

HIPOTRODE: A New Generation Electrode for Ecological and Economical Steelmaking

D. Capodilupo, M. Paura, E Repetto

The productivity and efficiency of electric arc furnaces (EAF) can be increased if the arc voltage is raised without extending its length and maintaining electric current constant. The aim of the project, conducted with the ECSC financial support, was to develop a technology for injection of fossil fuels such as gas and/or oil through hollow graphite electrodes into the arcing zone of EAF plants with the purpose of reducing the arc length. Experimental tests with gaseous hydrocarbons and nitrogen or oil introduced through a hollow electrode in the arcing zone by means of a lance have been carried out at Centro Sviluppo Materiali in a 1.9 MVA DC pilot furnace. In the most successful tests, gas was injected by means of a water-cooled lance, that was positioned very close to the electrode tip. This water-cooled lance worked into the electrode axial hole and its tip was located as far as 350 mm from the electrode.

Using this lance, both methane and oil were injected in the arcing zone, without any clogging after 2 hours' operation. Assuming a max. arc length of 175 mm as a reference, as measured by a special test, the arc length was decreased by 15% to 60% depending on fluid injection and process conditions. Arc voltage and current were maintained constant. This result is very significant for an industrial application of this technology to DC furnaces, with special reference to stainless steelmaking where foamy slag generation is very critical. Other possible applications are envisaged, e.g.: the treatment of EAF dusts and other compatible wastes with a plasma-arc furnace and the production of flat products with a hybrid reactor without providing over-quality and at low CO₂ emissions.

Parole chiave: produzione, acciaio, ecologia, gas, elettrochimica, riciclaggio

INTRODUCTION

The characteristics of the electric arc in the EAF are still the factors that most prevent specific electric power from being raised, as expressed in kVA/t, and productivity from growing.

Specific electric power can be increased by incrementing secondary voltage and/or electric current intensity.

Increasing secondary voltage will soon be possible in agreement with IEC directive 519-4 whereby it can be raised up to 1500 V for AC furnaces and 2100 V for DC furnaces.

However, the resulting arc extension is expected to increase radiation heat onto the furnace walls and bring up wear refractory, unless an efficient practice of foaming slag can be combined with electrode control.

To increase current intensity – particularly for DC furnaces – large-diameter electrodes should be used up to the present limit of 800 mm that are normally sold at an extra cost, due to the use of selected raw materials (low-expansion oil coke) and longer manufacturing times.

With these technologic restrictions, the only possible way to increase furnace productivity involves replacing a portion of electric energy with injected oxygen and fossil fuel.

Electric arc is also the main responsible for NO_x emissions into the atmosphere. It also promotes nitrogen pick-up in the steel bath, when the furnace is not fully sealed and air can leak in.

To respond to all the above questions, this report suggests to change both the volt-amp characteristics of the plasma arc in order to reduce heat radiations onto the furnace walls while maintaining the same electric parameters, and to change the plasma-arc chemical composition in order to affect the metallurgy of the steel bath and molten slag.

Injecting gas or liquid hydrocarbons through a water-cooled lance running inside a hollow electrode seems to be a possible way to hit both targets. It also provides the advantage of reducing graphite consumption below the present limits (1 kg/t) that are considered as the minimum obtainable.

THE ELECTRIC ARC

The electric arc strikes in a ionised atmosphere, commonly called plasma or plasma-arc area. The latter is composed of an aggregate of electrically charged particles whose ionisation is given by the ratio of charged particles and the total number of particles in a given volume.

If molecular gases are introduced into the arcing zone, then their ionisation and electric conductivity change.

Experimental tests [1] have shown that when molecular gases like N₂, CO₂, CH₄, C₂H₆, C₃H₈ are introduced in a plasma-arc area whose atmosphere was originally composed of pure argon and the arc current and length are kept steady, power increases depending on the gas injected.

This raise in power is caused by the voltage increase that is required in order to keep the arc current and length unchanged.

The ratio of power increase and quantity of injected gas is linear for all molecular gases used, although the effect of hydrocarbons is much more remarkable than the effect of N₂ and CO₂, see Fig. 1:

The slope of lines representing the percentage increase in power versus the percentage of molecular gas injects is:

- 20.9% for C₃H₈;
- 12.1% for C₂H₆;
- 10.9% for CH₄;
- 3.5% for CO₂;
- 0.67% for N₂.

The tests were carried out with steel melts of 150 kg in a pilot plasma furnace [1] equipped with two plasma torches containing thoria-doped tungsten electrodes.

D. Capodilupo, M. Paura, E Repetto
Centro Sviluppo Materiali S.p.A. - Rome (ITALY)

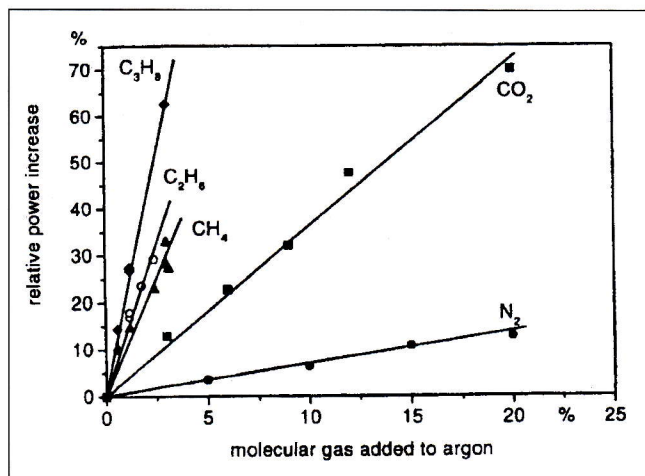


Fig. 1: Power increase in argon plasma arcs burning on liquid steel due to the addition of molecular gases

Fig. 1: Aumento di potenza in plasma d'argon operante su bagno d'acciaio, dovuto all'apporto di gas molecolari.

The torches were operated in the AC mode with transferred arcs and without a bottom electrode. Arc currents were kept constant at 1350 A, arc lengths at 240 mm each, and plasma gas flow-rates at 9 m³ STP Ar/h per torch.

Liquid steel was exposed to molecular gases for 60 to 80 min. Melt samples were taken every 20 min.

For pure argon operation, when the furnace atmosphere was > 99% Ar, arc voltages were in the range 80 to 85 V. Molecular gases were added to the furnace atmosphere from the periphery.

The significant effect of hydrocarbons, on the electric parameters of the arcing zone and the technological chance to increase the ratio of arc power and length at equal electrical values, have induced CSM to start a research on the development of a technique for the injection of liquid (oil) or gaseous (methane) hydrocarbons through a hollow electrode.

INJECTION OF FLUIDS THROUGH A HOLLOW ELECTRODE

The target of CSM tests was to study how injecting fluids and typically hydrocarbons through a hollow electrode affects the volt-amp characteristics of the plasma-arc and to measure the metallurgical reactions in the steel bath and graphite electrode consumption.

Tests with single-electrode furnace

The injection technique by means of a hollow electrode was tested in a single-electrode DC pilot furnace equipped with a 1.9 MVA power unit, installed at Acciai Speciali Terni (AST) steelworks.

