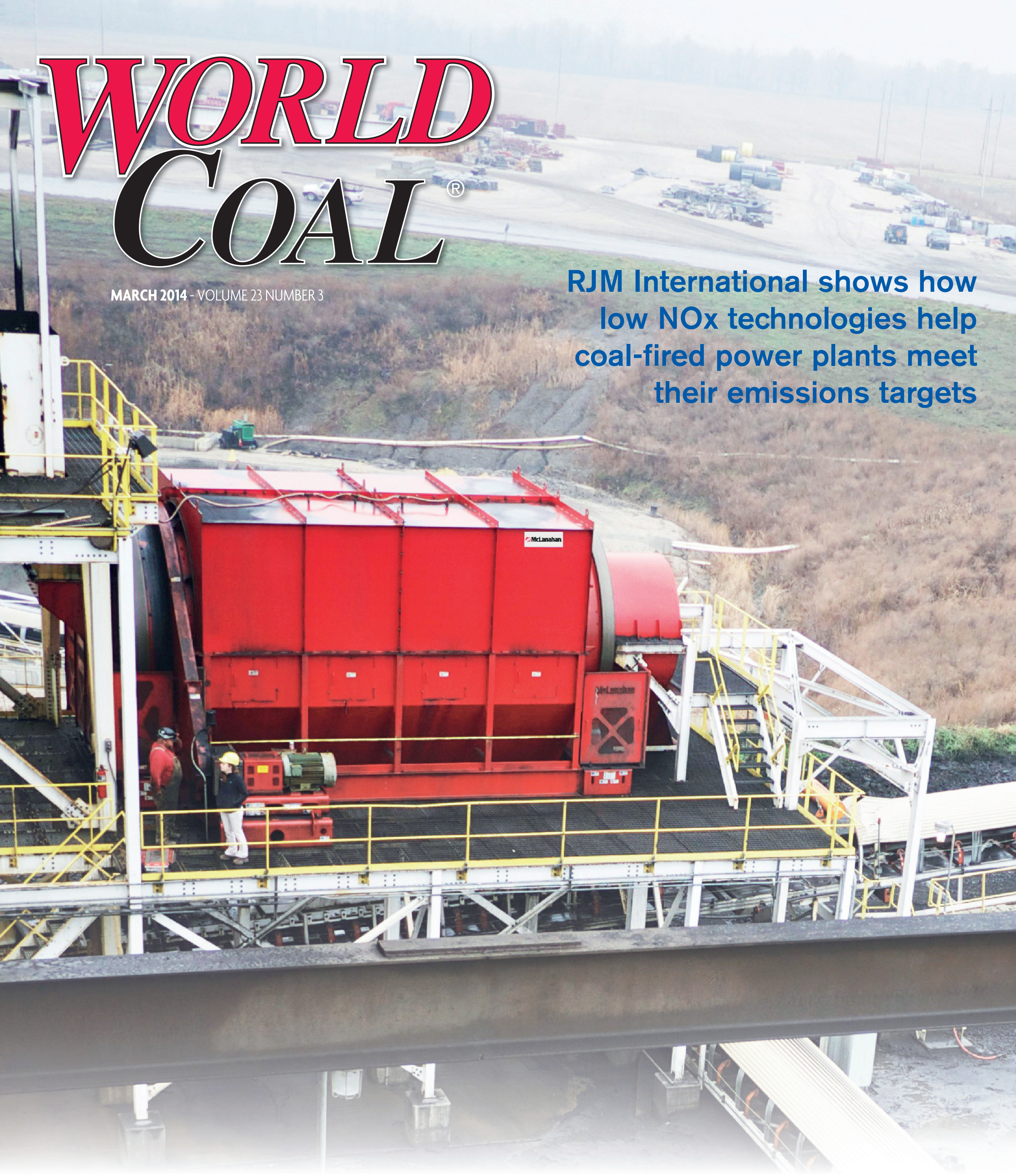
RJM International shows how low NOx technologies help coal-fired power plants meet their emissions targets



