EMISSIONS REDUCTION

More understanding, less hardware: cleaning up at Claus

Innovative engineering has solved emissions and performance issues at unit A of Essent’s Clauscentrale plant – with minimal outlay on new hardware.

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Clauscentrale (Figure 1) is a 1280 MWe power plant situated in The Netherlands. Consisting of two 640 MWe Stork supercritical boilers firing bio-oil, heavy fuel oil and natural gas through 18 opposed fired burners (Figure 2). Unit A entered operation in 1977. “So we knew that with the new LCPD regulations and new trading schemes coming in, we had to undertake some fairly major modifications to the plant,” says Jos Peeters, Essent senior asset engineer. “We were also aware that we had some other issues related to furnace vibrations, flame instability, and boiler performance which we wanted to resolve at the same time. And we wanted to achieve all this while keeping downtime to a minimum and keeping the financial outlay on new equipment and hardware as low as possible.”

Burning gas, the original NOx level was ~400mg/m³. The targetted NOx level for the modified plant was <200mg/m³, while oil-fired emissions had to be kept below 400mg/m³.

To achieve these reductions burner modifications (Figure 3) and increased flue gas recirculation (FGR) were applied at Clauscentrale A. The unit has been firing with these modifications since November 2005.

The project was carried out by RJM. “In early 2004 we investigated the work the company had done at several locations in the USA and were impressed by their approach of really understanding what is going on at every stage of the combustion process and working out what factors affect key performance criteria,” Jos Peeters notes.

As already mentioned, one of the major problems was the flame instability of the original units, resulting in excessive primary re heater metal temperatures and severe furnace vibrations at higher excess oxygen and FGR rates. The solving of this problem was a key objective of the upgrade. Also, as these boilers can be operated remotely by Essent’s electricity traders any improvement in the operation of the unit across its load range would be beneficial. When changing boiler load with the original burners, burners had to be turned on and off at certain load points. If all burners could remain in service across the turndown range of the unit this would enable the operators and traders to react much faster to the needs of the market.

These issues made the emissions solution more complex and therefore the engineered solution required careful and thorough study.

Using computational fluid dynamics (CFD), a single burner model was employed to investigate three factors: stability, NOx reductions due to mechanical changes; and NOx reductions due to increased FGR flow rates. A full furnace model was used to investigate a fourth factor, namely changes to furnace exit gas temperatures (FEGT) at higher FGR flow rates.

It was also recognised that these units had never before run at FGR rates above 10% so to confirm that no detrimental effect on boiler performance would occur, a boiler performance study (BPS) was carried out to check whether the change in mass flow through the convective heat exchangers would adversely affect steam output conditions, vibration (vortex shedding), desuperheater spray flows, FD fan capacity and heat exchanger metal temperatures, particularly the already marginal metal temperature limits of the primary re heater.

To consolidate the two models the CFD engineer and the BPS engineer checked that the inputs to both models were the same and that furnace gas exit temperatures of each model were in agreement with each other.

CFD modelling

A model of a single burner was constructed so that the geometry of the flame stabilisers, new gas pokers and spray patterns could be examined and compared in detail to the existing burner. Single burner models allow detailed investigation of burner design and quick optimisation of components.

The project at a glance

The plant: Essent Clauscentrale Unit A, The Netherlands. A 640 MWe once-through supercritical unit.

Fuels: natural gas, heavy oil, and bio oil.

Boiler: Stork Balcke Durr, once through Benson type, with 18 opposed fired oil/gas burners each rated at 93 MWe heat input.

Boiler parameters: 640 MWe, 1955 t/h, 25.8 MPa, 545°C SH, 538°C RH.

The project: engineer, model, supply and start up burner modifications with increased flue gas recirculation (FGR) to reduce NOx emissions to below Large Combustion Plant Directive (LCPD) limits.

Project objectives: 200 mg/m³ @ 3% O2 for NG firing; 400 mg/m³ @ 3% O2 for oil firing; CO less than 125 mg/m³ @ 3% O2; furnace vibrations below 0.3G; no decrease in boiler load or boiler efficiency.

Results: upgrades were started-up on time, emission guarantees demonstrated, and unit operation improved in a number of areas.

Other benefits: improved heat transfer in the furnace; stable flames - original burners unstable at higher FGR rates (see separate box); boiler furnace vibration eliminated; boiler turndown achievable with all burners in service and improved operability.
In addition to the existing configuration (Figure 4), a model of the proposed modification was developed, featuring exact poker drillings to ensure accurate flow representation.

