LINDARC™ EAF OFF-GAS ANALYSIS SYSTEM[1]

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Abstract
In today's competitive market, it is of utmost importance for EAF steel makers to perfect their processes in order to reduce operating costs and improve the safety and reliability of their equipment. The innovative LINDARC™ technology, with laser units installed on the fixed duct, just after the combustion gap, uses the technique of "Tuneable Diode Laser Absorption Spectroscopy" (TDLAS). It performs real-time off-gas emissions measurements of CO, O_2, H_2O and temperature of off-gas. A closed-loop operation is in place for dynamic control of the chemical energy package and dedicated post-combustors to perform CO, H_2 and CH_4 combustion into the EAF furnace shell. The system has, so far, proven its reliability, resulting in a maintenance free operation, and the optimization of carbonaceous fuels combustion with subsequent electric energy, oxygen and natural gas reduction.This paper describes LINDARC TDLAS laser technology, the laser on-site installations, the post-combustion injectors, the closed-loop-control strategy and future developments of the system.
Key words: Off-gas; Post-combustion; Chemical energy.

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1 INTRODUCTION

1.1 LINDARC™ Technology Concept

The laser emits a monochromatic light which contains one specific wavelength of light with a very narrow frequency band. Every molecule has a special frequency of absorption (single absorption line). If the light source emits the same frequency, the molecules will start moving and absorbing the emitted energy; energy absorption leads to a reduced signal on the receiver. The amount of energy absorbed is based on the Beer Lambert Law and depends upon the number of molecules between the transmitter-receiver and the measurement path length.

$$\text{Beer Lambert Law } T=e^{(-sg(f)NL)}$$

Where: T= transmission, s = absorption strength, g(f) = linear shape function, N = No. of molecules, L = optical path length

The LINDARC™ off-gas analysis system uses the technique of "Tuneable Diode Laser Absorption Spectroscopy - TDLAS". This single-line absorption spectroscopy measuring technique is based on the selection of one single absorption line (in the near infrared spectral range) for the specific gas to analyse (figure 1). The spectral width of the diode laser is considerably narrower than the one of the absorption line for the chosen gas. By varying the diode laser current, its wavelength is scanned across the absorption line. The light detected in the receiver unit varies due to the absorption of light from the specific gas molecules in the optical path between the diode laser and receiver. The detected shape and size of this single absorption line is used to calculate the amount of gas in the measurement path.

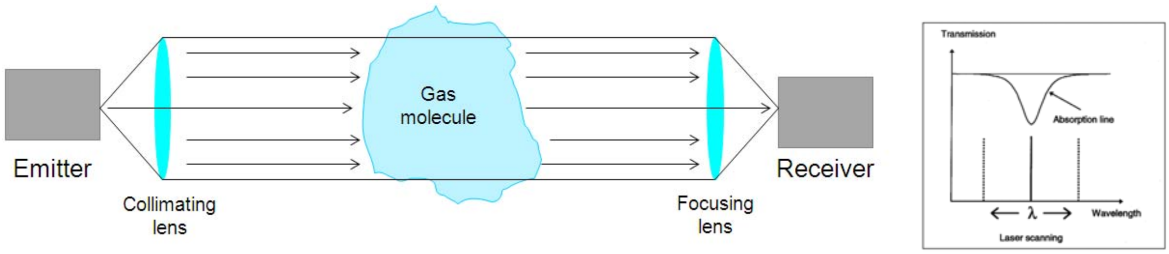

Figure 1: Tuneable Diode Laser Absorption Spectroscopy – TDLAS.

Absorption lines from other gases are not present at this specific wavelength, and therefore will not interfere with the single absorption line or the resulting gas concentration. Dust only weakens the light without interfering with the measurement if a minimum quantity of emitted light is reaching the receiver.

Previously presented papers[1,2] have already described in detail, the physics principles and the TDLAS laser detection technique. Until now the worldwide TDLAS experience has been very limited for very high temperature gases (peaks of 1600°C / 2912 °F could be recorder in the EAF). The proper selection of the wavelength has been a major challenge for Norsk Elektro Optikk company, that is a laser producer and our partner in this application. All previous experiences by LINDE Group in this application,[2,3] have been of extreme importance for the success of the project.

