

**EFFICIENCY IMPROVEMENT AND EMISSIONS REDUCTION IN
REFINERY BOILERS AND FURNACES**

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Introduction

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 utilised.

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. Boiler or furnace operation is typically supported by standardised procedures and operator experience, rather than by effective on-line information and optimised 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 optimised 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 optimisation 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 optimisation 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.

In order to solve these limitations, INERCO (a Spanish engineering company) has developed and successfully applied the Controlled Furnace technology (patent pending) for optimising boilers and furnaces of very different design and consuming quite diverse fuels (oil, gas, coal, petcoke, biomass).

This paper describes the overall technical approach and the latest results, regarding combustion efficiency improvement (overall CO₂ emissions reduction) and parallel effects in NO_x emissions control, through the implementation of this novel technology to the CH1-B crude oil furnace of CEPISA – La Rábida Refinery.

Fundamentals of Controlled Furnace Technology

Efficiency and emissions (CO₂, NO_x, CO) in industrial boilers and furnaces depend largely on the correct distribution of fuel and air supplies to the combustion process. Therefore, the effectiveness of stricter combustion controls will be a function of the actual balancing of the combustion process.

Taking this into account, the combustion optimisation technology relies on the adequate closed-loop control of local combustion conditions. Local effects are controlled promoting what is called a "Controlled Furnace" (Figure 1). 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 NO_x formation.

Controlled Furnace technology approach makes possible the individual optimisation of any single burner resulting in an overall optimisation of the combustion process. Its application improves unit efficiency and reduces CO or NO_x emissions by the application of specific optimisation strategies in multi-burner systems.

Consequently, for efficiency optimisation scenarios, Controlled Furnace technology is both a cost-effective alternative to the implementation of combustion system modifications (burner substitution, mainly) and an additional improvement tool if these modifications are finally installed. On the other hand, application of this technology to an existing combustion unit requires minimum modifications at the existing equipment, and very limited time of plant shutdown for implementing the associated new elements.

For reaching “Controlled Furnace” conditions, the following elements are considered (Figure 2).

Advanced monitoring technologies

As stated above, the achievement of an optimised combustion scenario is inexorably based on appropriate monitoring, regulation and control capabilities. Monitoring of local combustion conditions is carried out by ***ABACO-Opticom*** technology. This monitoring technology makes feasible the development of correct combustion surveillance, which is essential for implementing “Controlled Furnace” conditions.

This technology guides the operator so as to obtain the most adequate tuning of any individual burner. This fact brings about the overall optimisation of the combustion unit, and makes feasible the achievement of not only important improvements in operational results (efficiency and emissions), but also safer and more reliable and flexible unit operation.

The use of ***ABACO-Opticom*** technology results in the identification of different hidden furnace or boiler malfunctions which give rise to high CO levels, although operation is under correct average combustion conditions. Also, it makes possible the adjustment of flame geometries, the identification of the optimum number of active burners for each operating load, the measurement of flame stability, and/or the reduction of NO_x generation.

Examples of particular applications of the above mentioned technology are itemised below:

- 1) Direct assessment of combustion conditions at any furnace area and non limited by existing furnace viewing ports.
- 2) Correct determination of excess air level within the furnace, which facilitates the identification of possible air leakage, as well as the safe implementation of combustion optimisation strategies.
- 3) Supervision of real combustion conditions for scenarios of load regulation, supporting the decision making process on the number and location of active burners for each load, the optimisation of excess air level for each load, and the identification of maintenance problems.
- 4) Surveillance and tuning of combustion conditions for scenarios with significant fuel properties variations.
- 5) Control tool for the application of primary measures for NO_x reduction while maintaining an adequate control of safety limits for boiler regulations.

Apart from ***ABACO-Opticom*** technology, the achievement of Controlled Furnace conditions may be enhanced by the following complementary combustion monitoring capabilities:

- 1) Pyrometers grid for determining furnace temperature distribution.
- 2) On-line measurement of fuel and air flowrates.
- 3) Gas emissions monitoring.

The scope of the monitoring approach is to be decided, for each case, according to plant design, operation characteristics and performance objectives.

