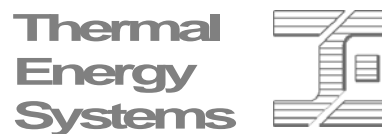


EPA Challenges for Bagasse Fired Power Stations

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Abstract

Traditionally, the sugar industry has been treated leniently with respect to emissions standards but, as it focuses more on electricity as a profitable by-product, that is changing even though bagasse is a renewable fuel. Nowhere is that more the case than at US Sugar's Clewiston factory in Florida: even though it is not a major exporter of electricity, when it installed a new boiler, the factory was obliged to conform with stringent EPA standards. The challenges imposed by the standards are discussed together with the engineering solutions and the results obtained. The outline specification was for a 500 000 lbs/h [~226 800 kg/h] boiler delivering 600 psig, 750°F [~4137 kPa, ~399°C] steam when firing bagasse. The main challenges were seen in obtaining the 0.026 lbs/MMBTU [~24 mg/Nm³] PM₁₀ limit and the original 0.12 lbs/MMBTU [~70 ppmvd] NO_x limit without exceeding the 0.38 lbs/MMBTU [~363 ppmvd] CO limit or the 20 ppmvd ammonia slip limit. Continuous monitoring was required.

Engineering was supported by fluid dynamic studies, in particular with respect to the NO_x and CO profiles in the furnace: i) maximum NO_x reduction was required from the urea injection system so location was critical; and ii) engineering down combustion NO_x increases CO. In the event, the unit comfortably passed all tests. The variable OFA nozzles which had been installed proved particularly useful in tuning the boiler and the low uncontrolled NO_x levels [meaning there will be reduced urea charges] were pleasing to see. Whilst these stringent requirements are unlikely to be applied to other bagasse boilers in the short term, the lessons learned will make it possible to rise to those challenges when they arise.

Introduction

The cane sugar industry has developed export cogeneration gradually over several decades, during which time many of the projects have been treated, from the emissions point of view, as no different to any other sugar industry project. That has frequently meant a very generous treatment compared to the requirements if, for instance, power utility standards had been applied.

There have been exceptions over the years of course, most notably the stations on the French islands [Bois Rouge, Le Gol and Le Moule] and the Florida Crystals station at Okeelanta in Florida.

However, perhaps as an indication of what is to come, when US Sugar needed a new boiler [Boiler #8] for its factory at Clewiston in Florida, the state authorities tried to apply environmental requirements more strict than those at Okeelanta even though the Clewiston site is only an *ad hoc* electrical exporter, primarily a sugar producer.

US Sugar has a strong environmental policy so readily agreed to the approach taken but the requirements did pose a challenge to the engineers tasked with the boiler design.

Clewiston Boiler #8

The USSC requirement was for a 500 000 lbs/h [~226 800 kg/h] boiler delivering 600 psig, 750°F [~4137 kPa, ~399°C] steam when firing bagasse as primary fuel and capable of 60% MCR output when firing oil, as a start-up and supplemental fuel. The unit was destined to become the workhorse of the site which typically has a 200 day crop period crushing at 38 000 stcd but also operates a nominal 1500 t/d RSO refinery throughout the year. It therefore had to operate 11 months a year without difficulty, much of that with a high turn-down ratio [capacity as low as 40 – 50% MCR during off-crop].

