EAF long term industrial trials of utilization of char from biomass as fossil coal substitute

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Biomass is a renewable resource having a steady and abundant supply, especially those biomass resources that are by-products of agricultural and industrial activity. Its use is carbon neutral, can displace fossil fuels, and helps reduce GHG emissions while closing the carbon cycle loop.

Steel produced starting from scrap, like in EAF route, already needs less energy if compared to BF-BOF route with beneficial effects on environment and economy that are greater as increases the share of fossil fuels in total energy feeding. The replacement, in EAF practice, of fossil fuels with char and syngas obtained from biomass can further improve the environmental performance and the attractiveness of the EAF based route, eventually increasing the amount of chemical energy respect electrical one, with beneficial effects on environment, economy and flexibility of the EAF process.

The feasibility of biochar as fossil coal substitute as charge material in EAF has already been proved in a previous RFCS project (SUSTAINABLE EAF STEEL PRODUCTION – GREENEAF - RFSR-CT-2009-00004). A test sequence of six consecutive heats were carried out replacing standard anthracite with biochar. The results of the industrial tests indicate that utilization of char as charge material can be done, but operating practice needs to be optimized with a long term experimentation.

In the ongoing RFCS project, (BIOCHAR FOR A SUSTAINABLE EAF STEEL PRODUCTION - GREENEAF2 - Grant Agreement Number RFSP-CT-2014-00003) an intensive industrial utilization of biochar is foreseen.

This paper describer the industrial long term trials with biochar in EAF, with the final target to replace fossil coal.

The results of industrial long term trials confirmed the feasibility of the use of biochar as charge material, without significant modification in steel and slag analysis.

KEYWORDS: EAF, ELECTRIC ARC FURNACE, COAL, CHAR, BIOACHAR, TORREFACTION, STEELMAKING

INTRODUCTION

Fossil sources are extensively used in the Electric Arc Furnaces (EAF), to provide energy (in addition to electricity) or in general for process needs (to provide carbon to steel bath and promote slag foaming which improves furnace energy efficiency). The substitution in EAF practice of fossil sources (natural gas and coal) with char coal obtained from biomass can improve the environmental and economic performance due to the fact that no new CO_2 emissions are introduced in the atmosphere (CO_2-neutral see Emission Trading European Directive).

Previous experience at pilot and industrial scale [1,2,3]confirmed that the char coal from biomass can replace coal. However the application at a specific EAF needs proper customization and long term trials.

The objective of this activity is the validation for the utilization of char from biomass as substitute of coal in the EAF.

Obtained results from preliminary experiences showed that char, due to the higher presence of volatile matter and specific area than fossil coal, is a highly reactive material. For this reason, in case of utilization as charge material, proper material pretreatment (briquetting) and optimization of operating practice is necessary. Due to the mentioned specific characteristics of char, flame formation during basket charge and a tendency to increase the thermal load of off gas is expected in case of EAF utilization as coal substitute.

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The carried out tests described in previous papers [1,2] revealed in any case that the EAF can work by replacing of fossil coal with char from biomass. In that tests, biochar from thermal pyrolysis was used. Thermal pyrolysis, is the most traditional and consolidated technology to transform biomass into charcoal, and the thermal treatment can be adjusted in order to increase as much as possible the fixed carbon content of biochar, in order to obtain a material having physic-chemical characteristics compared to fossil anthracite. On the other hand a more severe thermal treatment affects cost of material production, and material mechanical stability. Biochar from thermal pyrolysis, in fact, needs to be compressed into briquettes in order to obtain a material able to resist to handling operations inside the steel factory, avoiding the dispersion of very reactive powders during charging operation. Regarding the cost, a char market for steelmaking sector does not exist, even if costs analysis available in literature [4] reports a price still higher respect fossil coal (in the range 300-500 €/t).
In the ongoing RFCS project, (BIOCHAR FOR A SUSTAINABLE EAF STEEL PRODUCTION - GREENEAF2 - Grant Agreement Number RFSP-CT-2014-00003) an EAF utilization of biochar is foreseen for both injection (to promote slag foaming) and charging in the basket. In the project, three research centers are involved (Centro Sviluppo Materials, that is the coordinator, University of Aachen, and Imperial College, and three industrial partners, Ferriere Nord, Marhienutte and Georgemarienhutte). LCA study and economical evaluations are also included.
This paper is focused on the industrial activity carried out at Ferriere Nord, where utilization of charge material in the basket has been tested. In this new experimental activity, following aspects have been investigated:

- Long trials, in order to check the stability of the process
- Utilization of biochar with different characteristics (and lower production price), to check the sensitivity of the process to the different materials characteristics

The used material is produced by biomass torrefaction. Torrefaction is a relatively easy process, which differs from thermal pyrolysis for the process temperature, that is significantly lower (300-350 °C). Material produced from torrefaction has the following interesting characteristics:

- Market price is in general lower than already tested biochar (market price are in the range 200-300 €/t)
- Material densification is obtained very easily under the effect of pressure, without binding agent and obtained briquettes are very stable comparing to briquettes obtained with high temperature materials
- Torrefied biomass is hydrophobic

In what follows, description of materials characteristics and carried out industrial at Ferriere Nord tests are discussed.

EXPERIMENTAL ACTIVITY

The activity is focused on EAF utilization of biochar as charge material. The used material is a commercial biochar product delivered by TORR COAL company. Table 1 shows the characteristics of the used material; in the same table are also reported characteristics of:

- the standard anthracite currently used in the EAF
- the biochar already used successfully in the past industrial experimentation [1,2].

The char used in the current activity differs for many aspects respect to standard material and char from thermal pyrolysis:

- Higher amount of volatile matter (lower fixed carbon)
- Higher hydrogen content
- Higher density
- Higher mechanical stability of briquetted material
- Hydrophobic

These differences derive from the characteristics of the torrefaction production process. Torrefaction process is carried out at relatively low temperature (300-350°C), while thermal pyrolysis is carried out at higher temperatures (800°C). This fact determines for torrefied biomass a lower degree of carbonization of the material (higher content of volatile matter remains into the produce char). The residual presence of hydrocarbons of high molecular weight determines the hydrophobic characteristics of the material, while in general char from pyrolysed biomass is
Hydrophilic. For this reason storage of the torrefied material does not require special care.
Moreover, the mechanical stability of the obtained briquettes of biochar from torrefaction reduces the dispersion of powers during material handling into the steel factory.

Tab. 1 - Characteristics of standard charge material (anthracite), biochar used for industrial trials (torr coal) and material used for test carried out in past activity [1,2].

Component	Standard Anthracite	Biochar from TORR COAL	Biochar from thermal pyrolysis
C (%)	>80	55-75	70
H (%)	2	6	4
S (%)	<1,5	<0,14	0.05
Cl (%)	-	<0,05	<0,05
Ash (%)	<20	<4	10
Moisture (%)	<1	3-8	6
Volatile matter (%)	<10	50-70	25
Density kg/m^3	900	600	450

The scope of this activity is to carry out a long term experimentation, using a biomass derived material. In the first experimentation [1] the basic idea was to use a material as much as possible similar to the fossil coal. In this activity the main goal is to run the EAF process regularly, even in presence of a reduction and carburizing agent with different properties respect to the fossil.
Pittini steel factory is equipped with an EAF of 140 tons capacity, with three scrap buckets charging. Globally 1100 kg per heat of anthracite are used.
Being the selected char a new material, the experimentation has been divided into three steps:

1. A first sequence of six heats has been carried out just to check the first feasibility of material utilization; the goal was to have a qualitative evaluation of the suitability of the material in the EAF process
2. The second longer sequence has been carried out to optimize the EAF charging operation and to have e first check of process parameters (steel and slag analysis, productivity and consumption)
3. The third trial has been carried out to check the EAF operating parameters on one day production; supplementary stack analysis to check also the impact on environmental performances (mainly dust, dioxins and polycyclic aromatic compounds emissions at stack) have been also performed.