Novel regulation systems for combustion optimisation

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:

- 1) Automation of existing manual regulations from control room.
- 2) Implementation of fuel and air regulation dampers and valves.
- 3) 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 NO_x Burners (LNB), were installed. In case further NO_x 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 optimised 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 optimisation 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.

Case Study Description

Base case description

Crude oil unit of CEPESA-La Rábida Refinery includes 3 wall-fired multiburner vertical furnaces: CH1-A, B and C. These furnaces are in simultaneous operation as a function of crude oil duty requirements. Typical fuels used are fuel oil and refinery fuel gas, in a wide variety of proportions depending on overall refinery fuel gas balance and active burners arrangement. Fuel composition also varies linked to the type of crude oil processed, which is again an important variable within the refinery operating schedule.

CH1-B crude oil 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 independent 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.

Following these monitoring and regulating capabilities, excess O₂ in CH1-B has been historically controlled in figures around 4%, pursuing a 3% value as the control objective, as shown in Figure 3. A general scheme of the original situation of CH1-B crude oil furnace is presented in Figure 4.

Particular configuration of ABACO for CH1-B furnace

ABACO technology has been implemented in CH1-B crude oil furnace to enhance its combustion control capability and making possible the achievement of Controlled Furnace conditions. The aim of the system for this particular case has been mainly focused on the achievement of optimised furnace efficiency scenarios, covering every possible operating situation.

To this end, the application of **ABACO** technology to this unit includes the following capabilities:

- 1) **ABACO-Opticom** system (Figure 5).
- 2) **ABACO-Air** system for an optimised and automated regulation of air supply (Figure 5).
- 3) **ABACO Control and Expert Systems** for the closed-loop control of the overall combustion process (Figure 6).

Results of Controlled Furnace Technology Application

CH1-B combustion baseline characterisation

Combustion baseline has been characterised through the execution of a thorough testing campaign using new **ABACO** 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:

- 1) 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 optimisation through uncontrolled combustion tuning strategies due to the generation of unsustainable CO levels (Figure 7).
- 2) 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 **ABACO** monitoring system (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 **ABACO-Opticom** system and global furnace excess O₂. Therefore, existing monitoring is found to have lack of representativeness for overall excess O₂ characterisation in this furnace. Furthermore, the information given by a global excess O₂ monitoring is not comparable, in terms of combustion optimisation potential, with the valuable information given by **ABACO-Opticom**.
- 3) As a consequence of what has been stated in 1) and 2), high excess oxygen and minimum CO levels at the furnace outlet section were measured (Figure 7). High NO_x generation associated to these O₂ levels is also produced. Averaged furnace O₂ values measured by the **ABACO-Opticom** system are in the range 5.0% - 7.0%.

Implementation of Controlled Furnace conditions in CH1-B crude oil furnace

Figure 8 presents the results of the implementation of combustion control strategies through the Controlled Furnace approach in CH1-B furnace. A clear evolution of the excess O₂ levels, given by **ABACO-Opticom** monitoring, can be observed from baseline operation to controlled operation, resulting in final oxygen average figures 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 the **ABACO Control** system following a fully automated process.

The reported 3% - 5% excess O₂ minimisation 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 SO_x overall emissions.

Results included in Figure 7 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 (**ABACO-Opticom**) approach.

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

Conclusions

When facing combustion optimisation challenges, such as efficiency improvement and/or emissions reduction (CO₂, CO or NO_x), 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. This technology, which is commercialised as **ABACO** by INERCO, provides the possibility of simultaneously reaching performance and emissions improvements.

This novel technology, qualified as Best Available Technique for NO_x control at the European IPPC Directive, has been applied to more than 30 combustion units, including large utility boilers for electricity generation. Typical NO_x reductions achieved through the application of **ABACO** (20% - 50%) are comparable to those obtained by implementing new Low NO_x Burners. In this sense, **ABACO** technology can also be characterised as a Low NO_x Burner technology due to the fact that the burner retrofitting carried out by **ABACO**, for increasing the combustion regulation capability, and the precise combustion control induced by **ABACO**, convert any existing burner into a real Low NO_x Burner.