A conventional single pass, bi-drum design was adopted from the beginning, but a quick glance at the general arrangement immediately shows some unusual features :

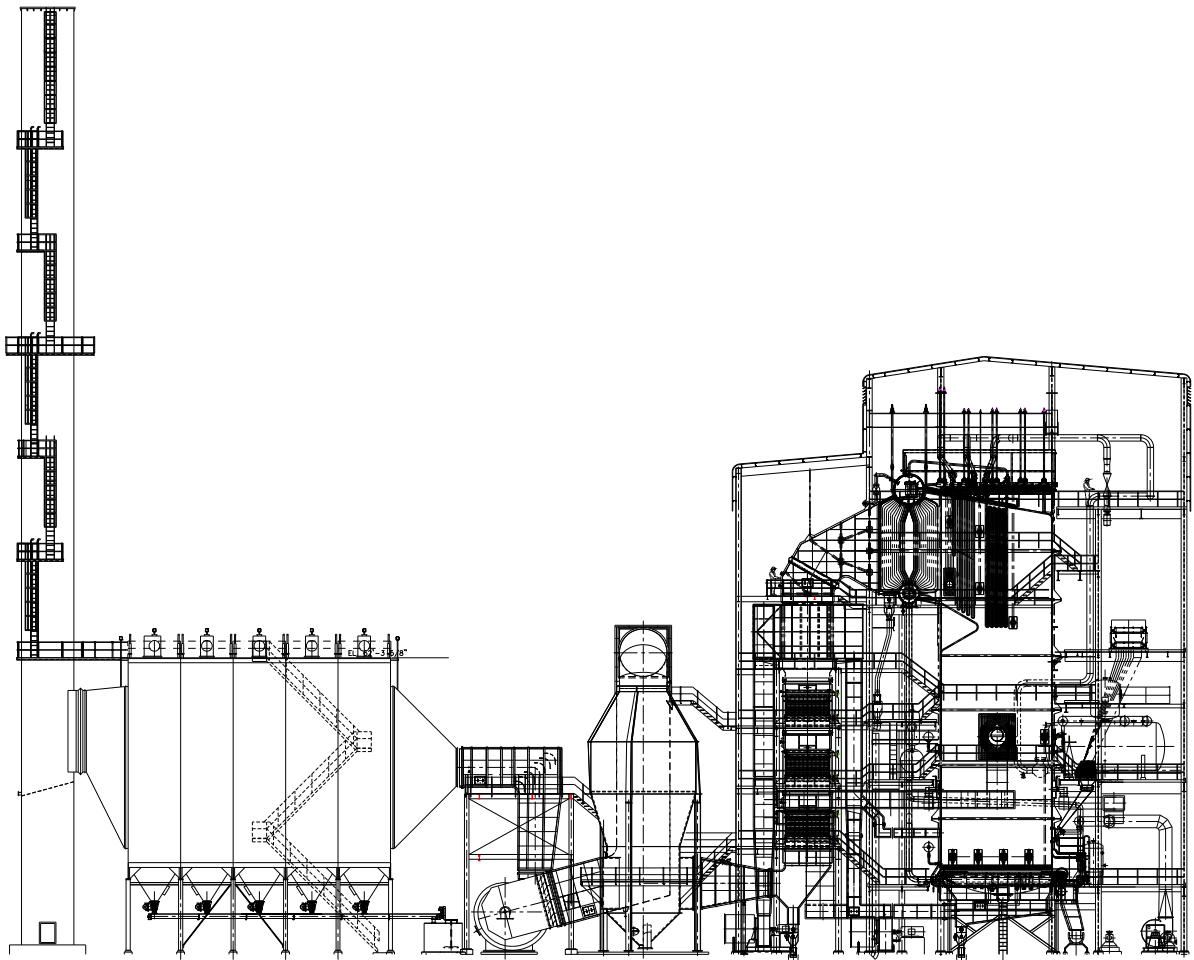


Fig. 1 : Side Elevation of Clewiston Boiler #8

The most obvious are :

- a continuous ash discharge [CAD] stoker instead of steam cleaned pinhole grate;
- an exceptionally tall furnace for a bagasse fired boiler;
- two stage superheater with inter-stage attemperation;
- flue gas scrubbing and a five field electrostatic precipitator [ESP];

The superheater arrangement is a result of the need for the high turn-down ratio but the others, as discussed later, and other less obvious features are all related to the emissions standards imposed.