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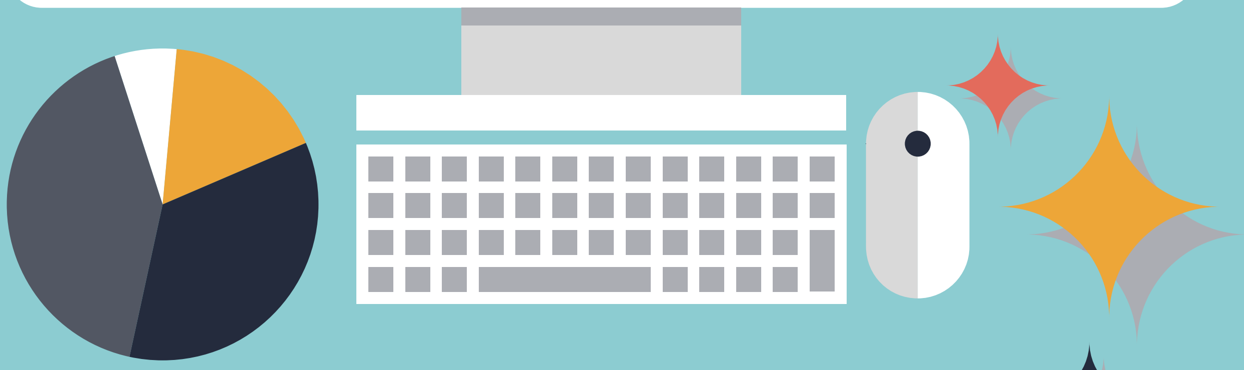
A dynamic model

John Goldring, RJM International, explains how using virtual models of power plant performance can help plant operators adjust to changing industry regulation and challenges.



It is a challenging time for the coal-fired generation sector. Governments across the world have enacted increasingly stringent legislation to decarbonise their industrial base and have focused on the big emitters – power plants and other large combustion plant. However, the day-to-day reality is that many developed and developing countries are still relying on coal to deliver a significant proportion of their baseload electricity.

Gone with the wind

In the 1990s, when the desire to move to a lower carbon future was gathering pace, it was envisaged that an orderly reduction in coal-fired capacity would be replaced by a steady increase in green power, drawn from a mixed basket of renewables led by onshore and offshore wind.

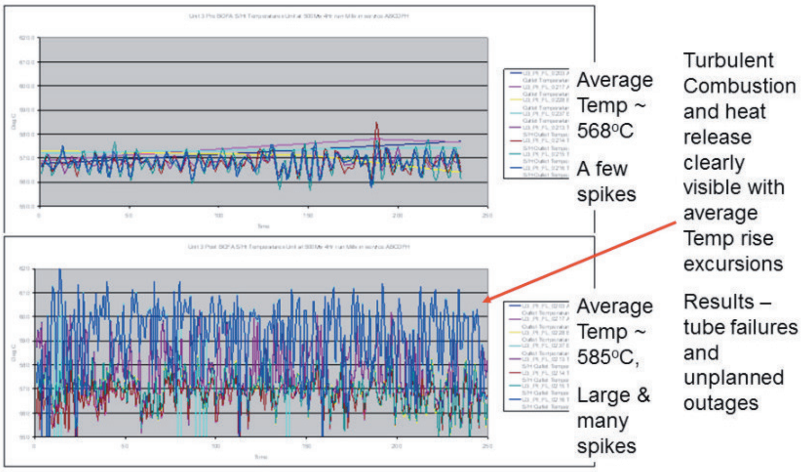


Figure 1. Actual pre- and post-BOFA header temperatures. The figure shows the average temperatures of the superheater before and after BOFA was fitted.

What is CFD?