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Currently, LINDARC™ technology is reading the following species:

Carbon Monoxide (CO) 0÷100% *(Best accuracy in a temperature range of 400÷1600°C / 752÷2912°F)*
Oxygen (O_2) 0÷25%
Water (H_2O) 0÷100% *(In a temperature range of 800÷1600°C / 1472÷2912°F)*
Off-gas temperature 0÷1600°C/*2912°F* *(Best accuracy above 400°C / 752 °F)*

2 MATERIALS AND METHODS

2.1 LINDARC™ Installation

LINDARC™ is installed directly after the combustion gap, on the fixed water cooled duct, to analyse the off-gas which is drawn off from the 4th hole (Figure 2). To have a correct analysis of the conditions inside the furnace (avoiding false readings caused by the false air entering the gap) only the centre of the off-gas stream is analysed. To do so, two water cooled lances protruding inside the off-gas duct to “shield” the laser light and expose the off-gas, only along a well-defined measuring path length. The location of these lances is established by Computational Fluid Dynamics (CFD) analysis. Lances are water cooled and kept clean by nitrogen purging cycles, which do not interfere with the measurement.

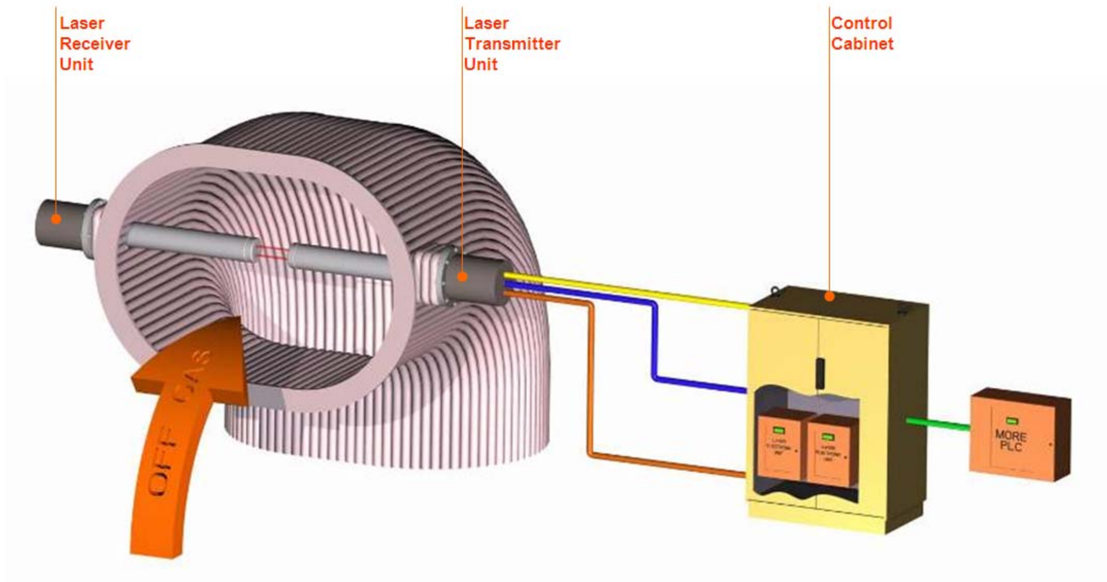

Figure 2: LINDARC™ equipment.

Due to the typically harsh environment of an electric arc furnace, the sensitive transmitter and receiver units are mounted outside the off-gas system to prevent high heat load and even mechanical damage (Figure 3). These units are protected within heavy duty water cooled housings.

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A dedicated cabinet contains the lasers electronic equipment, as well as all the valves and instruments to manage the cooling water, the purging air and nitrogen. A maximum cable length of 50 meters (164 ft) can be used between transmitter units and cabinet, in order to install the cabinet is a safe location away from the furnace area.

