Improvement of Efficiency, Emissions and Operational Safety in Combustion Units

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The article describes the overall technological approach and the latest results, regarding combustion efficiency improvement (overall CO₂ emissions reduction) and parallel effects in NOₓ emissions control, through the implementation of a novel combustion control technology to a crude oil furnace of a Spanish refinery.

General background. Combustion improvement offers the greatest potential for economic savings in industrial boilers and furnaces. Nevertheless, the combustion process is relatively opaque from the operator’s point of view. It is significant that in activities in which the greatest production cost is the cost of fuel, the lack of information is greatest precisely in how this fuel is utilized.

Despite the economic and environmental importance of combustion processes, they usually exhibit a low level of monitoring and control. These processes are typically governed by a few global variables like excess oxygen or process stream results, with no direct control of combustion conditions. Furnace or boiler operation is typically supported by standardized procedures and operator experience, rather than by effective online information and optimized flame control. Moreover, in most cases of multiburner application, standard monitoring used for global excess oxygen control in the combustion unit does not represent the real average excess O₂ value resulting at furnace level, introducing a critical restriction for an optimized tuning of combustion conditions.

This situation heavily contrasts with the current state-of-the-art of most of the industrial chemical processes, in which comprehensive monitoring and advanced control systems ensure process safety, plant availability and maximum efficiency. It is therefore surprising that a chemical process like combustion, with an impressive economic and environmental impact worldwide, still relies on nearly archaic controls.

In recent few years, a considerable amount of attention has been given to the application of combustion adjustments for efficiency optimization and emissions limitation. Nevertheless, the cost-effectiveness of these adjustments is greatly limited by the referred restrictions on combustion monitoring and control. This gives rise, for several cases, to the erroneous decision of upgrading the burner system without having attempted before the optimization of the current combustion system.

This situation is even more relevant in scenarios of high variability in fuel properties, load profiles and/or burner arrangement for multiburner systems. In these cases, uncontrolled combustion conditions might force operators to apply “too conservative” boiler settings, far away from optimum tuning.

“Controlled Furnace” technology: fundamentals. Efficiency and emissions (NOₓ, CO, CO₂, particles, SOₓ, etc.) in industrial furnaces and boilers depend largely on the correct distribution of fuel and air supplies to the combustion process. Moreover, the existence of inappropriate fuel/air ratios on critical locations is severely detrimental to these important parameters (Figure 1). Therefore, the effectiveness of stricter combustion controls will be a function of the actual balancing of the combustion process.

Figure 1. Industrial furnaces and boilers optimization: background

Taking this into account, the combustion optimization technology relies on the adequate closed-loop control of local combustion conditions, promoting what is called a “Controlled Furnace” (Figure 2). This is intended to be the critical factor to assure maximum benefit of combustion variables adjustment whose tuning has a direct effect on unit efficiency and NOₓ formation.

Novel regulation systems for combustion optimization. Implementation of "Controlled Furnace" conditions involves, in most cases, the improvement of boiler tuning capabilities by means of the application of an adequate combination of the following items:

I) Automation of existing manual regulations from control room.
II) Implementation of other fuel and air regulation dampers and valves.
III) Modification in the design of existing burners for increasing their tuning potential.

By the implementation of these aspects, the existing regulation capabilities are improved, similarly as if new burners, i.e. Low NOx Burners (LNB) were installed. In case further NOx reductions are demanded, these regulation systems are totally complementary to more substantial plant modifications (such as LNB or windbox redesign), improving also the results derived from the application of these measures.

Expert software for optimized combustion control.

"Controlled Furnace" conditions are established in closed-loop control scenarios by the integration of the previously described monitoring and regulation capabilities with advanced combustion control systems, which are configured for each specific application.

This integration allows the application of combustion optimization strategies with maximum reliability and profitability.

Main features of these strategies are implemented within an appropriate Expert Combustion Control, which is established in a subordinate manner to the combustion unit Master Control. Both control systems do not interfere, as the Expert Combustion Control will only affect adjustments not related to the unit Master Control.

The Expert System is configured individually for each combustion unit through specific combustion tests.

Results. The following results correspond to the combustion optimization of a direct-fired heater belonging to the crude oil unit of a Spanish refinery.

This furnace is equipped with 32 horizontal oil and gas burners placed in two opposite rows. A refractory division wall is located in the middle of the furnace for bending flames and defining two independents in-furnace areas.

For the base case of the furnace, monitoring of incoming combustion air was carried out by an O2 probe placed in the centre of the East side wall. Two manual draft regulating dampers located at North and South furnace chimneys were used for overall combustion air control. Burners were also equipped with manual primary and secondary air regulation capabilities.

"Controlled Furnace" approach. The scope of the approach implemented in the case study crude oil furnace has been decided in order to attain "Controlled Furnace" conditions. This approach is aimed to the attainment of optimized furnace efficiency scenarios, covering every possible operating situation, through the following capabilities:

- In-furnace monitoring system for the characterization of combustion process in each individual burner.
- Automation of air regulation dampers in both rows of multi-burners, for an optimized flame tuning, and furnace stacks, for the control of furnace draft.
- Control approach and Expert System for the closed-loop control of the overall process.