The other key aspect was the nature of the bagasse: Clewiston is on far sandier soil than most of the Florida industry so bagasse ash levels can be very high and during certain periods can reach 10%.

EPA Requirements

In general, the emissions standards in the USA are expressed in terms of pounds weight of a particular emission per million BTUs [lbs/MMBTU] of gross heat input, something which makes it difficult to express them exactly in more conventional terms or to compare them with the standards in other countries which are typically based on emission concentrations per normal cubic metre of flue gas referred to some standard condition. Another issue is the difference in conditions applied around the world, a value which is critical to normalising for comparison purposes.

The original indications from the authorities were that they would want a NO_x limit of 0.12 lbs/MMBTU and that was the basis that engineering started with. However, when the permit was issued some 8 months later, they had agreed that such a level was unrealistic so the permit for Clewiston's Boiler #8 required the following :

Table 1 : Boiler Flue Gas Permit Levels at Clewiston

Air Pollutant	Maximum Concentratio	Units	Approximate Alternative Units
Particulate matter [PM ₁₀]	0.026	lbs/MMBTU	~24 mg/Nm ³
Opacity	20	%	n/a
Sulfur dioxide	0.06	lbs/MMBTU	~32 ppmvd*
Nitrogen dioxide	0.14	lbs/MMBTU	~81 ppmvd*
Carbon monoxide	0.38	lbs/MMBTU	~363 ppmvd*
Volatile organics [as C ₂ H ₆]	0.05	lbs/MMBTU	~100 ppmvd*
Ammonia Slip	20	ppmvd*	n/a
Lead	3.8 x 10 ⁻⁵	lbs/MMBTU	
Mercury	3.0 x 10 ⁻⁶	lbs/MMBTU	
Metals (sum of 8)	1.0 x 10 ⁻⁴	lbs/MMBTU	
Hydrogen chloride	0.02	lbs/MMBTU	

* at 7% O₂

The permit enforcement for NO_x and CO was to be with a Continuous Emissions Monitoring System [CEMS] so there was no question of being out of permit as is often the case elsewhere. The only concessions were that the limits were on a rolling average basis. It was accepted that no chemical scrubbing would be used and, therefore, that the fuel-related pollutants [SO_x, heavy metals and HCl] would be whatever they would be. There was, however, still a need to be sure that the permit levels were not exceeded, so bagasse samples were analysed over an extended period in order to verify this and, coincidentally, to provide design data for the boiler.

Particulate matter limits are very typical of the environmental standards imposed around the world but the permit level at Clewiston is remarkably low :

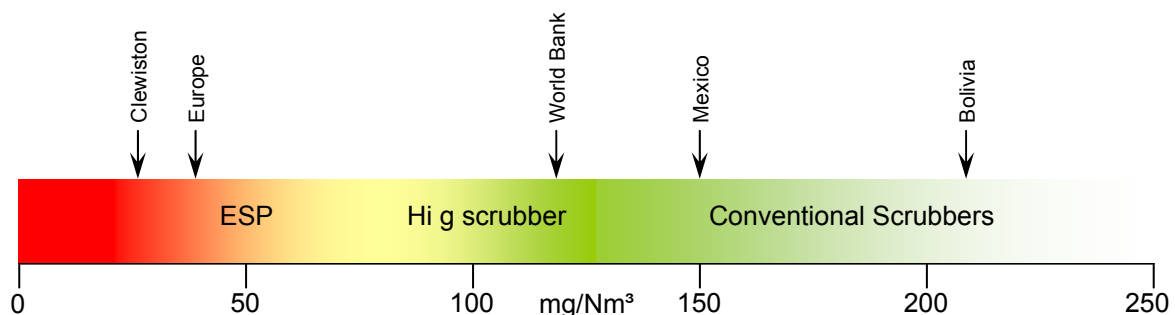


Fig. 2 : Boiler Flue Gas PM₁₀ Limits

PM₁₀, sometimes referred to as the 'thoracic' limit, refers to particles equal to or smaller than 10 µm. The limits shown have all been normalised to 12% CO₂ by volume dry.