The furnace in Fig. 2 is equipped with a 250 mm diam. hollow electrode.

Standard equipments, which measured electric parameters, the flow of fluids through the hollow electrode and the chemical analysis of exhausted gases, were completed with an encoder that can detect the position of the electrode arm and assess, with good approximation, the distance between the electrode tip and bath surface. The idea was to measure how the electric arc length changes when hydrocarbons are injected through the hollow electrode, keeping electric parameters (P, V, I) unchanged.

Various tests have been conducted in the above pilot furnace, using nitrogen, methane and oil. While the starting injecting tool was a non-refrigerated carbon steel lance, later it was replaced by a water-cooled lance, running inside the hollow electrode.

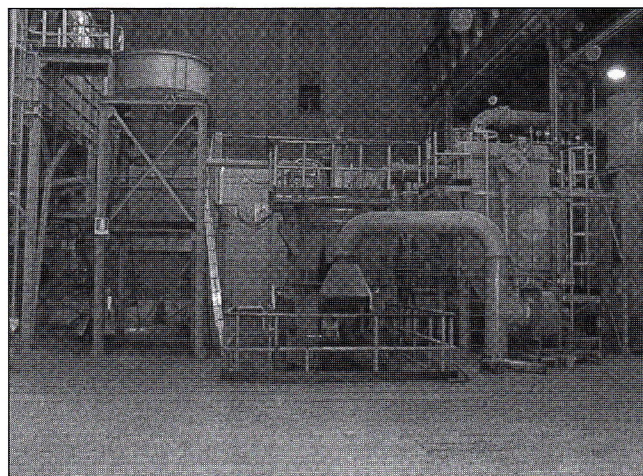


Fig. 2: Single-electrode DC arc furnace

Fig. 2: Forno monolettrodo in CC.

Injection of gaseous hydrocarbons (methane)

A non refrigerated carbon steel lance was used in the early tests with methane injection. The lance tip was kept at a distance of approx. 2 m from the electrode tip in order to avoid the damages caused by high temperature.

Although the electric arc had shortened soon after the beginning of the test, after a few minutes the electrode hole clogged because of the build-up of a substance containing approx. 92% of carbon.

This substance is the by-product of methane cracking, a reaction started before methane had reached the arcing zone. The disposable lance was then replaced with a water-cooled lance of 40 mm in diameter that was used to inject gas next to the electrode tip and avoid any chemical and physical alterations of gas before it could get to the arcing zone.

The device is composed of a graphite hollow electrode containing a water-cooled lance. It is called HIPOTRODE (HIGH POWER electRODE) [2] and its expected applications are mostly for UHP furnaces.

Tests lasted progressively longer up to 2 hours and no clogging was ever observed.

In the 2-hours test (Fig. 3) methane was injected at 15 Nm³/h flow-rate and at 2 bar pressure. The lance nozzle was kept constantly at approx. 470 mm distance from the electrode tip.

Fig. 3 also shows the electric parameters P_{arc} and V (basically constant throughout the test and equal to 450 kW and 90 V respectively) and the position of the electrode arm. Current intensity was also kept steadily at 5000 A.

Upon methane injection, the electrode arm lowered by approx. 50 mm and the electric arc shortened correspondingly. In percentage, it means 30%, being the arc length approx. 175 mm before gas injection.

During the test, the electrode arm rose progressively as the level of steel bath increased due to charge-mix materials including EAF dusts, see par. 5.

When methane injection was interrupted, the electric arc increased suddenly by the same quantity as the initial shortening.

Electrode consumption

The shape of the electrode after test was compared with its starting shape (Fig. 4).

It can be observed that the electrode tip is little consumed due to the shielding effect of the by-products (hydrogen and ultra-fine carbon particles) of methane molecular demolition.

Fig. 3: Electric parameters concerning the methane injection test

Fig. 3: Parametri elettrici in prove con iniezione di metano.

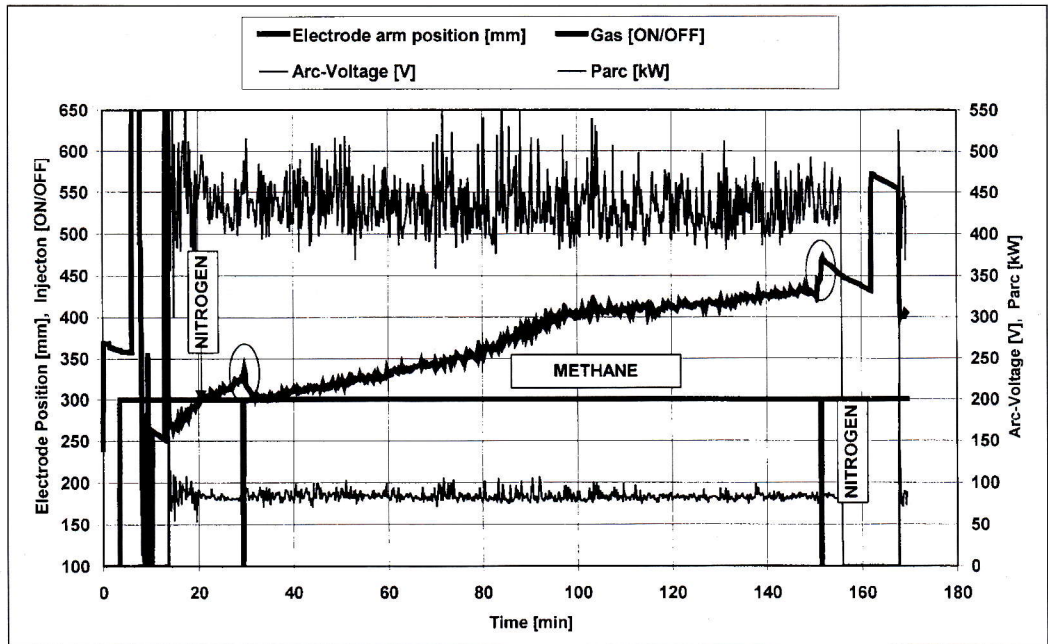
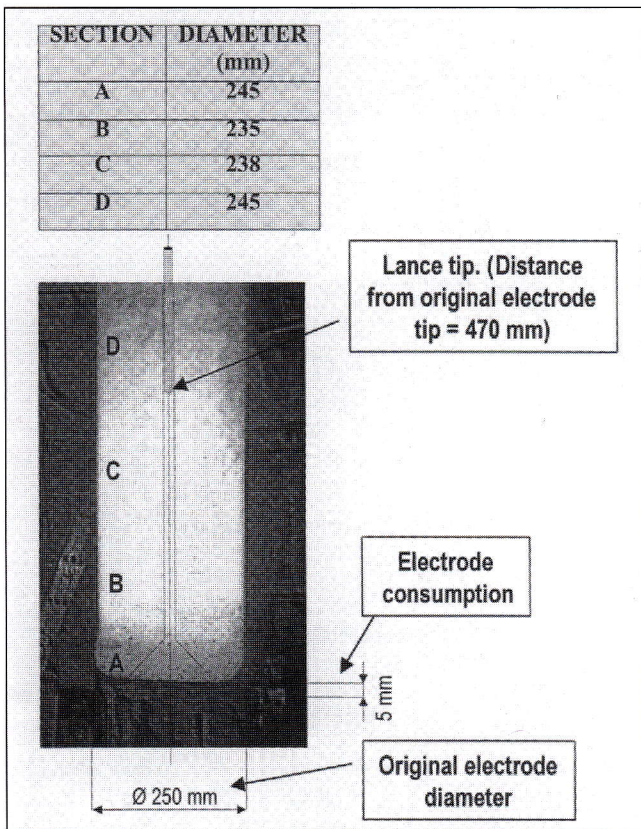


Fig. 4: Shape of the electrode tip at the end of test with methane injection

Fig. 4: Profilo della punta dell'elettrodo al termine di una prova con iniezione di metano.



