International Symposium “Strategic Approach for Implementation of Primary DeNO$_x$ Measures in Large EU Pulverised Coal and Lignite Fired Units”

Athens, June 2005

ABACO TECHNOLOGY FOR NO$_x$ CONTROL AND EFFICIENCY IMPROVEMENT

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ABSTRACT

This paper presents the fundamentals of a novel technology called ABACO (Advanced Boiler Automation for Combustion Optimisation), which has been developed for improving the emissions and efficiency of industrial boilers and furnaces.

ABACO relies on the adequate closed-loop control of local combustion conditions, by means of advanced monitoring and optimised regulation of industrial combustion processes.

ABACO allows to achieve “Controlled Furnace” conditions taking into account, as a critical factor, in-furnace gas concentrations profiles provided by OPTICOM’s novel monitoring approach. These “Controlled Furnace” conditions avoid not desired combustion imbalances, and allow the application, with maximum safety and profitability, of NOx controlling strategies based on air and fuel stratification, and excess air minimisation. This approach leads to NOx emissions reductions from 15 to 60%, without significant penalisation on carbon-in-ash formation, corrosion episodes or slagging phenomena, and making possible parallel improvements in heat rate and CO2 emissions up to 2.0%.

ABACO approach has been applied, in its open-loop version, to more than 25 boilers and furnaces, and it is currently being installed, in its closed-loop version, in 4 coal-fired units. These installations will be complemented with the extension of this technology in 2006 to other 8 coal-fired units and 4 oil-fired units.

ABACO constitutes a cost-effective alternative or complement to other NOx control technologies as the installation of Low NOx Burners, SCR or SNCR.
INTRODUCTION

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 steam properties, with no direct control of in-furnace 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.

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 coal or oil 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 primary measures, based on optimised combustion adjustments or implementation of new burners (Low NOx Burners) with higher regulation capabilities. The interest of such primary measures for NOx control relies on the restrictive limitations to be applied, in the next years, to these emissions, and the high investment and operation costs associated with the application of NOx abatement systems (SCR, SNCR).

Nevertheless, the cost-effectiveness of primary measures is greatly limited by the referred restrictions on combustion monitoring and control. This situation is even more relevant in scenarios of high variability in fuel properties and load profiles. 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 and consultancy firm) has developed the ABACO technology for optimising boilers and furnaces of very different design and consuming quite diverse fuels (anthracites, bituminous and sub-bituminous coals, lignites, petcoke, oil, gas, biomass).

This paper will describe the overall technical approach and the latest results, regarding NOx emissions control and parallel heat rate effects, of this novel technology for combustion optimisation.

ABACO OPTIMISATION PHILOSOPHY

Efficiency and emissions (NOx, CO, CO2) 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, ABACO (Advanced Boiler Automation for Combustion Optimisation) relies on the adequate closed-loop control of local combustion conditions, characterised by in-furnace gas concentrations (O2, CO, CO2, NOx, SO2) profiles, and promoting what is called a “Controlled Furnace”. This is intended to be the critical factor to assure maximum benefit of further adjustments, related to variables such as excess air, combustion air distribution, fuel
stratification, fuel/air ratios, or burners in service arrangement, whose tuning has a direct effect on NO\textsubscript{x} formation (Figure 1).

Therefore, ABACO’s Controlled Furnace approach allows any existing burner to be converted into a real Low NO\textsubscript{x} Burner, with additional NO\textsubscript{x} minimisation capabilities at furnace level, giving rise to the concept of “Controlled Low NO\textsubscript{x} Furnace (CLNF)”. Likewise, ABACO reduces overall NO\textsubscript{x} formation by the application of the following strategies:

- Avoiding the existence of individual burners running with unnecessarily high levels of excess oxygen. Results obtained show that when an individual excess oxygen control for each burner is not applied, some burners typically operate at oxygen excesses over 6%, promoting very high local NO\textsubscript{x} formation, whereas in other burners oxygen concentrations are below 1%, which may lead to carbon-in-ash, slagging or corrosion problems.