Main results obtained in the particular application of this technology to the CH1-B crude oil furnace of CEPESA-La Rábida Refinery are:

- 1) Improvement of unit combustion efficiency resulting in fuel consumption savings above 5% (with equivalent CO₂ and SO_x emission reductions).
- 2) Simultaneous reductions in total NO_x emission (t/h) of up to 45% - 50% (resulting in NO_x emissions levels ranging 300 – 350 mg/Nm³, referred to 3% O₂).
- 3) 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 **ABACO** to the CH1-B 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 optimisation 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.

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 investment pay-back times ranging 1 – 3 years, depending on base case situation, fuel type and heat recovery section performance, among other factors.

In addition, the important parallel reductions in NO_x emissions achievable through Controlled Furnace application could make feasible, from an environmental point of view, and especially in NO_x saturated

industrial areas, the request and authorisation of new projects involving extension of facilities or increase in capacity.

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Key Words

ABACO, low NO_x burner, combustion, monitoring, optimisation, efficiency, heat rate, CO₂, NO_x, CO, emissions, flame.

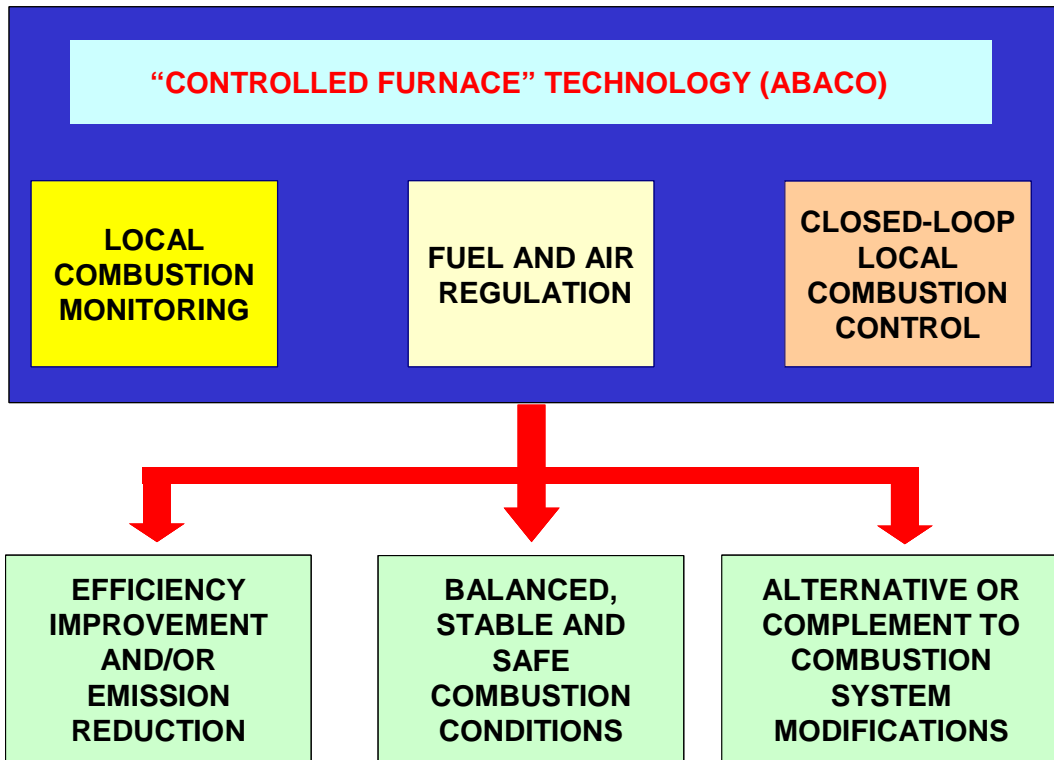


Figure 1: Controlled Furnace Technology Overall Approach

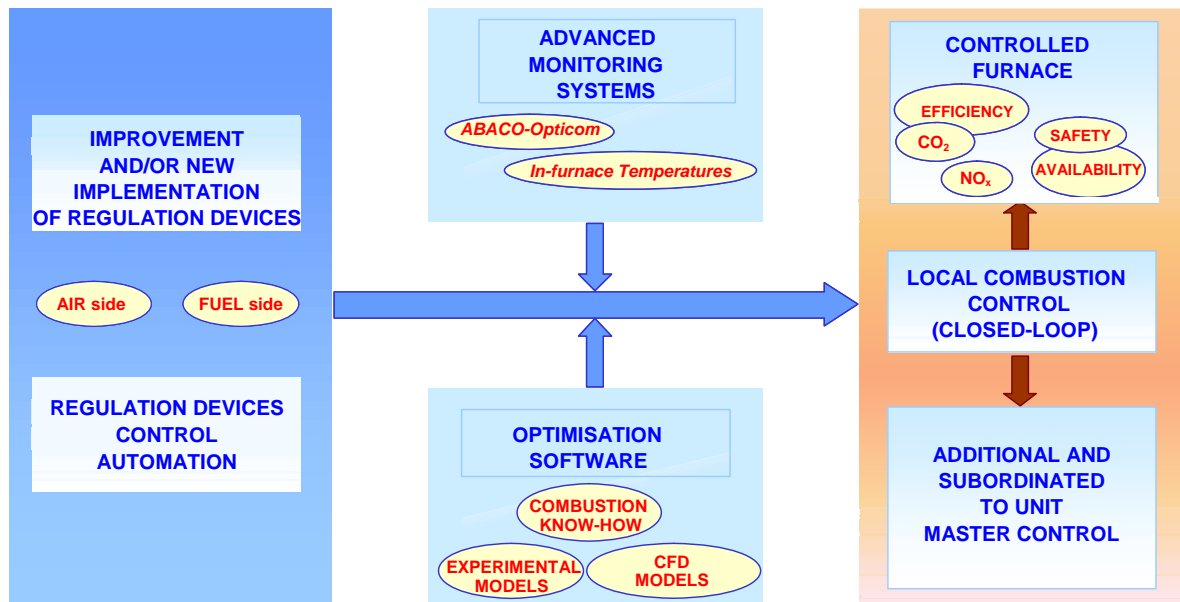


Figure 2: Controlled Furnace Technology elements

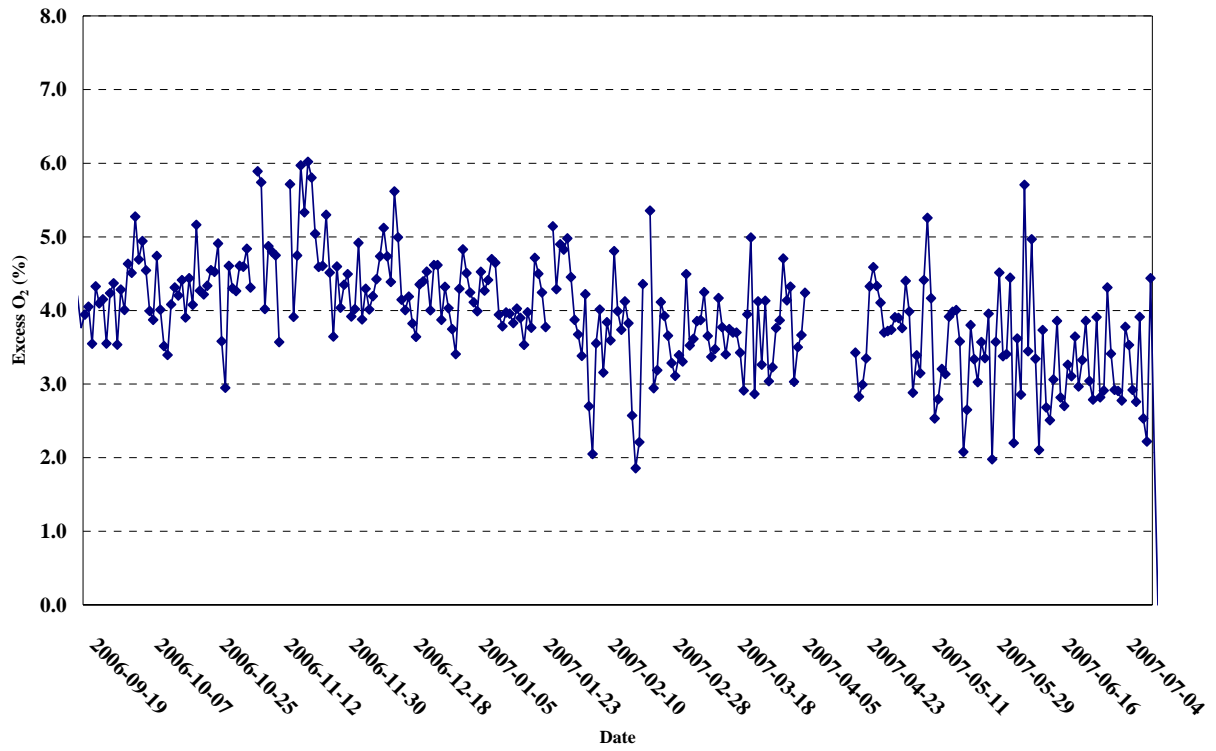


Figure 3: CH1-B excess O₂ figures measured by the original monitoring system. Historical trending

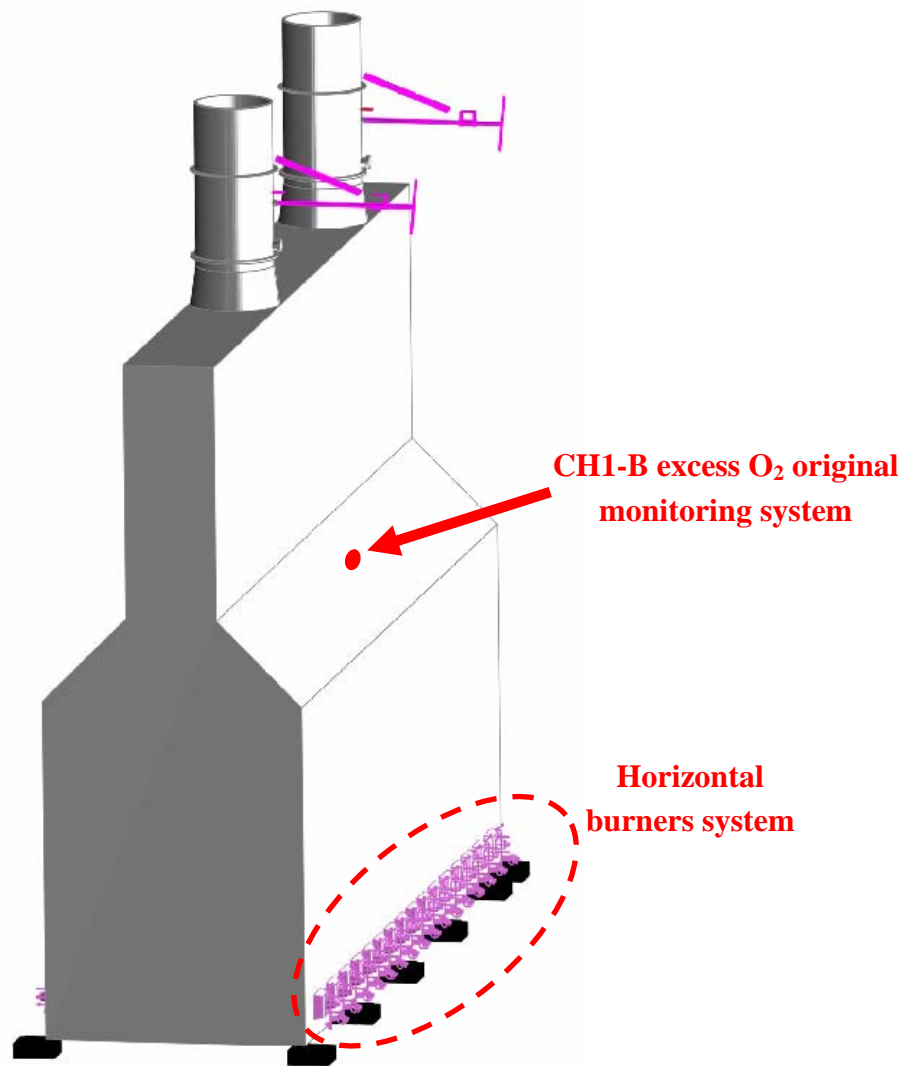


Figure 4: General scheme of CH1-B furnace of CEPESA-La Rábida Refinery



Figure 5: Particular arrangement of **ABACO** for CH1-B furnace of CEPSA-La Rábida Refinery