STEEL CHEMICAL ANALYSIS

ELEMENT	METHANE INJECTION	
	BEFORE	AFTER
C	1.79 %	2.60 %
Si	0.24 %	1.72 %
S	0.130 %	0.100 %
Mn	0.28 %	0.47 %
Cr	1.12 %	1.08 %
Ni	0.24 %	0.27 %
N2	210 ppm	150 ppm

Tab. 1 : Chemical composition of steel before and after tests with methane injection

Tab. 1: Composizione chimica dell'acciaio prima e dopo prove con iniezione di metano.

Contrary to what happens with conventional electrodes, wear was greater above the tip because of oxidation caused by furnace atmosphere. Oxidation consumption is asymmetrical around the electrode circumference, and this is due to the different fluid-dynamics that is induced around the electrode by the off-gas exhaustion plant.

Metallurgical aspects

Liquid steel was sampled and analysed before and after methane injection to measure any metallurgical effects of gas injection into the plasma-arc area.

Results of chemical analysis are reported in the following Tab. 1.

The chemical analysis of steel shows a reducing effect that has also involved silicon. This reduction is due to the redu-

cing environment that is created by methane dissolution by-products, both of which having strong reducing effects at the plasma-arc temperature.

It was also observed that this reducing effect provokes steel desulphurisation. The presence of hydrogen, that tends to create nitrogen-stable compounds, involves denitration of the steel bath, as shown in the above table.

Injection of fluid hydrocarbons (paraffin oil)

This test was conducted using a water-cooled lance, equipped with a copper nozzle that provided a coherent and linear oil jet.

In the test reported in Fig. 5, oil injection was carried out in several steps at a flow rate of approx. 30 kg/h at 2 bar pressure, in order to check univocally the correlation between electric arc behaviour and the presence of oil in the arcing zone. The lance nozzle was positioned around 450 mm from the electrode tip.

Fig. 5 reports the electric parameters P_{arc} and V that were kept steady throughout the test at 240 kW and 160 V respectively, and the position of the electrode arm. Also current intensity was kept constant at approx. 1500 A. The test lasted approx. 40 minutes in all.

At the beginning of every injection operation, the electrode arm has lowered by approx. 60 mm corresponding to an equal arc shortening. If the starting arch length of approx.

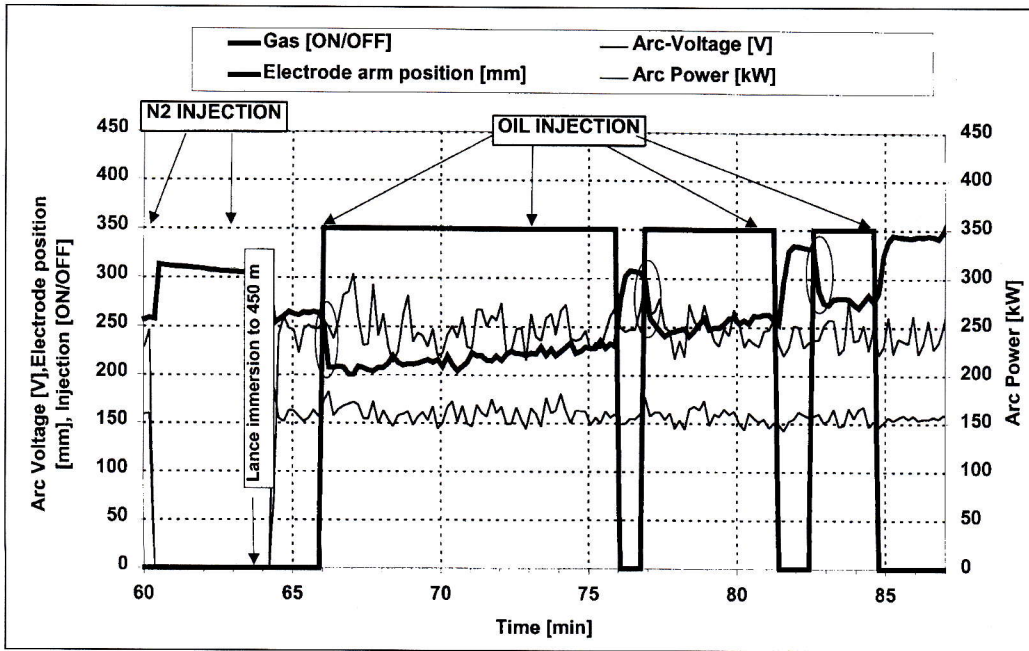


Fig. 5: Electrical parameters concerning the oil injection test

Fig. 5: Parametri elettrici in prove con iniezione di olio.

175 mm – as assessed in a past test – is taken for reference, than this shortening equals 35%.

At the end of the oil injection, the electric arc extended suddenly by the same amount as the initial shortening. No clogging has been observed during this test as well as in the following ones, that have lasted progressively longer up to 2 hours.

Electrode consumption

In the above operating conditions, after oil injection the electrode tip took up an intermediate shape between the one in fig. 4 and the one of a conventional electrode. Interaction between oil and molten slag created a solid layer of approx. 1 mm in thickness around the electrode immediately above its tip, that was composed of more than 90% of MgO and SiO₂, coming from the slag, as shown in Tab. 2.

CHEMICAL ANALYSIS OF THE SOLID LAYER

C	0.90 %
S	0.074 %
SiO ₂	22.91 %
MnO	0.60 %
Cr ₂ O ₃	0.26 %
Al ₂ O ₃	4.11 %
CaO	1.26 %
MgO	69.21 %
Fe _{tot}	0.70 %
ZnO	0.10 %
Pb ₃ O ₄	0.010 %

Tab. 2: Chemical composition of the solid layer on the electrode

Tab. 2: Composizione chimica dello strato solido attorno all'elettrodo.

Metallurgical aspects

Liquid steel and slag were sampled and analysed before and after oil injection in order to measure its effects. Results of chemical analysis of samples are reported in the following Tab. 3 and 4. The chemical analysis of slag shows a significant reducing effect in all cases, that has also involved silicon. From the steel chemical composition, such reduction is basically due to oil injection because no decrease in carbon content was observed. Moreover, denitration and desulphuration have also occurred.