Table 2 reports the summary of performed industrial trials. In the test 1, 500 kg of char have been charged on the first basket. Char was charged on the bottom of the first basket. Flame emissions, larger than standard practice, were observed during charging operation. In spite of flame emission, the EAF process run quite regularly. The flame emission was attributed to the presence of high volatile matter fraction and also on the production and further dispersion of powders under the effect of pressure of scrap on char briquettes. The positioning of char on the top of the basket avoided the dispersion of dust during charging but caused the flame formation once the basket is opened on the top of the steel bath, due to the fact the char start reacting rapidly before getting in contact with steel bath.

Tab. 2 - Performed industrial trials with biochar

Test number (N)	Number of Heats (N)	Charged char per heat (kg)	Goal of the test
1	6	500	First feasibility
2	12	1000	Optimization of EAF charging practice
3	>20	1000	Long trial, collection of operating parameters and supplementary off gas analysis. Test to be performed

Position of the char briquettes into the scrap basket has been optimized through the test 2.
The charging practice optimized was:

- Positioning of 10-15 tons of scrap on the bottom of the basket (about 1 m)
- Positioning of a layer of fine scrap
- Positioning of char briquettes
- Positioning of a layer of fine scrap
- Filling the basket with scrap according to the regular basket management up to the capacity of 40-50 tons

With this optimization of basket management a significant reduction of flame emission during charging was observed.

RESULTS

The tests 1 and 2 had the main objective to check feasibility of utilization of biochar from torrefaction and to optimize the charging operation, which is a fundamental step in the EAF process. Some process parameters have been collected just to have a first rough idea of the furnace running conditions before the long term trial.
Table 3 reports the variation of four main process indicators (productivity, power-on time, electrical consumption and O_2 consumption) of the test heats respect five subsequent standard heats.

Tab. 3 - Plant indexes comparing standard heats with biochar

Test N.	Productivity	Power-on	Electric consumption	O_2 consumption
1	-1.27%	0.18%	-0.44%	-1.54%
2	1.02%	0.02%	-1.43%	-0.53%

Table 4 reports the average FeO content of the slag and the C content of the steel (at tapping) of three heats from test N. 1 and the subsequent standard heats. The oscillation of concentration values is in the range of what observed during regular EAF running.

Tab. 4 - FeO content of the slag and the C content of the steel (at tapping) of three heats from test 1 and three standard heats

Test 1	FeO (%)	C (%)
With biochar	29.1	0.170
standard	30.5	0.175

The carbon concentration in the steel at tapping is relatively constant (average C concentration calculated over eleven heats is 0.207% with standard deviation of 0.007%)
Trend of carbon concentration for the sequence of eleven heats is (test 2) reported in Figure 1.

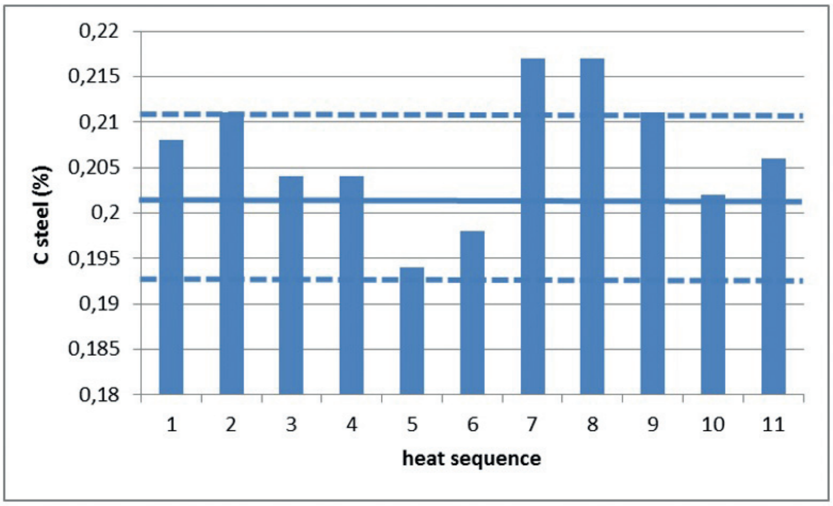

Fig. 1 - Trend of C concentration in the steel at tapping, test 2.