Similarly, the NO_x limit – not a typical requirement – is remarkably low and lower even than that at Okeelanta, only a few miles south :

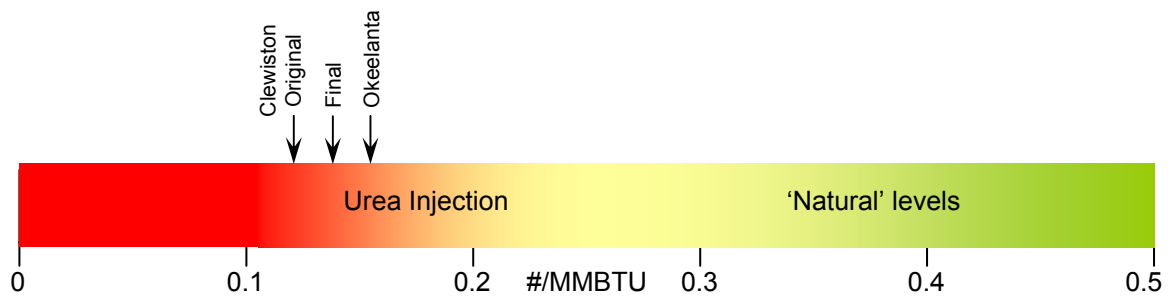


Fig. 3 : Boiler Flue Gas NO_x Limit

The CO limit, on the other hand, was not considered too onerous if taken on its own. The problem is, however, that trying to drive down NO_x by careful furnace design tends to drive up the CO content of the flue gas.

Engineering

USSC wanted a boiler which was efficient [in order to maximise the bagasse available for off-crop use], easy to operate and maintain, able to operate at a high turndown ratio and, of course, be permit compliant under all operating conditions.

Experience at Okeelanta showed that any form of intermittent discharge grate would result in permit excursions during cleaning. The ash content of the bagasse indicated that this would be quite frequent at times. It was, therefore, decided from the outset that the unit would be equipped with a CAD stoker in order to avoid that problem and assist with ease of operation. That decision also gave USSC the option of burning other fibrous fuels during off-crop after the surplus bagasse supply was exhausted. The Thermal Energy Systems stoker is engineered to minimise maintenance: it has larger diameter shafts than comparable units, very robust catenary tensioned chains and high temperature castings throughout. In order to deliver the 227 t/h of steam, it would have to be one of the largest stokers in the world.

Having established the grate concept, the focus of the engineering for Boiler #8 moved to the furnace and the need to control NO_x, ammonia slip and CO. Selective Catalytic Reduction [SCR] of NO_x was considered inappropriate and therefore the only practical alternative, non-catalytic reduction [SNCR], was adopted. The significance of that decision was that SNCR, which involves injecting ammonia or, more conveniently, urea into the furnace in order to reduce the NO_x content to molecular nitrogen [N₂], is only 50% effective at best so untreated NO_x levels had to be no more than 0.28 #/MMBTU, a low target.

One of the other issues with SNCR is that it is most effective within tight temperature ranges, so it was necessary to predict the temperature profiles in the furnace for the full range of possible operating conditions and to design the urea injection system to cover that range. In addition, over-treating with urea leads to 'ammonia slip': surplus ammonia being released to the atmosphere in one form or another. When SNCR is adopted, a limit on ammonia slip of 20 ppmvd [at 7% O₂] is imposed.

SNCR is a highly specialised technology so the supplier was selected from an early stage and the furnace engineering developed in conjunction with him. It was clear that computerised fluid dynamics would be needed to determine the shape of the furnace, the optimum way to inject the secondary combustion air to approximate perfect mixing within the furnace volume and the optimum injection points for the urea injection. For the latter two challenges, the systems had to be capable of working within the full range of possible operating conditions, whether that be steam generating capacity or fuel characteristics.