SLAG CHEMICAL ANALYSIS

SUBSTANCE	OIL INJECTION	
	BEFORE	AFTER
C	0.016 %	0.015 %
S	0.37 %	0.26 %
SiO ₂	33.44 %	21.94 %
Cr ₂ O ₃	0.16 %	0.12 %
Al ₂ O ₃	21.67 %	28.85 %
CaO	24.10 %	21.33 %
MgO	17.80 %	25.15 %
Fe _{tot}	0.47 %	2.37 %

Tab. 3: Chemical composition of slag before and after test with oil injection

Tab. 3: Composizione chimica della scoria prima e dopo l'iniezione di olio.

STEEL CHEMICAL ANALYSIS

SUBSTANCE	OIL INJECTION	
	BEFORE	AFTER
C	2.27 %	2.23 %
Si	1.05 %	2.24 %
S	0.092 %	0.029 %
Mn	0.52 %	0.65 %
Cr	0.72 %	0.77 %
Ni	0.25 %	0.25 %
N2	180 ppm	110 ppm

Tab. 4: Chemical composition of steel before and after test with oil injection

Tab. 4: Composizione chimica dell'acciaio prima e dopo l'iniezione di olio.

Discussion of results

The tests conducted with oil and methane injection have proved consistent as regards electric arc behaviour and metallurgical effects of hydrocarbons in the arcing zone.

As electrode clogging was solved using a water-cooled lance, it can be considered that the molecules of oil and methane injected through the hollow electrode reach the arcing zone with unchanged characteristics, and they dissolve into their basic components (mainly C and H) because of the very high temperatures in the plasma-arc area.

Plasma resistivity changes depending on the dissolution of molecules into their atomic components at gaseous state and on ionisation processes [1].

In particular, the presence of hydrogen in the atmosphere of the arcing zone increases both its resistivity and arc voltage drop [3].

It means that if arc current and length are kept constant, there will be an increase in arc power, and if all the electric parameters are kept steady, then the electric arc length will decrease as in the above tests.

Moreover, since hydrogen is a reducing element, it combines with oxygen and prevents other oxides from rising. It also tends to form N-H connections with nitrogen [4].

These characteristics are in line with the metallurgical results of CSM tests.

Inner and surface temperature of the HIPOTRODE

The water-cooled lance running inside the hollow electrode, that typically keeps at a temperature of 20°C, greatly lowers the inner temperature of the electrode.

A standard heat model was worked out that can calculate the distribution of temperature in a conventional electrode and in the HIPOTRODE at either steady or unsteady state at flat bath conditions.

Heat flows from the electrode to the lance and furnace environment were taken into consideration in the model, leaving aside any possible effects of hydrocarbons on the electrode tip in the arcing zone.

The following parameters were introduced in the heat model: Tab. 5.

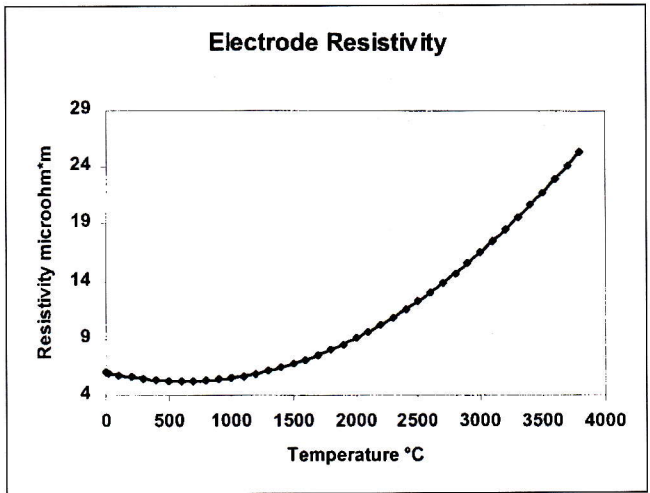


Fig. 6: Electrode resistivity according to temperature

Fig. 6: Resistività dell'elettrodo in funzione della temperatura.

PARAMETER	SIZE	UNIT
Electrode outer diameter	250	mm
Hole diameter	46	mm
Electrode length	3700	mm
Electrode density	1840	kg/m ³
Arc power	225	kW
Arc current	1500	A
Arc voltage	150	V
Furnace diameter	900	mm

Tab. 5 - Main parameters adopted in the model calculation

Tab. 5: Parametri principali impiegati nel calcolo modellistico.

Background conditions were set as follows:

- Variable temperature inside the furnace, with a linear trend from 1600°C at bath level to 1200°C at the furnace roof;
- 7% of arc energy radiated towards the electrode tip [5];
- temperature of the electrode outside the furnace equal to 200°C;
- electrode resistivity, a function of temperature, is reported in Fig. 6.

Fig. 7 reports the model results. When the electrodes work at steady state, the HIPOTRODE shows remarkably lower inner and surface temperatures than in a conventional electrode.

The time trend of average surface temperature for both electrodes was calculated starting from cool electrode condition up to steady state.

Fig. 8 shows that at steady state the surface temperature of

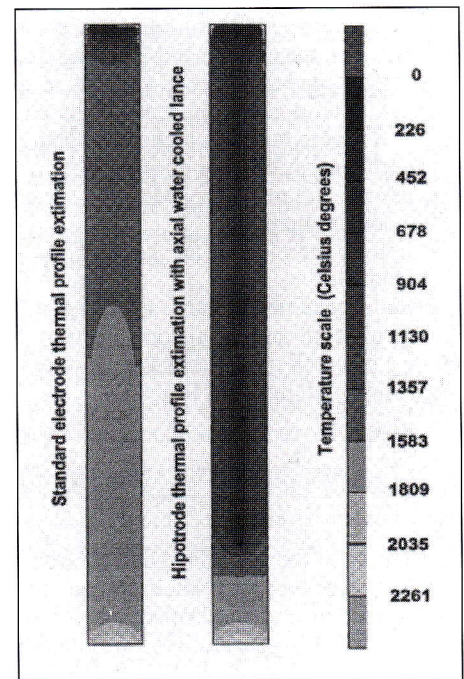


Fig. 7: Temperatures calculated by the heat model at steady state

Fig. 7: Temperatura calcolata con modello termico in condizione di regime.

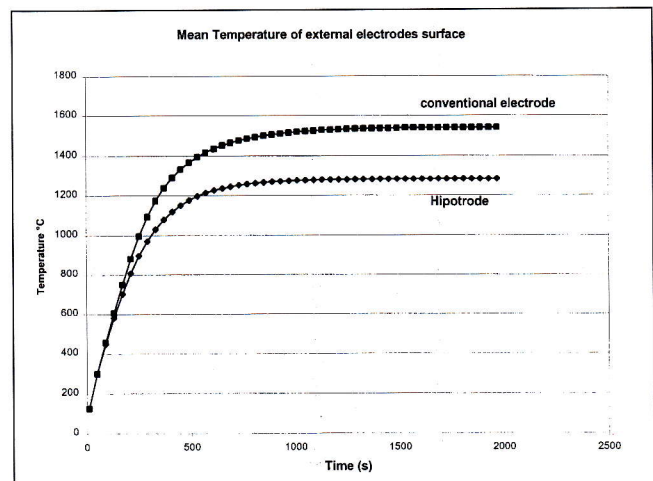


Fig. 8: Trend of average surface temperature in a HIPOTRODE and in a conventional electrode up to steady state

Fig. 8: Andamento della temperatura media superficiale nell'HIPOTRODE e nell'elettrodo convenzionale fino a condizioni di regime.

the HIPOTRODE is at least 200°C lower than the one of a conventional electrode, and this gap gets greater for the inner temperature.