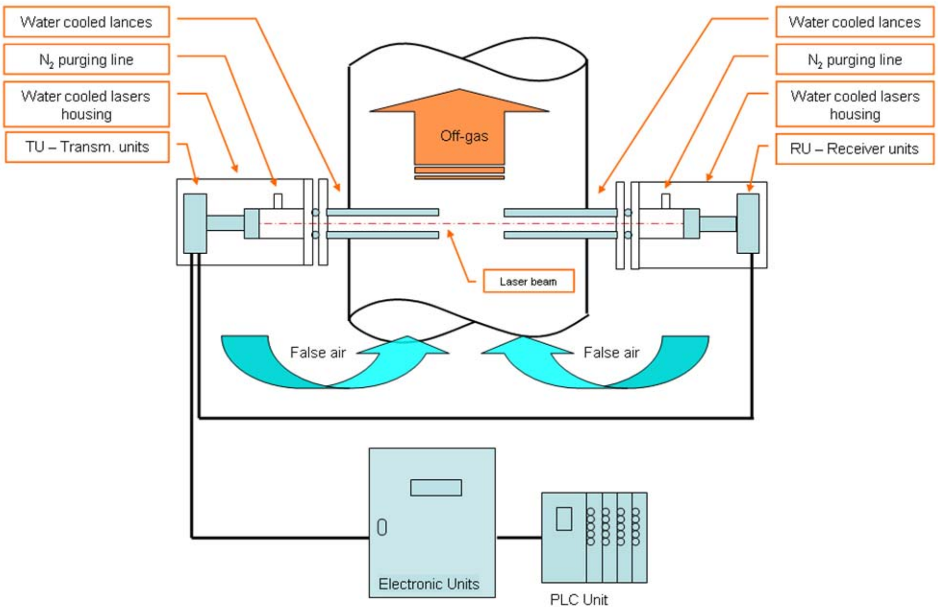

Figure 3 : transmitter and receiver units mounted outside the water cooled duct.

The main advantages of the LINDARC™ TDLAS technology compared to conventional measurement techniques are:

- Measurement of the real off-gases volume (no sampling and gas conditioning is needed);
- Fast response time (less than 2 seconds compared to more than 20 seconds of the extractive method);
- Direct H_20 content measurement (not possible with conventional extractive method);
- Maintenance free (no movable parts, no gas conditioning systems or filters to be maintained).

Additional care was given during the engineering stage to strengthen the reliability of the system, with limited and simple maintenance operation and improve the durability of the installed elements.

Key points of the LINDARC™ manufacturing include:

- Extensive use of water cooled elements to resist the flames and high temperature generated in the EAF;
- Simple alignment of the lasers units;
- Easy inspection of the water cooled lances;
- Automatic lance cleaning cycle;
- Sensitive equipment (lasers electronics, control valves, instrumentation) installed in a protection cabinet, in safe place.

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From the automation system point of view, the LINDARC™ automation system can be connected through the plant network with the PLC and Human Machine Interface - HMI system in service for the Chemical energy package, as well as with the Level 1 and Level 2 EAF automation (Figure 4). An internet remote connection is available for the remote assistance of LINDARC™ technology from MORE headquarters located in Italy.

The automation system includes a LINDARC™ Control Computer (LCC) with specially designed HMI and Closed Loop Control (CLC) and Dynamic Water Leak Detection (DLWD) software. EAF and off-gas measurement data are stored into a SQL server and a powerful database is used for the analysis of historical process data, which can be either performed locally or on remote computers via Internet or Intranet connections.

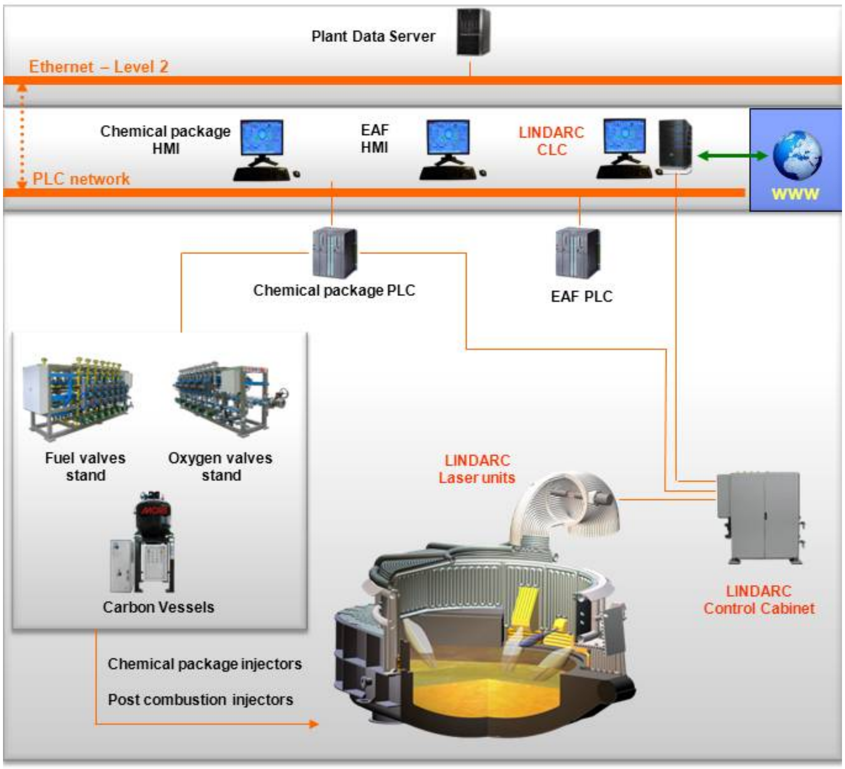

Figure 4: LINDARC^{TM} automation scheme.