The boiler was modelled using the 'Furnace' computerised fluid dynamics [CFD] code developed in Australia using over ¾ million individual cells. In the end, because of the relationship between NO_x and CO, it was decided to use CO concentration in addition to gas velocities and particle trajectories to analyse the mixing within the furnace.

The output from the modelling was portrayed as a series of elevation and plan sections showing predicted values for the gas velocity vectors, temperatures, particle trajectories, O₂ concentrations and CO concentrations. Figure 4 shows examples of two such portrayals :

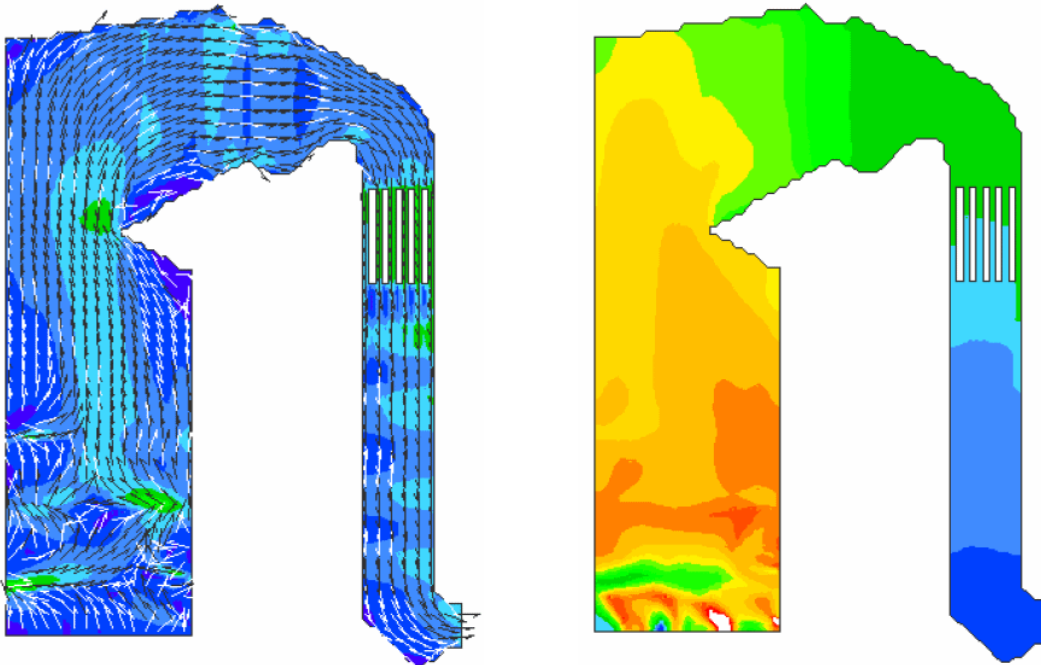


Fig. 4 : Example Portrayals from CFD Analysis

The left hand image shows the predicted gas velocities and directions for a particular configuration. [Dark blue is up to 3 m/s and the green – the highest velocity in this instance – is 12 to 15 m/s.] The right hand image shows the predicted gas temperatures for a different configuration. [Dark blue is up to 100°C and the darkest reds are in excess of 1300°C.] Other portrayals showed the same parameters in plan sections and other parameters included particle tracks, oxygen levels and CO levels.

Once the basic model had been established it was possible to evaluate various configurations, in particular of the overfire air [OFA]: both the percentage of total air applied as OFA and the number and arrangement of OFA nozzles. The ultimate objective was to approximate a perfectly mixed furnace and hence minimum CO production with an understanding of the temperature profile and hence the locations for urea injection under various load conditions.

Part of the solution ultimately adopted was to use variable throat OFA nozzles specifically developed for the project so that the injection profile could be changed during the operation of the boiler and the urea injection optimised for different steam output conditions.