Computational fluid dynamics (CFD) is a software tool used to replicate plant behaviour and performance. In the power generation sector, actual data is fed into the computer model so that the power plant can be run in the virtual world. Once the CFD operators have established an accurate working model within the CFD programme, input changes can be made within the model to provide evidence of what impact these changes would have on specific outputs. For example, changing the velocity, direction and dimension of the coal particles entering the furnace impacts on furnace performance and emissions. The ability to reach key performance objectives in the virtual world, through the rigorous testing of various virtual configurations, eliminates error and ensures that only the right changes to plant procedures and the right hardware upgrades are manufactured, thus keeping costs and downtime to a minimum.

However, without a significant critical mass of different renewables to smooth the intermittency of wind, many countries realised that some form of conventional power generation capability would still be needed to fill the gap. This was especially so during periods of peak demand when cold snaps coincided with periods of no wind. At other times, there may be too little wind to contribute meaningful MW to the grid or too much wind, when wind turbines must be taken out of service to protect them from over-revving.

This low use rate for wind means that when coal-fired power plants are required to fill the generation gap, they work at their least efficient. The result is higher CO_2. The strain placed on providing a balanced grid is a challenge for many western countries that have invested heavily in wind.

The key for most countries will be to maintain a healthy mix of different power generation plants. Coal needs to have a future in this because it can sustain a high production of electricity. It is also cheap, plentiful and the pollutants can be cleaned up at source. Using the latest supercritical technology allows high cycle efficiencies to be achieved. Many countries are therefore currently investing in new coal-fired generation capacity – not divesting of it.

Nuclear, regarded as a zero-carbon energy source, could have cut out the need for more conventionally-fired power plants. However, following the accidents at Chernobyl in 1986 and Fukushima in 2011, many countries have rejected an investment programme in new nuclear power plants. That said, with new nuclear on a 15 year lead-time at best, this still put the focus firmly back on legacy generation to keep the lights on.

So where does that leave coal today? While many governments consider policy for future power generation, the reality is that coal still remains an important, necessary and significant contributor to many national grids. This means that older plants are still needed. What's more, these plants must meet increasingly demanding emissions legislation, while maintaining high availability and high flexibility with minimal effect on efficiency or, ideally, even operating at improved efficiency rates.

While research into lowering carbon emissions from coal through such techniques as carbon capture and storage (CCS) pilot projects and co-firing coal with biomass, conventional coal-fired power plants are still key players.

Realities of generation

Firstly, it is important to remember that most coal-fired power plants are owned and operated by large, multi-national supply companies, which typically operate a range of generation assets, across many fuel types. Many of these coal-fired power plants are nearing the end of their operating lives, having generated electricity for 40 years or more. Yet for the reasons previously explained, their operating lives are being extended and the plants are required to run beyond the operational envelope for which they were originally designed.

When these power plants were built, they were typically sited adjacent to a coal mine and the plant was configured to accept that particular fuel type. They were also engineered to provide a continuous baseload, with relatively minor variations in output. However, in today's deregulated energy market, it is a very different situation.

Coal is now sourced globally and purchased centrally by international supply companies to secure the best prices. This means that an individual plant may have to fire a product that causes operational challenges.

In addition, the plant is likely finding it necessary to vary its output

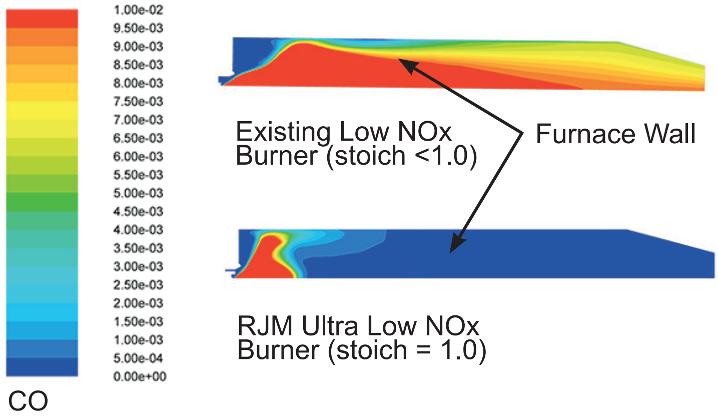


Figure 2. Burner models CO – 10,000 ppm max.