3 RESULTS AND DISCUSSION

3.1 Closed Loop Control and Optimization Strategy

A specific software has been developed by MORE to generate a Closed Loop Control (CLC) between the LINDARC™ and the injectors / post-combustors (Figure 5). Oxygen / Natural Gas ratio of burners is dynamically controlled by the CLC, based on the O_2 and CO readings from the LINDARC™. Oxygen flow through the post-combustor is also controlled by the CLC software with the aim of maximizing the post-combustion inside the furnace and save electrical energy.

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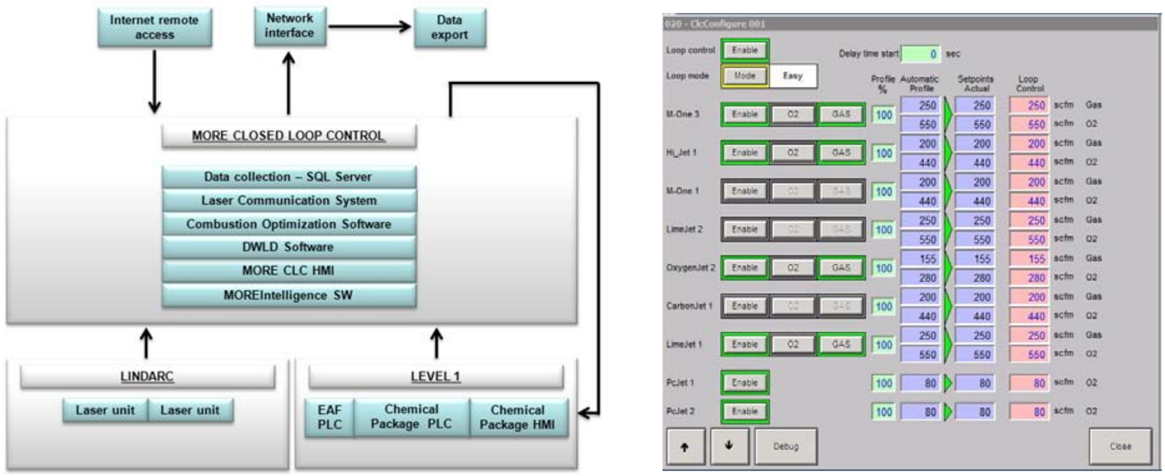

Figure 5: Closed Loop Control (CLC).

Considering that the post-combustion of CO into CO_2 happens above the liquid steel, the CLC intervention is active mainly during melting phase, when it is possible to transfer post-combustion energy to the un-melted scrap with a high heat transfer rate. During the flat-bath stage, the CLC is dedicated to the control of the oxygen and carbon injectors for the dynamic optimization of the complete EAF performances. Post-combustion control strategy of the CLC is summarized in Table 1.

Table 1: Post combustion control strategy

	O_2 ⇧	**O_2 ⇩**
CO ⇧	↘ CH_4	↘ CH_4 ↗ O_2
CO ⇩	↗ CH_4 ↘ O_2	↗ CH_4 ↗ O_2

The Post-combustion strategy also has to take into consideration the presence of CH_4 and H_2 in the fumes. Even if CH_4 and H_2 are not measured with the LINDARC™, it is possible to calculate their amount from the CO reading. Off-gas analysis data from several analysis campaigns made with conventional extractive devices was analysed. A relation between CO and H_2 as well as CO and CH_4 does exist (Figure 6). This correlation is used by the MORE CLC software to calculate the total amount of oxygen needed to complete the off-gas combustion.[4]