Having finalised the furnace, it was possible to proceed with the remaining thermal design and the design of the boiler ancillaries. Allowance had to be made for the additional gas burden imposed on the system by the injection of the urea solution: the resultant ammonia [and reaction products] plus the carrier water. The aspect relevant to this paper was the flue gas treatment in order to achieve the required particulates levels.

It was clear that an electrostatic precipitator [ESP] was going to be an essential part of the solution required but it would only be part of the total solution. The main issue with ESPs on fibrous fuel boilers is that the discards, containing activated carbon from semi-combusted [in this case] bagasse, are highly flammable so the ESP should be operated under positive pressure to minimise the gas oxygen content and avoid fires. That places the ID fan before the ESP and hence exposes it to the erosive grit content of the flue gas.

In addition, ESPs are not particularly good at collecting carbon particles : there is a tendency for them to break free again from the plates and pass up the stack.

USSC, as part of its ongoing environmental impact abatement policy, had recently retro-fitted one of its existing boilers with a non-saturating scrubber system, the water uptake rate being carefully controlled to avoid saturating the gas which would result in condensation and consequently corrosion within the ESP. What was not understood at the time was that the ash content of the Clewiston fuel would essentially be calcined in the furnace and form a concrete in such scrubbers.

The system adopted for Boiler #8 was therefore a pair of non-saturating Thermal Energy Systems cyclonic scrubbers before the ID fan, followed by a five field ESP after it. The use of five fields was to ensure that permit levels would still be achieved even when rapping one of the five. The cyclonic scrubbers use a highly turbulent venturi inlet section where the gas is sprayed, followed by a high-g cyclonic section to separate the water again, together with the scrubbed solids.

Results

The engineering of this complex boiler started in March 2003 and commissioning started in late January 2005 when the first oil was fired to warm up and dry out the unit. The formal testing of the unit took place just before Easter in that year, very much towards the end of crop and not long after first firing bagasse.

The environmental tests were conducted by specialist consultants on behalf of Florida State using their own portable instruments which were also used to calibrate the CEMS. The first values, compared to the permit values, are presented in Table 2.

Table 2 : Measured Values of Pollutants in the Clewiston Boiler Flue Gas

Air Pollutant	Maximum Permitted	Measured Value	Units
Particulate matter [PM ₁₀]	0.026	0.0039	lbs/MMBT
Opacity	20	n/a	%
Nitrogen dioxide	0.14	0.131	lbs/MMBT
Ammonia Slip	20	26.2	ppmvd
Carbon monoxide	0.38	0.354	lbs/MMBT
Volatile organics	0.06	0.012	lbsMMBT

The measured values were each the average of three runs and the boiler was generating an average of 500 853 lbs/h of steam at the specified conditions. Opacity, an alternative measurement to the PM₁₀ was not measured because PM₁₀ was. It can be seen that, even at this early stage, the boiler was running well : only the ammonia slip was outside of permit value, something which was put down to incomplete commissioning of the SNCR system. It was soon brought under control and within permit once the SNCR system had been fully commissioned and tuned.

The variable OFA nozzles which had been installed proved particularly useful in tuning the boiler and the low uncontrolled NO_x levels [meaning there will be reduced urea charges] were pleasing to see.

The issue of the formation of a sort of concrete in the scrubbers, as referred to early, was unexpected and caused blockages in the scrubbers' outlets from time to time. In the end, the factory engineers came up with an ingenious solution by designing and installing macerators in the bases of the scrubbers. These are operated typically once a shift to break up any lumps of this concrete which might have broken loose from the walls so that they are flushed away by the scrubber water.

Conclusions

It is accepted that the stringent requirements of the Florida DEP and Federal EPA are unlikely to be applied to other sugar industry boilers in the short term – not even in other states of the USA – but the important point is that, with the lessons learned at Clewiston, it will be possible to rise to those challenges when they arise.