Being lower, the HIPOTRODE temperature causes less oxidation consumption and lower electric resistivity, whose dependency on temperature was already shown in Fig. 6.

Lower resistivity means that electrodes can carry more electric current, although their diameter remains unchanged. This result is especially important for DC furnaces, where current carrying capacity is restricted by electrode diameter (≤ 800 mm according to the present technology).

NEW ECSC PROJECT FOR DEMONSTRATION PLANT

Tests have been carried out under the ECSC project that has assured its funding.

Following the results obtained from this research, a new technological development has been launched to be carried out at demonstration plant level.

Tests for this new pilot plant where methane, oil or even emulsion injections will be tested for long periods, and the execution of application tests for methane injection in two industrial DC furnaces: the one of 110 MV being devoted to carbon steel manufacture and the other of 45 MVA to special steels.

The target is to check present results on an industrial scale and to measure how this technology can affect:

- electric energy consumption
- electrode and refractory wear
- furnace productivity
- length of the electric arc keeping the electric parameters unchanged
- metallurgical performances for slag and steel quality

Concerning oil and emulsion injection, the project will include a research on industrial scale only if successful results are achieved in the pilot furnace.

POSSIBLE APPLICATIONS OF HIPOTRODE ON INDUSTRIAL SCALE

Starting from the base design described before, including a hollow electrode and a water-cooled lance equipped with a nozzle for gas and fluid injection in the arcing zone, CMS has worked out other designs with an increasing innovation degree.

Fig. 9 shows the "standard" electrode (a) as compared with the new (b) and (c) designs that stem from the basic project. The latter are composed by two segments, a water-cooled metallic segment at the top and a graphite segment at the bottom, that are joined together both electrically and mechanically by means of a special joint.

Electrode type a) can be applied to DC single-electrode EAFs and especially to those furnaces where – due to charging practices – melting is carried out mainly at flat bath conditions (Consteel, EcoArc, etc.) and the furnace walls are shielded by foaming slag.

AC furnaces are not excluded from this application, provided the presence of three water-cooled lances does not increase operating expenses significantly.

Electrode type b) is based on the injection of anti-oxidising substances from the water-cooled segment onto the electrode surface. The purpose of that is to reduce side electrode consumption further.

Electrode type c) can be applied to metallurgical reactors that – on account of their geometrical shape – require especially long electrodes. If the latter are made fully in graphite, they can be too fragile and exposed to frequent breakouts.

The figure shows the water-cooled segment that has a smaller diameter than the graphite segment. It is equipped with

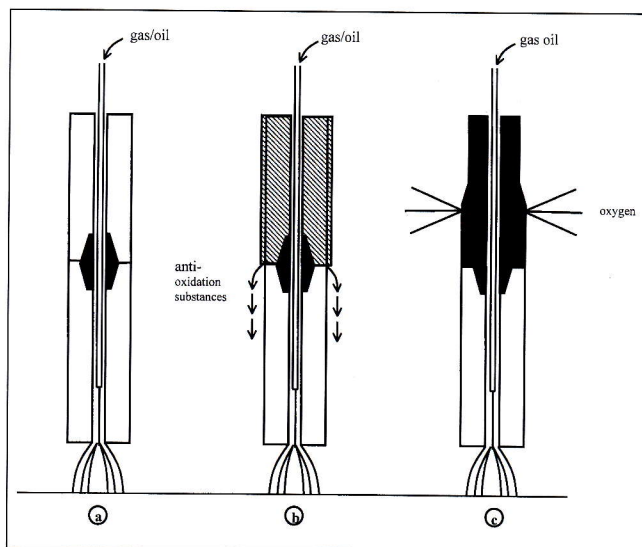


Fig. 9: HIPOTRODE for fluid injection into the plasma-arc area

Fig. 9: HIPOTRODE per iniezioni di fluidi nella zona dell'arco-plasma.

nozzles around its circumference that blow O₂ to promote post-combustion from CO to CO₂ from inside the reactor. The advantage of this practice is to recover heat, which can be reused for scrap preheating.

Before suggesting the application of the HIPOTRODE to the EAF or a hybrid reactor, this design was also tested in a pilot furnace, as described in Fig. 2. Test campaigns were carried out involving the treatment of steelmaking wastes and especially of EAF dust.

The treatment of these wastes according to a CSM technology named Full-Rec (full recovery) includes a pyrometallurgical stage to be conducted in the plasma-arc furnace and a hydrometallurgical stage, for total recovery and upgrading of valuable metals contained in wastes.

CSM has suggested the application of type c) HIPOTRODE to a hybrid reactor called iCSMelt (improved Converter for electrode Steel Making) described later on.

It provides for flexible use of scrap and hot metal in very variable percentages.

The Full-Rec technology for the treatment of compatible wastes

The Full-Rec plant is composed of a single-electrode plasma arc DC furnace (pyrometallurgical section) and a sulphuric-acid hydrometallurgical section downstream.

The pyrometallurgical section

The furnace applies a reducing process to treat steelmaking wastes such as EAF dusts, cutting scale and mill scale containing valuable metals such as Fe, Zn, Cr, Ni, Mn etc. in the form of oxides.

The charge-mix contains these wastes as well as lime and reducing agents.

The plasma-arc process turns the charge-mix into:

- hot metal or ferroalloy (containing chromium and nickel) to be charged back to the EAF for steel manufacture;
- fully inert slag to be sent for dumping, and
- ZnO enriched powder (ZnO > 70%) having a high trading potential.

To fully exploit the potentials of the plasma-arc furnace and reduce treatment costs, a further step is to aggregate these steelmaking by-products with other wastes that arise from industrial processes and end-of-life products, provided their chemical compositions are compatible one another.