- Making possible the safe application in selected areas of the furnace of air and coal stratification policies, which tend to limit NO\textsubscript{x} formation without negatively affecting other combustion performance parameters. The main feature of ABACO in this respect is its local combustion control, which allows to use these restrictive regulations up to that point in which, for each furnace region, no problems are induced regarding carbon-in-ash, slagging or corrosion. An example of the scope of this type of controlled furnace stratification would be the higher coal supply applied by ABACO to the lower burner levels in front-wall boilers. By the use of this strategy, more coal is supplied to a furnace area where NO\textsubscript{x} formation is low, and it still has a sufficient residence time for not causing overall carbon-in-ash problems. The limit of application of this approach is guided by the gas concentrations (O\textsubscript{2}, CO, CO\textsubscript{2}, NO\textsubscript{x}, SO\textsubscript{2}) measured at this furnace region using ABACO’s OPTICOM monitoring system.

- Reducing overall excess oxygen levels, once individual burners have been conveniently balanced, taking into account established limits for in-furnace local gas concentration levels.

As it can be observed, some of these strategies for NO\textsubscript{x} control (i.e. overall excess oxygen minimisation controlling carbon-in-ash formation) may also lead to parallel heat rate improvement.

Consequently, ABACO (patent pending) is both a cost-effective alternative to the implementation of new Low NO\textsubscript{x} Burners (LNB) and an additional improvement tool if these LNB are finally installed.

For reaching “Controlled Furnace” conditions, ABACO integrates the following elements (Figure 2):

- Novel monitoring technologies.
- Specific regulation devices.
- Cutting-edge control software.
ABACO MONITORING SYSTEMS

ABACO is based on OPTICOM technology for in-furnace characterisation of gas concentrations profiles. This monitoring technology allows to make a correct surveillance of combustion, which is essential for implementing “Controlled Furnace” conditions.

Apart from OPTICOM, ABACO might include the following combustion monitoring capabilities:

I) Pyrometers grid for determining furnace temperature distribution.
II) Measurement of fuel and air flowrates (including EMIR technology for pulverised solids).
III) Characterisation of other fuel properties (for pulverised solids), such as ash and volatile contents (ABACO-Proximate) and size distribution (ABACO-Size).
IV) ABACO-Loi for carbon-in-ash measurement.
V) Gas emissions (O$_2$, CO, NO$_x$, CO$_2$, SO$_2$) monitoring, including systems for sequential measurement at different sampling points.

These elements are integrated with ABACO’s regulation and control systems. The scope of ABACO monitoring approach is to be decided, for each case, according to plant design, operation characteristics and performance objectives.

Figure 3 presents the overall monitoring approach, for pulverised coal boilers, based on the automated versions of OPTICOM, EMIR and ABACO-Loi technologies. Measuring points for these systems are briefly indicated for a front-wall boiler. Due to the novelty of these 3 monitoring technologies a basic description of them is detailed below:

I) OPTICOM

This technology ¹, ², ³, ⁴ allows the characterisation of local gas concentrations (O$_2$, CO, CO$_2$, NO$_x$, SO$_2$) in selected points within the furnace, typically located in the near burner regions.

A sketch of OPTICOM is presented in Figure 4. In order to access the inside of the furnace, OPTICOM is provided with retractable and extremely narrow water-cooled probes, which are 10-12 mm width.

These probes have been specially designed for insertion through small openings (around 12-14 mm), to be made in the membranes (typically 14-20 mm width) joining the tubes of the boiler walls. Therefore, it is possible to place these openings in any location required, without being limited by the existing inspection ports or by the need to apply significant structural modifications to the unit.

OPTICOM’s probe design avoids any kind of blockage due to slag deposits, at the same time that allows to withstand the high temperatures in these areas of the furnace. These probes are coupled to a proprietary sample and probe conditioning unit, which guarantees long-term unassisted operation of the system.
II) EMIR

EMIR technology $^{1,5,6}$ provides a reliable assessment of coal flowrates to each burner. This reliability is based on the application of the ISO 9931 standard and INERCO’s wide experience in pulverised coal characterisation.

The foundation of this measurement consists of the isokinetic sampling of pulverized coal. Therefore, a representative sample is obtained, whose effects related to coal particles segregation in the conduits have been minimised.