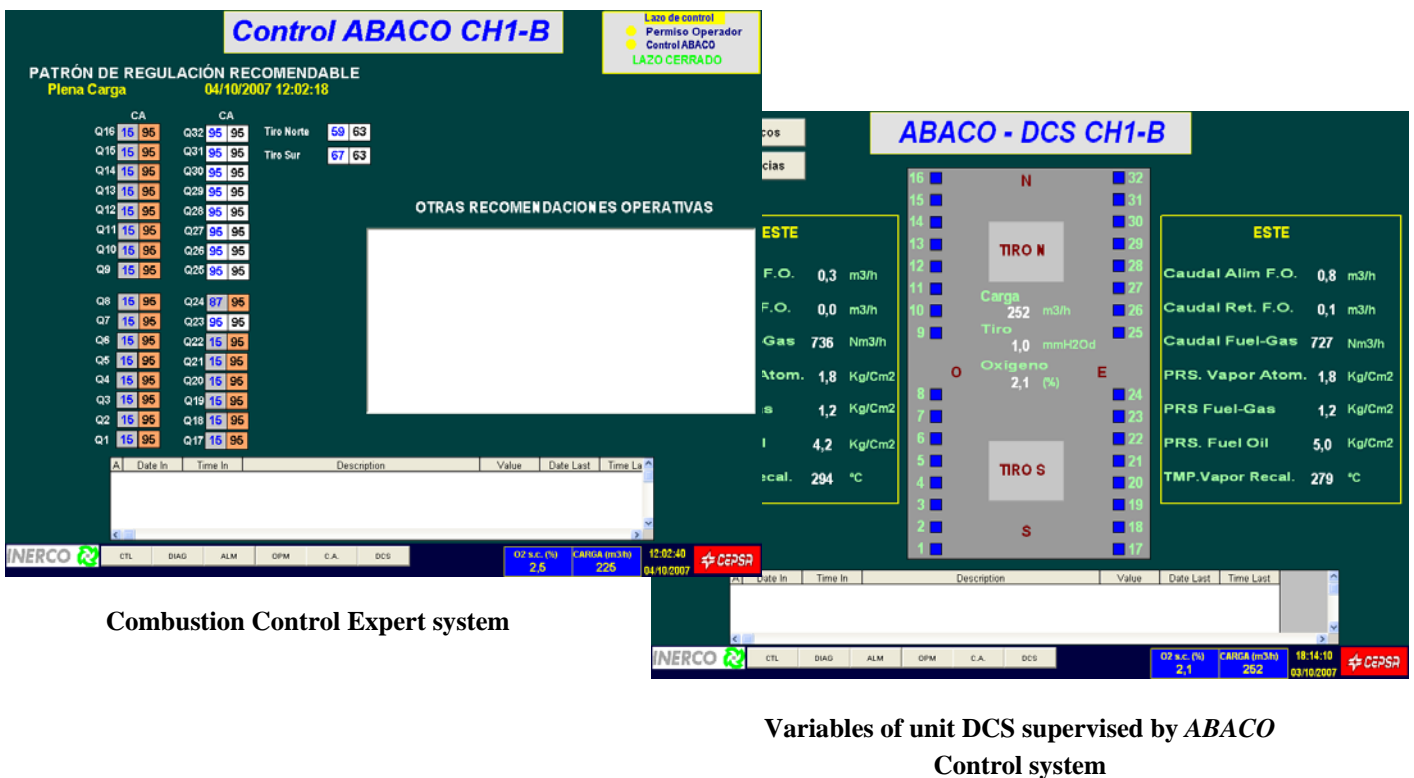


Figure 6: **ABACO** combustion Control and Expert System. Typical supervision screens in the particular application to CH1-B crude oil furnace (CEPSA-La Rábida Refinery)