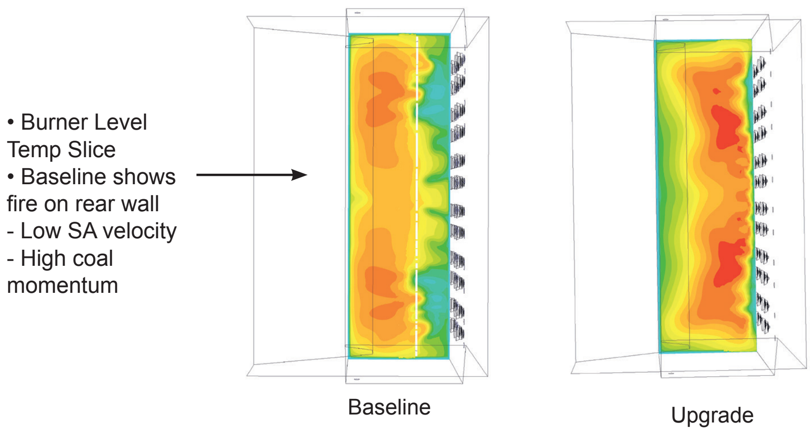


Figure 3. Local burner temperature comparison – full furnace.

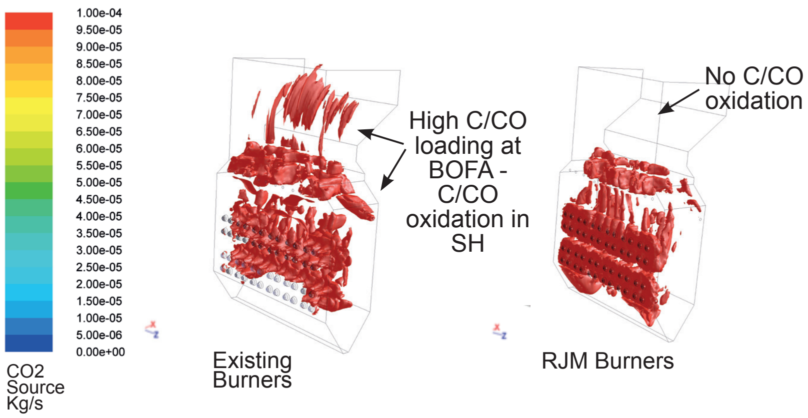


Figure 4. Furnace models – carbon oxidation – 1 g/sec iso-surface.

considerably throughout any 24 hour cycle in order to help balance the overall portfolio of its owner (or the requirements of the national grid) and enable the owner to take full commercial advantage of any sudden within-day upswings in the price of wholesale electricity.

As if burning different fuels and turning an elderly baseload plant into a flexible baseload-plus-peaking unit was not enough, the steady drive to meet emissions targets set by governments relating to SOx, NOx, carbon and other particulates has made it that much more difficult for plant managers to maintain a high level of flexibility and reliability, while remaining emissions-compliant.

In response to this challenge, RJM International is currently working on a number of projects with international generators, helping them keep their coal-fired power plants ready by resolving a host of different, complex operational challenges.

Case study: Ferrybridge power plant, UK

Ferrybridge power plant, in the north of England, is a coal-fired plant operated by the utility, SSE. It is also an example of the type of difficulties plant operators currently face. SSE first called in RJM for support in 2010 to help ascertain why the plant's Unit 3 was running with long flames, very high levels of CO and high temperatures in the convective section, resulting in tube leaks and unplanned outages.

The first priority for RJM was to establish what was actually taking place during combustion, as Unit 3 was originally commissioned in 1966 and had been significantly modified since then to meet various emissions targets. To track these changes, the company carried out a detailed site survey. RJM also built three separate computational fluid dynamic (CFD) models:

- A single burner model for comparative burner performance.
- A full furnace CFD model to review combustion in the furnace.
- A full furnace model, including the superheater and reheater convective heat exchangers.

RJM used these models to understand what might be causing elevated metal temperatures at the superheater header locations.