There is a portable version of EMIR (EMIR II), for semiautomatic pulverised coal sampling (Figure 5). This partial automation determines the following advantages over manual systems:

I) Improved measurement repeatability and reliability:
   * Automatic adjustment and control of sampling conditions (motorisation of probe movement, isokinetic collection, sampling period).
   * Minimisation of operator uncertainty.
   * High capture efficiency.
   * More representative sample collection (in 4 circumferences at sampling section).

II) Minimal utilisation requirements:
   * Only one operator (mainly for installation and sample recovery).

Additionally, EMIR III is the totally automated version of EMIR technology for the measurement of coal flowrates (Figure 6). This device is based on the automated weighing of really representative samples taken from the pulverised coal conduits. It also provides the additional capability of recovering these coal samples (pulverised and dried) for laboratory or on-line analysis of other coal parameters. Weighing is performed using a system based on load cells.

EMIR III allows, in contrast to other systems for coal flowrate monitoring, a direct measurement, not affected by changes in coal properties.

III) ABACO-Loi

Systems at the market place for on-line carbon-in-ash determination are based on indirect techniques (microwaves, IR, etc.), which give non-representative results when ash properties significantly vary.

In order to solve this problem, ABACO-Loi $^6$ includes controlled sample collection and weight measurements (at different temperature conditions) for Loss On Ignition determinations at pulverised coal boilers.

ABACO-Loi consists of two different systems (Figures 7 and 8):

I) Automated sampler, to be located at boiler outlet duct or in the transport duct from ESP to silo, which provides pulverised solid samples for laboratory or continuous on-site analysis.

II) Analysis unit, based on standardised weighing and calcination techniques.
As it is shown in Figure 9, ABACO-Loi results present a direct relationship with measurements made according to laboratory standards (as ASTM C-311), due to the fact that it employs similar principles for LOI determination.

**ABACO REGULATION SYSTEMS**

Application of ABACO includes the improvement of boiler tuning capabilities by means of the:

I) Automation of existing manual regulations from Control Room.
II) Implementation of ABACO dampers and valves, for balancing fuel and air flowrates to each burner.
III) Installation of new classifier regulation devices.
IV) Modification in the design of existing burners for increasing their tuning potential.

These aspects allow, in fact, improved regulation capabilities, similarly as if new burners (as LNB) were installed. In case further NOx reductions are demanded, ABACO 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.

An example of ABACO regulation systems is the ABACO-Coal damper shown in Figure 10, which has been designed for control of coal flowrate to each burner.

ABACO-Coal provides an effective regulation of pulverised coal flowrates in the conduits from mills to burners, as it is shown in Figure 11, where its typical regulation range is plotted. This capability allows to tune the coal flowrate distribution in each mill, controlling at the same time the Primary Air/Coal mass ratio (Figure 12), and therefore providing an optimised combustion balance.

**ABACO CONTROL**

ABACO performs the closed-loop control of local combustion conditions, based on its monitoring and regulation capabilities (Figures 13 and 14). ABACO control includes an advanced expert system (Figure 15), which is configured for each specific application.

ABACO control allows applying strategies consisting on minimising excess air or stratifying air and fuel supplies. These strategies are implemented with maximum reliability and profitability based on the adequate control of local combustion conditions provided by ABACO.

The overall strategies for combustion optimisation applied by ABACO for a typical coal-fired boiler consists of:

I) Control of coal flowrates to each burner, decreasing typical imbalances of $\pm 20\% \div \pm 30\%$ to $\pm 5\% \div \pm 10\%$.

II) Controlled coal stratification (as a function of burners out of service, mill and classifier adjustments, fuel and flame type) by means of:
· Supplying a higher quantity of coal in lower boiler levels, where minimised oxygen concentrations (determining reduced NOx formation) have a limited effect on carbon-in-ash, due to coal higher residence times for these burners (tangential and front-wall boilers).
· Adjusting coal distribution between “high NOx” burners and “Low NOx” burners, according to OPTICOM’s NOx measurements (i.e. conditioning coal distribution between central and outer burners).

III) Controlled air stratification:
· Overfire (OFA) and Underfire (UFA) adequate management for front-wall and tangential boilers.
· Flame type control for arch-fired units.
· Stoichiometry control as a function of coal flowrate modifications.

IV) Excess air minimisation, for balanced combustion conditions and taking into account local O2, CO and CO2 levels provided by OPTICOM.