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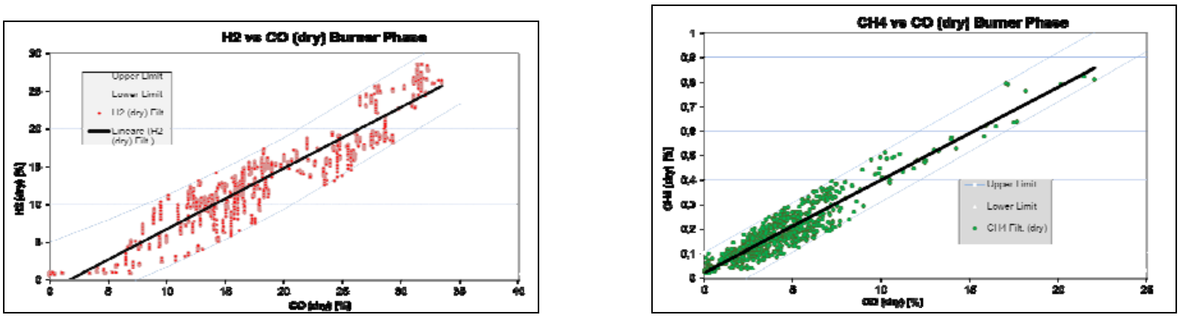

Figure 6: Correlation between CO, H_2 and CH_4.

3.2 DWLD - Dynamic Water Leak Detection

During EAF operations, water content in the off-gas is variable and depends on several factors (natural gas combustion during burner time, scarp mix and electrode cooling). Measured water levels in the off-gas are very high and variable during the whole melting phase and it appears to be more repetitive and constant during superheating.

Using a specific algorithm software, that considers all the above variables, it is possible to plot an expected water baseline level for the actual heat. Any accidental water leaks that may occur, will increase the water content above the predicted baseline level and generate a warning message for the operators. This feature, which is included in the LINDARC™ software, is extremely useful for the prevention of dangerous explosions in the EAF.

The following screenshot (Figure 7), shows what happened during one heat; the blue line represents the expected water threshold that triggers the warning message for the furnace operators, the red line was the actual water reading from the LINDARC™ DWLD software (consequent inspection confirmed a water leak from the roof).

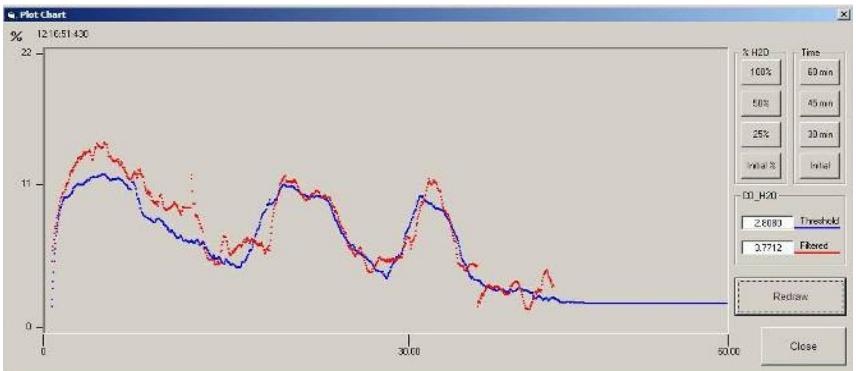

Figure 7: water concentration in the off-gas.

3.3 Data Validation

A validation campaign has been performed to verify the accuracy of the LINDARC™ readings using a conventional extractive device.[5] A water cooled probe was inserted in the duct, very close to the laser measuring gap (Figure 8).

Figure 8: Installation of water cooled probe for validation.

The following aspects have to be taken into consideration when comparing the extractive device data with the LINDARC™ readings:

- Extractive device analysis was effected by a delay due to the length of the sample pipeline. Using a tracing gas, the delay was measured and noticed.
- Instruments with different resolution time (2 sec. for LINDARC, 10 sec. for extractive O_2,CO and CH_4, 120 sec. for extractive H_2O)
- LINDARC readings are all "wet" measurements (calculated on the total off-gas volume), while extractive measurements are "dry" (the sample gas is dried before sending it to the analyser)

The result of the validation campaign was positive proving the accuracy of the LINDARC™ system as demonstrated in the this example related to the CO reading (Figure 9).