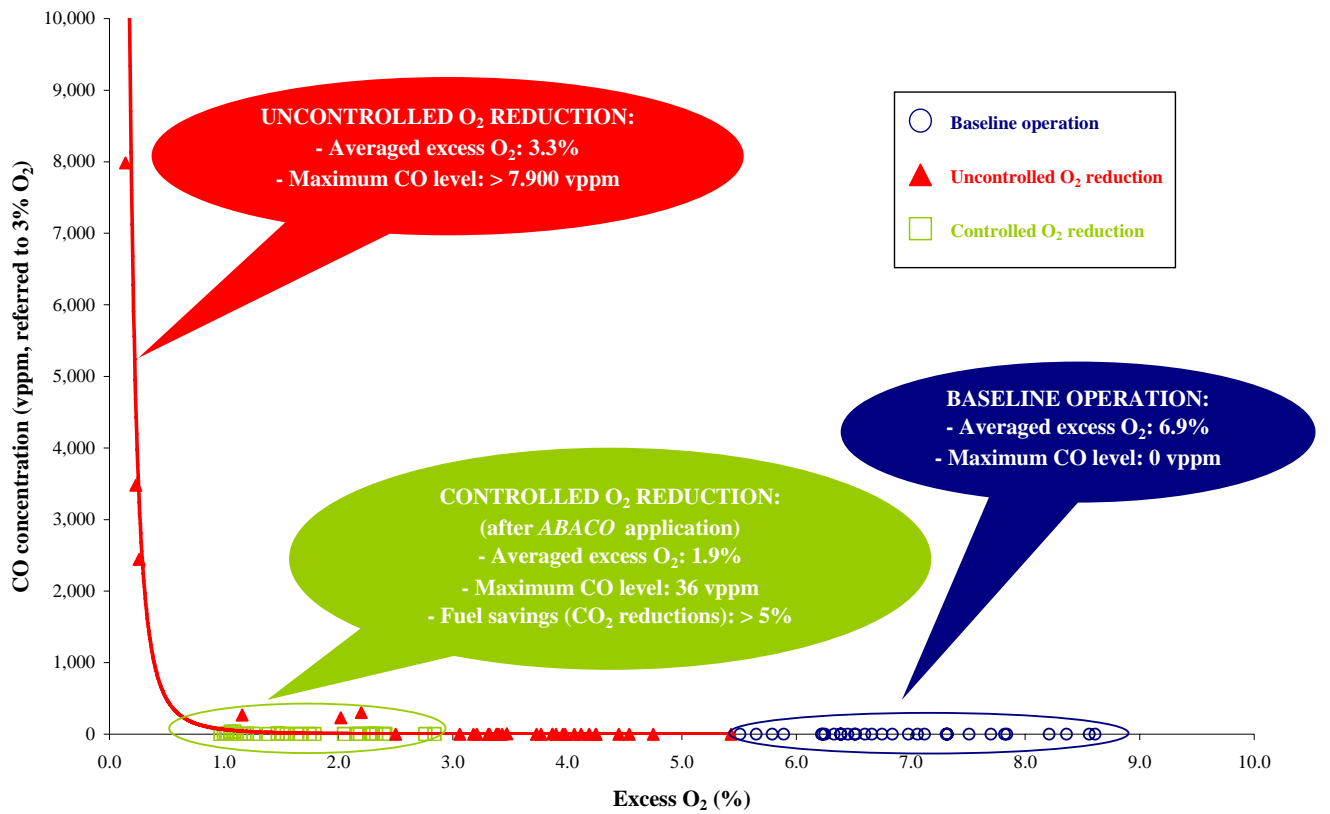


Figure 7: Results of Controlled Furnace application. Evolution of CO-O₂ pairs for CH1-B burners. Measurements obtained through *ABACO-Opticom* monitoring system.
 Comparative a) Baseline operation, b) Uncontrolled O₂ reduction, c) Controlled O₂ reduction