What the Ferrybridge site survey and CFD models confirmed was that adverse plant performance could be traced back to measures put in place to meet reduced NOx emission limits. New first generation low NOx burners had been installed in the mid-1990s to meet a new upper NOx limit of 650 mg/Nm^3. While they were designed to operate with 15% excess air, RJM found them to be actually operating at sub-stoichiometric conditions.

When the company explored this further, it concluded that the boilers had much higher levels of in-leakage air, compared to the original design intent. This meant that the induced draft fans were already operating at capacity and the boiler was physically unable to operate with additional levels of excess air.

With the second round of NOx reductions setting a new upper NOx limit of 500 mg/Nm^3 in 2008, additional measures were required. Many power plants began supplementing what the first generation low NOx burners were delivering, by modifying the burners and adding an overfired air system, either by boosted overfire air (BOFA) or from windbox air.

Once again, for many power plants, meeting that new 500 mg/Nm^3 target meant that existing, relatively minor combustion problems were becoming exacerbated.

A number of power plants took the BOFA route rather than go to SCR or SNCR, as it was the most cost-effective fix; however, RJM's site survey at Ferrybridge confirmed that adding BOFA to the first generation low NOx burners was causing a considerable drop in windbox pressure, as a result of 15% – 25% of the combustion air now being re-directed to the BOFA ports.

RJM's combustion calculations also showed that where the plant suffered from high air in-leakage, the velocity of the coal at the burner nozzle could exceed the register air velocity. This explained why the fires were becoming even longer, why levels of CO were higher and why temperature control in the superheater and reheater areas was becoming significantly compromised, resulting in expensive tube failures and unplanned outages.

Running the models with the existing first generation low NOx burner at a stoichiometry of <1.0 and comparing it to the performance of RJM's ultra-low NOx burners produced some impressive results across a number of different criteria.

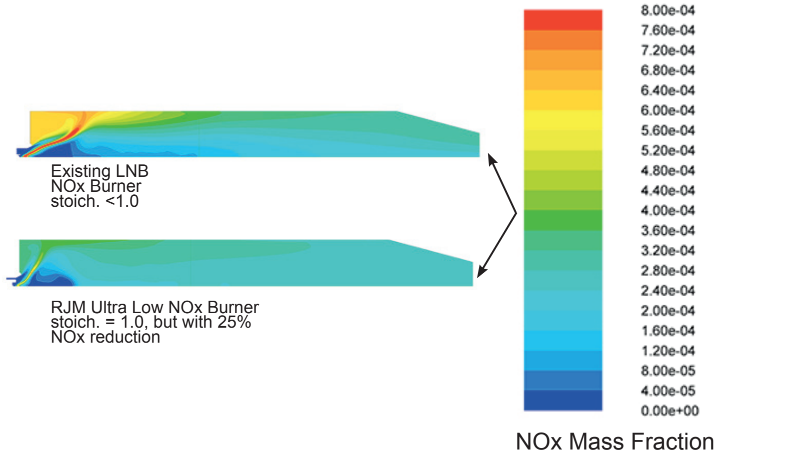


Figure 5. Burner models – NOx.