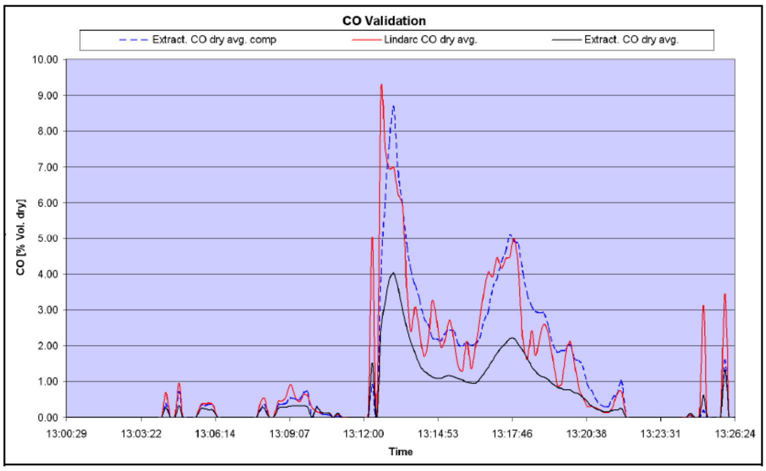

Figure 9: validation results.

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3.4 Maintenance

Laser light transmission is continuously monitored as an index of the cleaning of the system. Unlikely dirt deposit inside the water cooled lances and/or on the lasers lances, will immediately effect the total light transmission.

Regarding maintenance, the system has proven to be almost “maintenance free” due to the design and manufacturing details that MORE engineers taken into account, based on almost three decades of experience in the steelmaking industry:

- Due to the automatic cleaning cycle, dirt cannot be deposited inside the water cooled lances so maximum laser light transmission is assured. Continuous operation for several months without human intervention for lance cleaning has been experienced.
- The lifetime of the water cooled lances is expected to be much longer than that of the water cooled duct. LINDARC™ lances have been in service for more than 2 years and haven’t presented any installation problems or signs of erosion.

Manual lens cleaning can be performed by maintenance personnel very quickly (it will take just a few minutes during a programmed EAF maintenance day) and very easily owing to the special design of the laser housing which can be easily opened from outside of the duct.

More than 12 months of continuous operation have been experienced with NO MAINTENACE AT ALL performed on the LINDARC™ packages installed.

3.5 LINDARC™ Installations and Operating Results

Since November 2009, two LINDARC™ systems have been in operation with successful results (Figure 10.a and 10.b) together with MORE Modules Technology chemical energy package.

Figure 10.a: Lindarc installation

Figure 10.b: Lindarc installation

The following table describes the average results achieved, compared with the performances before the LINDARC™ installation.

Table 2: Average results

	LINDARC average results
Electric Energy consumption	-5,0%
Oxygen consumption	-10%
Natural Gas consumption	-6,0%
Injected carbon consumption	- 10%

Moreover, additional benefits are: reduced skulls (un-melted scrap) on the furnace walls, with consequent better scrap charging and a better knowledge of the furnace melting process.

By adopting the LINDARC off-gas analysis, savings of 2 USD/t have been generated thanks to the precise control of all melting phases and the reduction of the overall transformation costs.

4 CONCLUSIONS

The laser off-gas analysis technology has proven to be a highly precise and extremely fast tool to obtain exact data for the various gas species in the EAF off-gas system. It improves carbonaceous fuel combustion with subsequent electric energy, oxygen and natural gas reduction.

From the safety point of view, the system enables the monitoring of real-time water content in the off-gas to prevent explosions generated by water leaks. Moreover, real-time signal of CO value in the off-gas will prevent explosions in the dust settling chamber or bag house and it is possible to set-up gap/dumper positions.

The system has proven its reliability resulting in a maintenance free operation due to the application of design and manufacturing details base on more than 25 years of experience in the steelmaking industry by MORE engineers.

The following benefits can be expected by adopting the LINDARC^{TM} technology:

- Reduction of Power On time
- Reduction of electrical energy consumption
- Optimization of oxygen, fuel and carbon consumption
- Increased productivity and yield
- Increased meltshop safety
- Fast pay back of the investment

MORE is focusing on continual engineering improvements on the LINDARC^{TM} system and presently MORE is working on the following upgrades:

- MORE*Intelligence*: with the LINDARC off-gas analysis system, customers are able to get immediate benefits and reach an extremely high level of knowledge thanks to the useful information the system can provide. Moreover, there is a vast amount of data that will be collected, of which only a small fraction will be properly analysed to obtain useful information concerning the metallurgical process. To get the best from the LINDARC technology, MORE has developed MORE*Intelligence,* a specially made “data mining” advance analysis software based on the multi-dimensional data-base technology (Hypercube). The advanced MORE*Intelligence* software will simplify the data analysis and it will

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boost the possibility of finding connections between the off-gas analysis and process variables to transform huge amounts of process data into information to support decisions related to the process.

- *CO_2 analysis:* New laser diodes are now available on the market; our partner NEO is running a testing campaign to implement the CO_2 reading.

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