Process baseline characterization. Combustion furnace baseline has been characterized through the execution of a thorough testing campaign using new monitoring and regulating capabilities. Testing campaign has been designed to cover all possible furnace operating scenarios in terms of duty requirements, nature and proportions of fuels used, burners in service, etc.

Main results of this combustion diagnosis of the furnace base case are the following:

I) Identification of important imbalances between individual burners. Measured differences, above 3.5% in excess O2 levels (and even higher for uncontrolled global O2 reduction scenarios), are limiting the effective efficiency optimization through uncontrolled combustion tuning strategies due to the generation of unsustainable CO levels (Figure 4 – Baseline operation).

II) Disagreement between O2 figures detected by the original oxygen monitoring system (averaged figures within the 3.5% - 4.5% interval) and the more accurate values resulting from the complete "Controlled Furnace" approach (with O2 average figures typically 1.0% to 3.5% higher). Manual measurements carried out at furnace exit sections demonstrate the full agreement between the averaged measurements from implemented system and global furnace excess O2. Therefore, existing monitoring is found to have lack of representativeness for overall excess O2 characterization in this furnace. Furthermore, the information given by a global excess O2 monitoring is not comparable, in terms of combustion optimization potential, with the valuable information given by the advance monitoring system.

III) As a consequence of what has been stated in I) and II), high excess O2 and minimum CO levels at the furnace outlet section were measured (Figure 4 - Baseline Operation). High NOx generation associated to these O2 levels is also produced. Averaged furnace O2 values measured by the local in-furnace monitoring system are in the range 5.0% - 7.0%.
**“Controlled Furnace” system performance.** Following the implementation of combustion control strategies through the “Controlled Furnace” approach, a clear evolution of the excess O₂ levels, given by the local in-furnace monitoring system, can be observed from baseline operation to controlled operation (Figure 4 - Controlled O₂ Reduction), resulting in a final oxygen average values around 2% (from initial average values around 5% - 7%).

Final combustion conditions are achieved by the implementation of “Controlled Furnace” strategies giving rise to safer, sustainable (negligible CO levels), homogeneous and efficient combustion scenarios. “Controlled Furnace” conditions are reached through appropriate global and individual air regulations tuning carried out by Expert Combustion Control system following a fully automated process.

The reported 3% - 5% excess O₂ minimization is coupled to a gas temperature reduction higher than 30 °C at the furnace outlet, causing overall fuel consumption savings above 5%. An equivalent reduction is therefore obtained for CO₂ and SOₓ overall emissions.

Results included in Figure 4 shows, in addition, a clear reduction in the results dispersion for controlled operation, identifying this dispersion reduction as O₂ results grouping.

The scenario of controlled operation makes possible the immediate and unequivocal identification of burner malfunctions. This sort of malfunctions remains hidden when only conventional monitoring is applied, constituting therefore a clear limitation in this latter case for the implementation of O₂ reduction policies. As it has been shown, this limitation is totally overcome when using the “Controlled Furnace” approach.

Burner malfunction identification is an essential tool for a cost-effective burner maintenance programme. Therefore, optimized maintenance schedules can also be achieved with the application of “Controlled Furnace” technology.

**Conclusions.** When facing combustion optimization challenges, such as efficiency improvement and/or emissions reduction (NOₓ, CO, CO₂ or particles), the “Controlled Furnace” technology has proved to be an advantageous alternative and an essential complement to the application of larger scale measures in combustion installations.

Main results obtained in the particular application of this approach to crude oil furnace (Figure 4) are given below:

- Improvement of unit combustion efficiency resulting in fuel consumption savings above 5% (with equivalent CO₂ and SOₓ emission reductions).
- Simultaneous reductions in total NOₓ emission (t/h) of up to 45% - 50% (resulting in NOₓ emissions levels ranging 300 - 350 mg/Nm³, referred to 3% O₂).
- Control of unburnt fuel and CO emissions, resulting in negligible CO levels even for the most stringent low excess air scenarios (averaged figure of excess O₂ around 2%).

The application of “Controlled Furnace” approach to the crude oil furnace has resulted in a clear improvement in combustion control that makes feasible higher unit reliability, safer operation and reductions in maintenance costs. Crucial information for preventive maintenance actions is obtained through the immediate identification of burners malfunctions (before major failures or damages are produced) and continuous control of CO or unburnt fuel, which are also associated with fouling and coke deposits scenarios.

Potential of this optimization strategy is significantly increased in scenarios of variable fuel supplies or operation loads, where combustion unit operators are otherwise totally “blind” to the changes occurring in the combustion process.

“Controlled Furnace” approach is either a cost-effective alternative or a valuable complementary tool to larger scale combustion system retrofits which would necessarily lead to combustion facilities with more complex designs and greater needs for surveillance and control (Figure 5).

Improvements in unit efficiency carried out through the application of “Controlled Furnace” strategies lead to fuel savings and emissions penalties reductions that typically result in reduced investment pay-back times, depending on base case situation, fuel type and heat recovery section performance, among other factors.

In addition, the important parallel reductions in NOₓ emissions achievable through “Controlled Furnace” application could make feasible, from an environmental point of view, and especially in NOₓ saturated industrial areas, the request and authorization of new projects involving extension of facilities or increase in capacity.
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