RESULTS OF ABACO APPLICATION

ABACO “Controlled Furnace” approach has been extensively applied (Figure 16) in boilers with tangential, front-wall and arch-fired designs, consuming very diverse fuels (high, medium and low rank coals, oil, petcoke, orimulsion, gaseous fuels, biomass).

Particularly, ABACO has been applied, in its open-loop version, to more than 25 boilers and furnaces, and it is currently being installed, in its closed-loop version, in 4 coal-fired units. These installations will be complemented with the planned extension of this technology in 2006 to other 8 coal-fired units and 4 oil-fired units.

ABACO permits the implementation of “Controlled Furnace” conditions, providing higher capabilities regarding emissions and efficiency combined improvement. In this sense, NOx emission reductions from 15 to 60% have been reported for Controlled Low NOx Furnace (CLNF) regulations, at the same time that efficiency and CO2 emissions are significantly improved (up to 2.0%).

ABACO has proved to be a cost-effective alternative to other NOx controlling measures as Low NOx Burners (LNB), SCR and SNCR. In any case, ABACO is complementary to these technologies, allowing a more efficient tuning of LNB or significant reagent cost reductions for SCR and SNCR.

As an example of ABACO approach, Figure 17 presents the results, obtained at a Spanish tangentially-fired boiler (560MW), regarding local combustion conditions and coal flowrates distribution, respectively characterised by means of OPTICOM and EMIR systems.

This figure shows important variations (>10%) at the total coal flowrates fed to the four burners located at the corners of each boiler level. These coal supply imbalances were additional to those measured for individual burners (with deviations among certain burners higher than 30% respecting the average coal flowrates).
This situation was confirmed through the OPTICOM measurements performed at different points, located at the front and rear wall of each level, and in the 4 walls for regions above the OFA level (at distances up to 3 m from the wall).

In this sense, Figure 18 shows the existing low oxygen areas in the lower furnace (levels 1 and 2), where the total coal flowrates are clearly above the average corresponding to all boiler levels. Besides this, a higher average oxygen concentration was reported for level 4. This has been related to the design of the secondary air duct, that reaches the windbox at that intermediate boiler level.

Local NO\textsubscript{x} levels also seem to present a straightforward relationship with local O\textsubscript{2} levels. Overall NO\textsubscript{x} emissions were around 650 mg/Nm\textsuperscript{3} for this base case.

In order to improve these emissions, different NO\textsubscript{x} controlling measures were applied, basically consisting on decreasing excess oxygen and burner tilt, and applying strategies for coal and air stratification.

Once identified, these Low NO\textsubscript{x} modifications have been applied in two opposite situations, regarding balance of local combustion conditions (Uncontrolled and Controlled Furnace). Figure 18 illustrates the results obtained. As it can be observed, NO\textsubscript{x} levels were quite similar (around 450 mg/Nm\textsuperscript{3}). This 30% reduction, respecting baseline, allowed to decrease NO\textsubscript{x} emissions below the 500 mg/Nm\textsuperscript{3} forthcoming limit for this installation.

Nevertheless, when the Low NO\textsubscript{x} regulations were introduced for the Uncontrolled Furnace situation (ULNF), the lower boiler levels exhibited local oxygen concentrations below 0.1%, which is a situation not be maintained for this boiler, due to very low stoichiometry conditions that might lead to high slagging, corrosion and carbon-in-ash scenarios. On the other hand, for the ABACO Controlled Furnace case (CLNF), these oxygen levels were above 1% in the most significant measuring points.

The ULNF situation allowed to keep a similar boiler efficiency to that of the base case, whereas the ABACO CLNF permitted an improvement of 0.4% in this parameter. This enhancement was also associated with a better cycle efficiency, resulting in heat rate and CO\textsubscript{2} emission improvements higher than 0.6%.

Results obtained in other tangential boilers using a similar approach have confirmed NO\textsubscript{x} reductions above 20-30%, with parallel heat rate and CO\textsubscript{2} improvements above 1%.
CONCLUSIONS

When facing optimisation challenges, such as efficiency improvement and/or emissions (NOx, CO2) reduction, ABACO (Controlled Furnace) technology has proved to be an advantageous alternative compared with the application of larger scale measures in combustion installations.