In the figure are reported also the average value of standard heats previous eleven standard heats and the standard deviation. The oscillation of the C concentration is in the range of standard operations.
The main process aspect outlined during the first two experimental campaign was the increase of fumes temperature. This fact is attributed to the high presence of hydrocarbons formed during devolatilization from charged biochar.
A better quantification of this phenomena will be given through planned longer test in table 1 (Test 3).
The best advantage in biochar utilization in EAF would be obtained with optimization of utilization of fumes energy, acting on:

- Improvement of EAF postcombustion and energy transfer to the bath
- Utilization of technologies of energy recovery from EAF off gass [7]

The environmental impacts of the usage of biochar during electric steelmaking in the EAF were investigated by a Life Cycle Assessment (LCA) study. The LCA study is currently at starting stage and will be presented in the Report of the Project.
In general a LCA study is divided into four phases:

- Goal and scope definition
- Life cycle inventory
- Life cycle impact assessment
- Interpretation

The LCA studies about the utilization of biochar in the EAF were carried out to compare the usage of fossil and biogenic carbon carriers. Therefore the modeling is focused on the melting process in the EAF without any upstream and downstream processes to calculate the CO_2 intensity of the electric steel production.
The Functional Unit (FU) was determined as 1 ton of liquid steel. The determination of the system boundary is based on the gate-to-gate approach.
The economical evaluations about biochar utilization are still onoing inside the RFCS project. The starting point is that an assessed market of biochar for steelmaking utilization (which means high volumes of production, low grade of input biomass) is not present. So the economical evaluation takes into account the purposely designed torrefation plant, for an hypothetical production of 10.000 ton of biochar per year
The torrefied material has following advantages:

- lower price respect to pyrolised materials (lower temperature process, and relatively easy plant configuration, see Figure 28)
- Hydrophobic
- Easily densified into briquettes without addition of bindings

On the other hand, the torrefied biomass has high volatile matter content, but industrial trials demonstrated that operating practice can be adjusted.
The torrefied biomass has a current market price in the range 250-350 €/t.

A first estimation carried out in the ongoing project report as first hypothesis of a tailored biochar production, the following cost figure (table 2). Table reports the simulated final price of torrefied biochar according to three different price of biomass.
On the basis of the costs figure of table 21, final char cost as a function of biomass costs have been simulated (Table 5).

Tab. 5 - Final price of biochar according to three different price of starting biomass

biomass cost €/t	torr char €/t
70	310
50	244
15	104

The complete economical evaluation of biochar utilization will be more precise after the longer trials, which would permit to better estimate the EAF energetic performance
First evaluation, in any case confirms that price can be competitive with col in case of utilization of low grade biomass. Size scale effect, and utilization of low grade biomass [6], which determines more than 60% of final cost of char production, would lead to a significant cost reduction, competitive with fossil coal.

CONCLUSIONS

Fossil sources are extensively used in the Electric Arc Furnaces (EAF), to provide energy (in addition to electricity) or in general for process needs (to provide carbon to steel bath and promote slag foaming which improves furnace energy efficiency.
This paper describer the industrial long term trials with biochar: series of industrial tests have been carried out using biochar as charge material, (about 1 ton per heat) replacing fossil coal.
The results of industrial long term trials confirmed the possibility to use the biochar as charge material, without significant modification in steel and slag analysis.
Better advantages will be obtained through the efficient utilization of the energy deriving from hydrocarbons emitted by biochar during EAF operation. The efficient utilization of such energetic potential require optimization of EAF postcombustion and energy recovery from offgas.
Market price of torrefied biomass is in the range 250-350 €/t. the price higher than fossil coal. Preliminary economical evaluation, considering a tailored production of biochar starting from low grade biomass showed that a price competitive with fossil coal can be obtained with torrefied material.

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