As well as developing the single burner models, a full furnace model of the upgrade configuration was constructed. For computational speed, and since the furnace is fully symmetrical front to back, only half of the furnace was actually modelled, and a symmetry plane was imposed.

Using the simplified geometry established from the modelling effort, a combustion model was then used to calculate temperature and flow fields for both the existing and proposed upgrade geometries. The temperature fields were used to simulate and confirm the improved flame stability of the upgrade design at higher FGR rates. The output is shown in Figure 5.

The 0% FGR figure compares the temperature contours (°C) for the existing geometry and proposed upgrade. In both cases, high temperature zones are shown near the burner outlet. This is as expected, as a stable burner will include features in its geometry that maintain flame stability. This stabilised flame is by definition near the burner. It is through examination of the temperature contours that instability can be identified.

For the 6% FGR case, there is no difference from what was seen at 0% FGR except for modest reductions in temperature.

For 15% FGR, significant variations are observed. The existing geometry shows no high temperature region near the burner. Instead, the entire high temperature region is located 3-4 burner diameters downstream (3m - 4m distance). In this configuration, reliable combustion seems to be occurring, but because there is no point where the flame always exists, it is the type of flame that will experience large scale movements. These are observed in the field as furnace “rumble” or combustion driven vibration.

In contrast to the existing geometry, the proposed modification maintains a high temperature region near the burner which will ensure the combustion driven vibration will not occur.

For 23% FGR the existing configuration still reliably combusts the fuel and oxygen, but the flame is detached from the burner (large scale vibration would be anticipated) while the proposed modification still has a high temperature region near the burner. Full furnace simulations were run for gas and oil fuels at 0% and 15% FGR rates. This was done to compare furnace exit gas temperatures with the boiler performance modelling also carried out.

In addition, absolute NOx estimations from the models were compared with single burner predictions, as an independent check (Figure 6). The CFD modelling led to the following conclusions:

- Burner modifications, which included new staged flame stabilisers, low NOx gas lances and low NOx atomisers, were shown to produce stable flames.
- Burner stability was demonstrated on gas, from 0% FGR to 23% FGR.
AI helps Chinese cut NO\textsubscript{x}

A new artificial intelligence package at a 300 MW\textsubscript{e} unit of Shenzhen Energy Company’s Mawan power station in the Chinese southern coastal province of Guangdong should help the plant achieve major emissions reductions.

The system, GNOCIS Plus, developed and installed by E.ON UK Power Technology, has the potential to help the plant reduce NO\textsubscript{x} emissions by up to 45% at full load, while maintaining plant efficiency and operability. At a later stage of the project, carbon dioxide emissions should fall as a result of better use of fuel.

E.ON UK expects the system to be installed at more of the Mawan power station’s six units in the future, and reports that other generators around the world are also interested in the package.

GNOCIS Plus—the acronym standing for Generic Neural Optimisation Control Intelligent System—works as an extension of the host power plant’s distributed control system. Its artificial intelligence operates in real time and adjusts combustion settings in the boiler to minimise NO\textsubscript{x} formation subject to programmable constraints which can include unburned carbon and plant efficiency.

The neural network retrained itself according to changes in plant conditions, reflecting them in the combustion settings. GNOCIS Plus can operate in a fully automatic—‘closed loop’—mode, adjusting combustion settings, or in an ‘open loop’ role to advise plant operators on optimum settings.

GNOCIS Plus represents an advance over the original GNOCIS product because it incorporates this automatic model retraining.

The system is configured to read from and write to the plant’s DCS system and uses the selected input control parameters to predict the resultant output parameters such as NO\textsubscript{x} emissions, carbon-in-ash levels etc. The novel feature of GNOCIS Plus is that it acts in a ‘reversed role’, ie limits or targets for emissions are set and the inputs are optimised to satisfy both these limits and any other specified operational constraints. Once the network has been trained on historical data, it can respond very rapidly to new inputs, predicting the optimum settings of control parameters on-line.

On commercial plant it is apparent that NO\textsubscript{x} and carbon-in-ash levels also vary significantly during long-term operation due to changes in plant condition. Since these factors vary with time, optimisation conducted at one time may not be optimal over a longer period. The ability to learn and adapt to changing plant conditions is the biggest advantage of GNOCIS Plus over the original GNOCIS product.