In this sense, ABACO allows an easy and quick plant implementation, providing also the possibility of simultaneously reaching performance and emissions optimisation objectives. These features of ABACO consolidate the interest of its application as a previous step to other possible solutions based on plant design modifications (for instance, Low NOx Burners, windbox redesign, or SCR or SNCR abatement techniques).

Furthermore, for those situations where more stringent NOx reductions are required, the combined application of ABACO and any of these other technologies would result in the benefits outlined below:

1. Identification of what large-scale modifications are really necessary in the installation: low NOx burners number and configuration, windbox retrofitting requirements, effective sizing of abatement technologies, etc.

2. Improvement of overall results, allowing a more effective regulation for Low NOx Burners, as well as significant reduction in reagent costs, for SCR and SNCR applications.

3. Control of collateral effects associated with the introduction of these design modifications in the routine unit operation: performance loss, LOI excursions, generation of reducing atmospheres, appearance of corrosion phenomena, establishment of gaseous stoichiometry imbalances, etc.

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

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the collaboration of other personnel involved in activities resulting in this paper. Special thanks are given to the technical staff of ENDESA and IBERDROLA, and to the INERCO Industrial Processes Division. This development has been carried out with a partial financial grant from the European Coal and Steel Community.
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Key Words

ABACO, combustion, monitoring, in-furnace, optimisation, heat rate, efficiency, NO\textsubscript{x}, emissions, flame, pulverised coal, coal flowrate, CLNF.
ABACO: CONTROLLED FURNACE (LOW NO\textsubscript{x} : CLNF)

TUNING FOR UNIFORM, STABLE AND SAFE COMBUSTION CONDITIONS
MAXIMUM NO\textsubscript{x} AND EFFICIENCY CONTROL USING IMPLEMENTED CAPABILITIES
ALTERNATIVE OR COMPLEMENT TO DESIGN MODIFICATIONS (LNB, WINDBOX)

Figure 1: ABACO Overall Approach

Figure 2: Integration of individual ABACO elements
Figure 3: Example of ABACO monitoring approach for a pulverised coal boiler

Figure 4: Sketch of automated OPTICOM technology for in-furnace gas profile characterisation
Figure 5: EMIR portable version (EMIR II)

Figure 6: Sketch of automated EMIR III technology for coal flowrate measurement
Figure 7: Scheme of ABACO-Loi (Sampling + analysis units)

Figure 8: Integrated ABACO-Loi Sampler + Analysis Unit
Figure 9: ABACO-Loi results vs. ASTM laboratory results

Figure 10: Example of ABACO-Coal damper
<table>
<thead>
<tr>
<th>CASE</th>
<th>COAL FLOWRATE (PRIMARY AIR/COAL FLOWRATE)</th>
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<tr>
<td></td>
<td>B1</td>
</tr>
<tr>
<td>B1+B4: 100%</td>
<td>7.98 (2.30)</td>
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<tr>
<td>B1: 45%; B3+B4: 100%</td>
<td>6.50 (2.19)</td>
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Coal flowrates: t/h
Primary Air/Coal: mass ratio

Figure 11: Effect of ABACO-Coal opening on coal flowrate through that burner

Figure 12: Tuning of coal flowrate distribution for the 4 burners of a mill using ABACO-Coal (closing ABACO-Coal at Burner (B1) from 100% to 45%)
Figure 13: ABACO overall approach

Figure 14: Scheme of ABACO Control Software
15-60% NOx DECREASE
1.0%-2.0% HEAT RATE AND CO2 IMPROVEMENT

APPLICATION OF ABACO TO MORE THAN 25 BOILERS

BOILER DESIGN
- TANGENTIAL
- FRONT-WALL

FUEL CONSUMED
- ARCH
- COAL (ANTHRACITES TO LIGNITES)
- OIL ORMULSION PETCOKE GAS

Figure 15: ABACO Expert System

Figure 16: Typical results of ABACO application
Figure 17: In-furnace O₂ and NOₓ profiles and coal flowrate distribution per level for a tangentially-fired boiler (base case, 560 MW)

Figure 18: NOₓ emission and efficiency results for most relevant cases in the optimisation programme developed at a tangential unit (UF: Uncontrolled Furnace; ULNF: Uncontrolled Low NOₓ Furnace; CLNF: ABACO Controlled Low NOₓ Furnace)