Besides adding value to wastes (upgrading) this aggregation hits the target of total material productivity (TMP) and con-

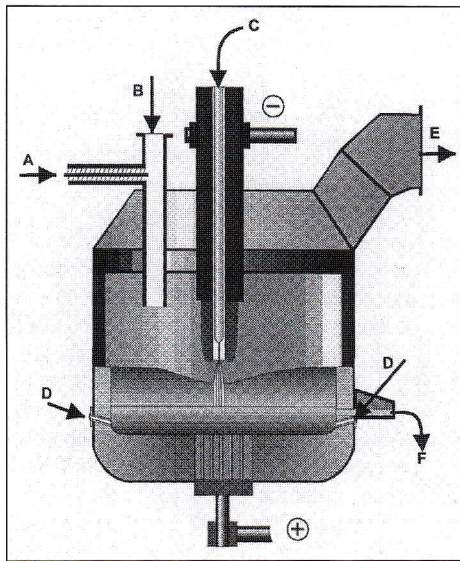


Fig. 10: Sketch of a plasma-arc furnace for compatible waste treatment: A.B.C.D. = EAF dusts, scrap tyres, spent batteries, expired drugs, non-recyclable oils
E = ZnO enriched off-gas
F = slag, ferroalloy

Fig. 10: Schema del forno ad arco-plasma nel trattamento dei rifiuti.

tributes to reducing emissions towards the zero-waste goal. In a CSM survey, a set of compatible by-products and end-of-life products was identified in addition to steelmaking wastes, namely: non-recyclable oils, spent batteries, scrap tyres, etc. The sketch of the pilot plant in Fig. 10 reports several ways to introduce these materials into the furnace according to their physical status: powdery materials are blown under the liquid bath, end-of-life products are dropped into the furnace after crushing or as such, and materials in the form of briquettes or pellets are driven into the furnace by a screw feeder or conveyor belt.

As already mentioned oil can be injected in the arcing zone through the HIPOTRODE in the a) or b) design. Injection of oil (non-recyclable or containing PCB) allows thermal destruction of liquid wastes and improvement of operating conditions to be achieved along with reduction in graphite and refractory consumptions.

Hydrometallurgical section

Based on the principles of total material productivity (TMP), ZnO enriched powders from the plasma-arc furnace

can be reused as a secondary raw material instead of selling them at market prices that are not always profitable. In this case, they would feed a hydro plant, downstream the pyro equipment, to produce metallic zinc. This was the path followed by CSM that, after a technical assessment of the various options available, has developed a sulphuric hydrometallurgical process.

After preliminary laboratory tests, CSM constructed a pilot plant where the sulphuric-acid hydrometallurgical process takes place according to the following steps:

- alkaline washing (to guarantee removal of fluorine and chlorine);
- sulphuric leaching (where both exhausted electrolyte and washed sludge are added);
- coagulant oxidation (this section consists of removing Fe⁺⁺ iron by oxidation into Fe⁺⁺⁺ through ferric hydrate);
- purifying treatment (to eliminate Cu, Cd and Ni), and
- electrolytic cell (to collect metallic Zn of high grade [HG] purity).

Combining the pyro process with the hydro process (downstream) results in a pyro-hydrometallurgical line that is sketched in Fig. 11. The figure shows incoming materials and outgoing products that are fit for the market.

In the industrial version, the pyro-hydro process might also assure the recovery of off-gas heat in order to generate steam or electric energy. This chance is enhanced by continuous charging of wastes and end-of-life products into plasma-arc furnaces that produces high temperature off-gas stream at basically steady flow-rate, which is only interrupted for tapping hole maintenance.

iCSMelt technology

The iCSMelt technology was designed by CSM for the fabrication by the integral route of those products, especially flat, whose chemical composition can be obtained using a percentage of hot metal that can typically range from 30% to 80%.

This would make it possible to meet customer requirements without providing steel overquality, something which occurs with the BOF because it requires 80% to 85% of hot metal as an average.

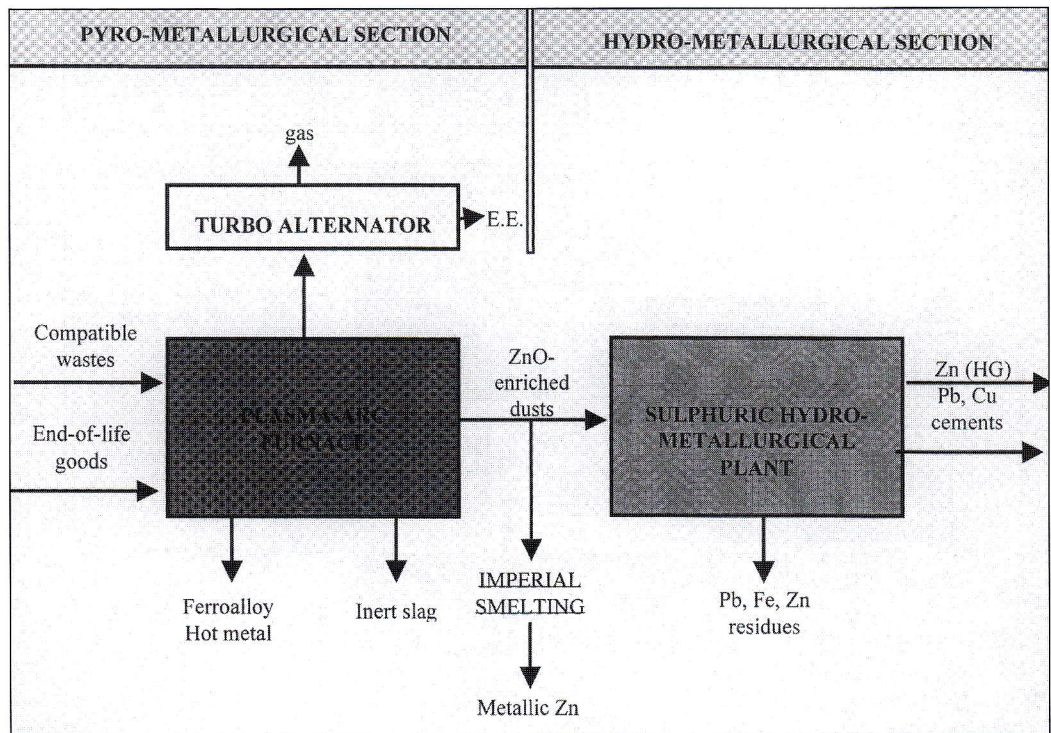


Fig. 11: Electrochemical line for production of ferroalloy, Zn oxide and/or metallic Zn, with energy recovery

Fig. 11: Linea elettrochimica per la produzione di ferroleghhe, ZnO e/o Zn, con recupero di energia.

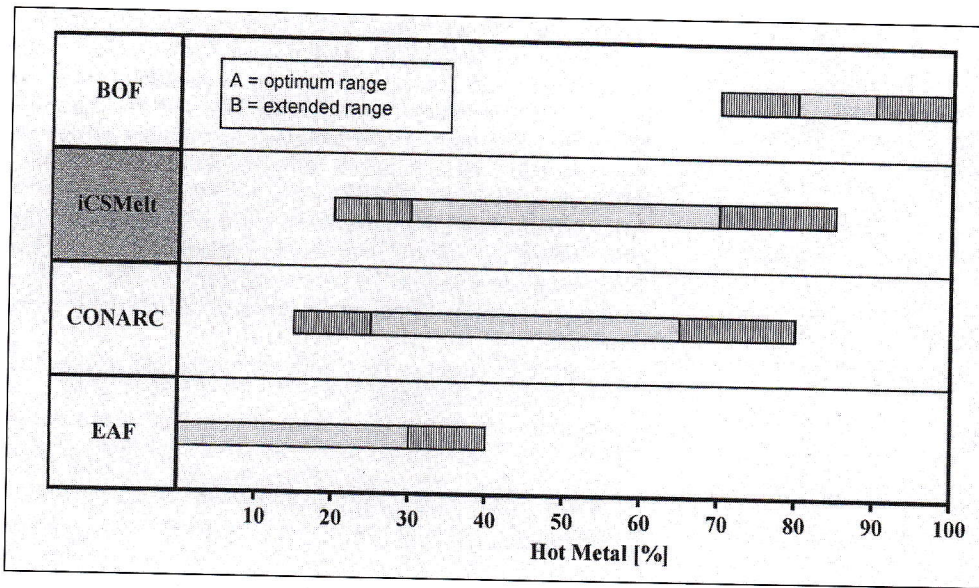


Fig. 12: Reactors working with mixed charge (scrap and hot metal).