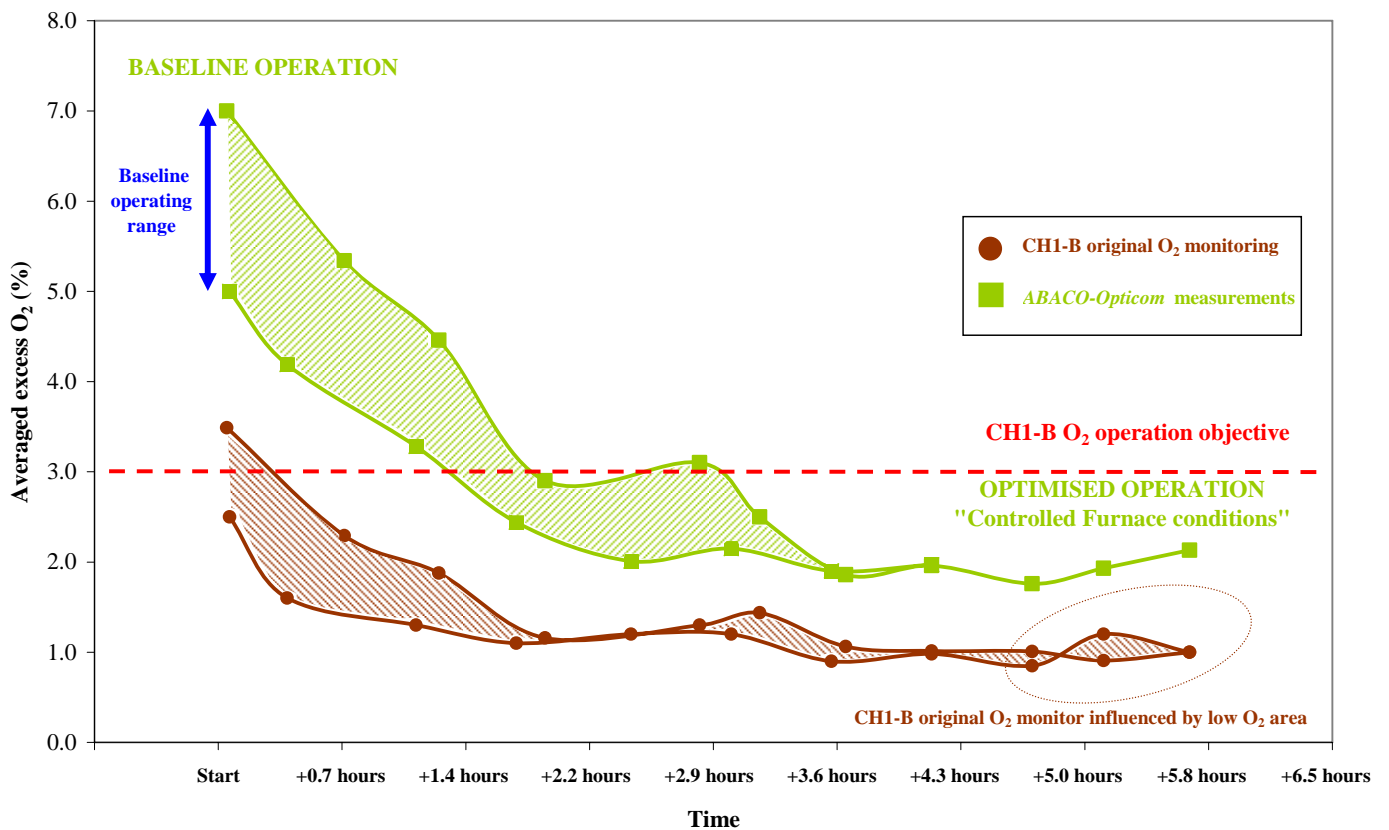


Figure 8: Results of Controlled Furnace application. Averaged excess O₂ at furnace exit. Evolution of excess O₂ from Uncontrolled Baseline operation to Controlled Furnace conditions