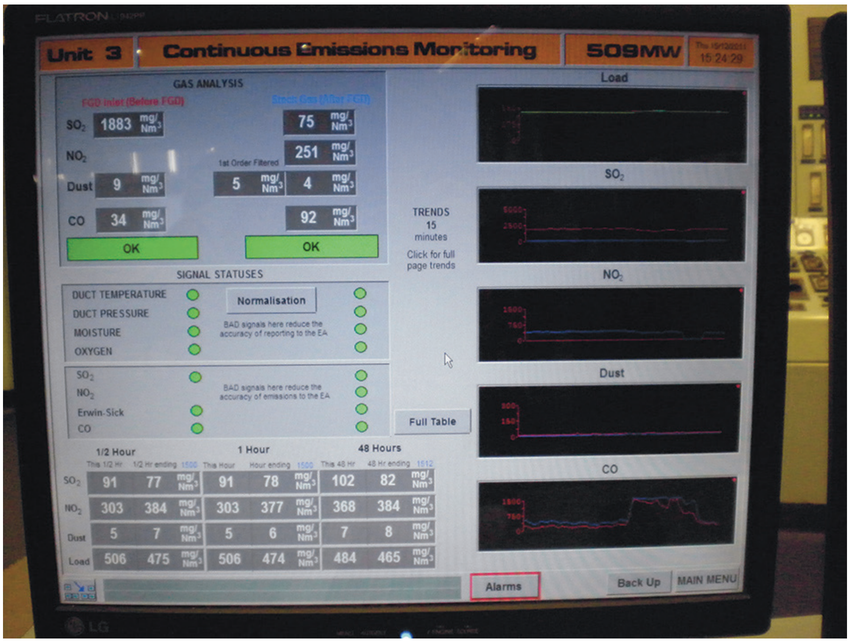


Figure 6. Actual performance: 510 MWe, NOx levels 251 mg/Nm^3, dust levels 4 mg/Nm^3, and CO levels 92 mg/Nm^3.

Table 1. CFD furnace models expected performance

	Baseline results and convergence	RJM Med S results and convergence
O_2	3%	3%
CIA	›8%	‹7%
NOx (mg/Nm^3 at 6% O_2)	~500	‹350
CO (ppm)	High	‹200 ppm
Peak flame temperature (°C)	1754	1776

In terms of flame length, the ultra-low NOx burner delivered a shorter fire than the existing burner, as demonstrated by CO concentration in Figure 2 taken from the single burner model work.

Using a CFD temperature slice across the boiler from the full furnace CFD model, it was clear that combustion was not happening in the right place and that the fire was concentrated on the rear wall, because of low secondary air velocity and too high a momentum of coal.

Figure 4 shows in the model how high levels of carbon and CO bypass the BOFA section and combusting to CO_2, whereas all combustion should be concentrated within the main part of the furnace, as can be seen with the RJM ultra-low NOx burner now fitted to the CFD model as the comparison.

All of these factors impact on NOx. When RJM looked at overall NOx performance, it could see that the ultra-low NOx burner was predicted to deliver a reduction of 25% compared to the existing low NOx burner – even when running at higher stoichiometry i.e. with a lower BOFA flow.

Conclusion

In summary, what RJM was able to conclude from the CFD modelling at Ferrybridge was that it can:

- Deliver lower CO by optimising the dynamics of the burner.
- Meet full compliance on NOx.
- Produce power with a much lower carbon loading at the BOFA ports.
- Raise burner O_2 and thus reduce the BOFA air flow.

Having reviewed RJM's recommendations based on the site survey and the CFD work, the plant operators at Ferrybridge ordered a full refit for 48 RJM ultra-low NOx burners to be installed on Unit 3 with some additional work to be carried out on the existing BOFA nozzles.

This work was completed in 2011 and has been operating successfully since that date. Figure 6 and Table 1 show how the CFD data was confirmed by the actual readings taken from the control room on Unit 3, post-upgrade.

The expected performance for the CFD furnace models can be seen in Table 1.

The unit has been running consistently for two years and the original problem of high metal temperatures in the convective section is under control. In addition, there is a stable furnace yielding excellent emissions performance, in terms of NOx, CO and dust.

Using the full CFD survey, operators were provided with a full complement of new settings for the burners. Consequently, commissioning and optimisation was completed in just four days, with the full burner retrofit immediately firing at full load.

As a follow-on assignment, in October 2013, SSE commissioned RJM to replace all 48 burners on Unit 4 at Ferrybridge with RJM's proprietary ultra-low NOx burners, together with modifications to the over-fire air system.

RJM is also currently working with a number of other generators, exploring their options around converting to biomass co-firing and has developed the CFD modelling software for biomass and co-firing analysis. This work has also informed the design of RJM's own proprietary combined coal/biomass nozzle for co-firing and this component is now being developed and patented to enable plants to quickly change between biomass and coal, without the need for a lengthy shutdown. WC