Fig. 12: Reattori operanti con carica mista (rottame e ghisa liquida).

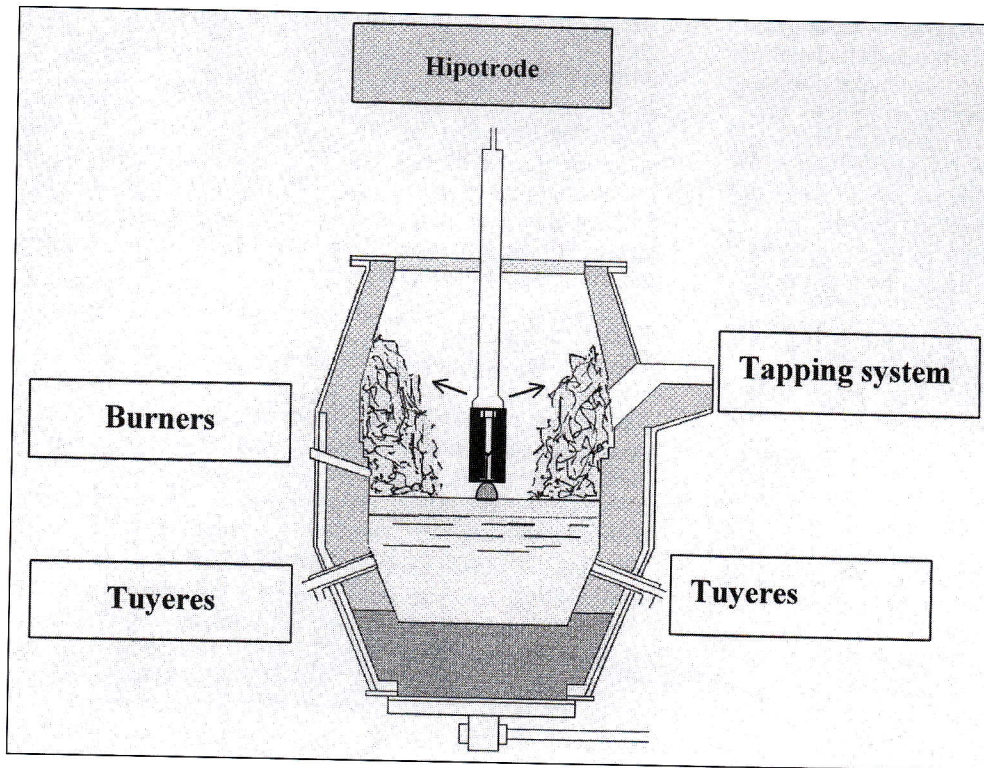


Fig. 13: Sketch of the iCSMelt reactor.

Fig. 13: Schema del reattore iCSMelt.

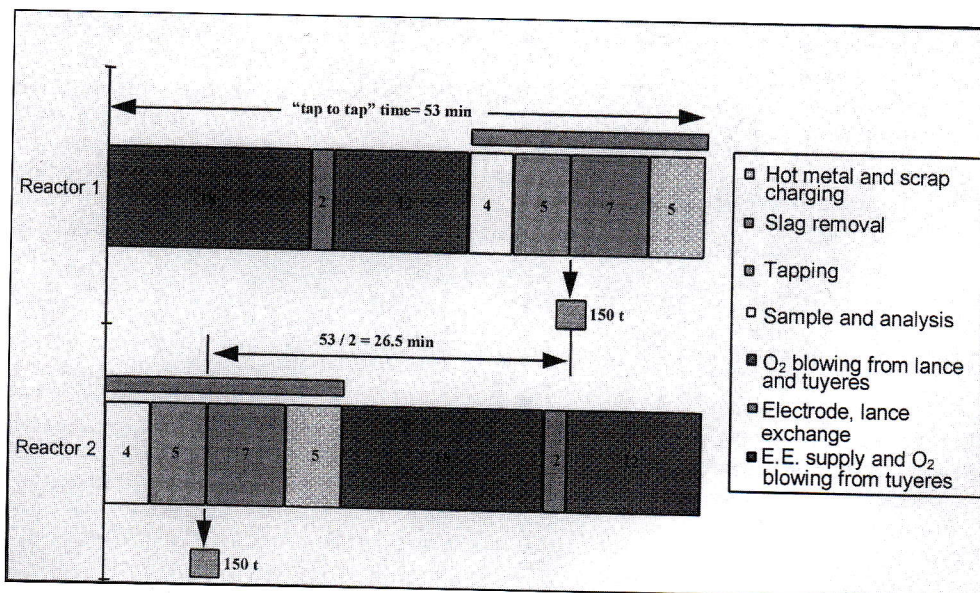


Fig. 14: Heat pattern of iCSMelt hybrid reactor.

Fig. 14: Ciclo operativo dell'iCSMelt nella versione a doppio reattore.

Fig. 12 reports and compares the hot metal ranges that are applied by the EAF, BOF, CONARC and iCSMelt. The latter two are positioned in the middle, covering a range that goes beyond the intrinsic limits of the EAF or BOF.

The iCSMelt reactor showed in Fig. 13 – at the design stage – is equipped with a single electrode, namely a HIPOTRODE type c) and a vertical lance, both of which are interchangeable during the manufacturing process.

Electric current is returned from the bottom of the reactor, where there is a conductive electrode of various designs. Tuyeres and burners combine the functions of the HIPO-TRODE and vertical lance in order to accelerate scrap melting and metallurgical reactions (deC, deSi, deP, etc.).

In order to maximise productivity and optimise DC power supply, it is recommended to apply the iCSMelt reactor in the twin design. The standard heat pattern is shown in Fig. 14.

Starting from reactor no. 1, electric energy is supplied at the beginning of the manufacturing cycle when scrap shields the refractory walls from arc radiations. Then, the electrode is replaced by a lance, which blows O₂ until the set points of Temperature and Carbon content are achieved and the liquid bath is fully molten.

If the values of temperature and chemical composition of the liquid bath fall within the set limits, then steel can be tapped at the end of oxygen blowing and slag is removed. Otherwise, O₂ continues to be blown and/or electric energy to be supplied until the aimed values are achieved. After steel tapping and reactor resetting by means of gunning and fettling – if required – the reactor is recharged with hot metal and scrap and a new cycle starts. The operating practice to supply electric energy before blowing oxygen and the use of high-power low-radiation HIPOTRODE avoid recourse to water-cooled panels, thus decreasing heat losses from the reactor.

The operating cycle of reactor no. 2 is similar, but it is offset with respect to reactor no. 1 by half the length of the tap-to-tap time. If a tap-to-tap time of 53 min. is considered for each reactor, there is a gap of 26.5 min. from one tapping to another. In practice, however, any delay in the operation of one reactor affects the other, therefore a corrective coefficient has been introduced to rise that gap to 32 min.

As a consequence, the output capacity of an iCSMelt plant equipped with 150 t reactors is 281 t/h. If it works 7,200 h/year, then its output capacity is 2 Mt/y of steel.

By optimising the hot metal percentage in the charge-mix according to product requirements, without providing over-quality, it will be possible through the iCSMelt technology

to reduce CO₂ emissions as compared with the BOF route. The curves in Fig. 15 have been drawn by calculating the emissions of CO₂ from the EAF (300-350 kg/t, with or without scrap preheating) and the integral route (2180 kg/t assuming that the BOF charge-mix is composed of 15% scrap and 85% hot metal). These curves can be used to calculate the emissions of CO₂ by iCSMelt with respect to the BOF, depending on the content of hot metal in the charge mix.

In the case of a 2 Mt/y melting shop, CO₂ emissions can drop by 1.5 Mt/y for the iCSMelt as compared with the conventional BOF route, assuming that the two reactors are fed with approx. 50% of scrap and 50% of hot metal as an average.

CONCLUSIONS

A new type of electrode has been developed, composed of a graphite hollow electrode that contains a water-cooled lance working through its axial hole. The lance is equipped with a nozzle on its tip from which gas or liquid substances are injected into the arcing zone. This new type of electrode is called HIPOTRODE (HIgh POWER EleCTRODE).

Tests in a single-electrode DC 1.9 MVA furnace have confirmed that by injecting gas or liquid hydrocarbons into the plasma-arc area it is possible to improve the volt-amp characteristics of the arcing zone and reduce graphite consumption. This practice can also affect the metallurgical characteristics of the steel bath and molten slag and reduce the environmental impact.

Several applications have been envisaged for the HIPOTRODE on industrial scale, namely:

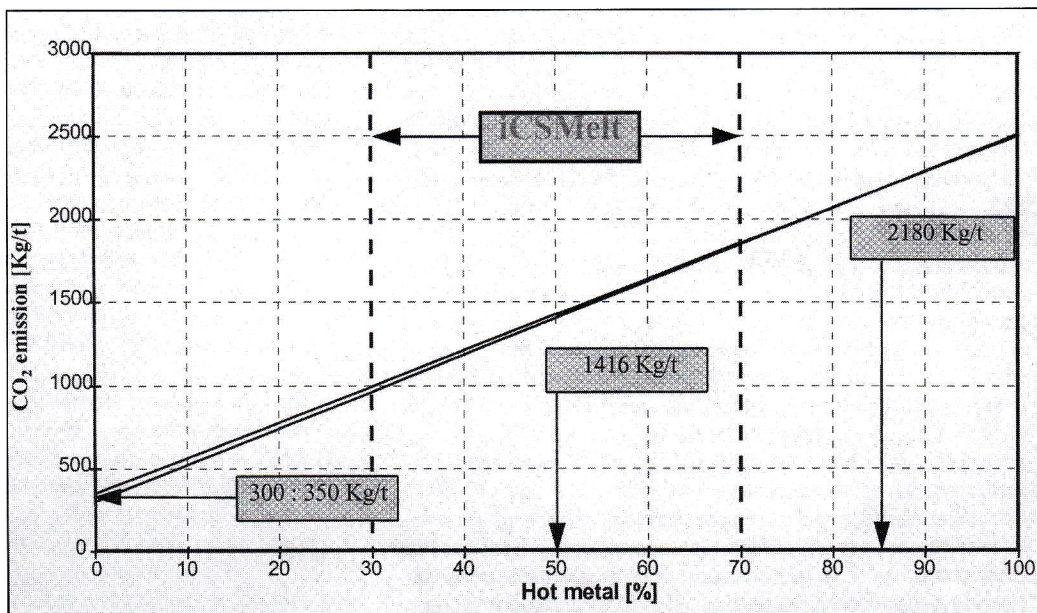
- high-power DC furnaces using the max. secondary voltages (up to 2100 V according to IEC directive 519-4) and standard-diameter graphite electrodes;
- low-heat-loss hybrid reactors that provide high flexibility of the charge-mix and use 30 to 80% of hot metal, a range that is not covered by the EAF or BOF. These reactors will be devoted to the manufacture at low CO₂ emissions, of flat steel products without providing overquality; and
- furnaces for compatible waste treatment, especially EAF dusts, where the injected fluid could be non-recyclable oils.

ACKNOWLEDGEMENT

Financial support granted by ECSC, contract 7210-PR-077, is gratefully acknowledged.

Fig. 15 CO₂ emission from the iCSMelt reactor according to hot metal charge.

Fig. 15: Emissioni di CO₂ da reattore iCSMelt in funzione della ghisa liquida in carica.



BIBLIOGRAPHY

- [1] D. Neuschütz, I. Hahn, D. Spirine "Power increase and metallurgical effects during arc heating of liquid steel due to the addition of molecular gases" - Steel Research 70 (1999) N° 8+9 -pp.309-313
- [2] Patent N° RM2001 A 000 634 "Elettrodo in particolare per forni elettrici ad arco di tipo siderurgico e simili e relativo metodo di esercizio"
- [3] J. Tusek, "Influence of Hydrogen in the Shielding Gas Argon on Productivity of Welding of Austenitic Stainless Steels"
- [4] H. Kiyama and S. Kiyama "Low Energy Hydrogen & Methane Ion Beam Plasmas with Low Electron Temperature" National Institute and Advanced Industrial Science and technology (AIST)
- [5] K. Krüger, A. Ehrbar, K. Timm "Schlackenanbackungen und thermische Verluste eines Drehstromofens" Stahl und Eisen 119 (1998) N° 9, pp 63-67

A B S T R A C T

HIPOTRODE: ELETTRODO DI NUOVA GENERAZIONE NELLA FABBRICAZIONE DELL'ACCIAIO AL FEA

L'introduzione di sostanze nella zona dell'arco, veicolate attraverso il foro assiale nell'elettrodo, è una tecnica già sperimentata in passato sui forni FEA ma che trova limitazioni applicative a causa della progressiva ostruzione del foro, dovuta alle reazioni chimiche che si manifestano nel condotto.

I vantaggi potenziali, specie per i forni in CC, sono quelli di poter elevare la potenza elettrica erogata, di ridurre i consumi di elettrodo, di intervenire sul processo metallurgico senza penalizzare il consumo dei refrattari.

Viene qui presentata una nuova tecnica che evita il fenomeno dell'ostruzione, sviluppata nell'ambito di un progetto CECA multipartner, basata sull'impiego di una lancia raffreddata scorrevole all'interno del foro assiale nell'elettrodo, dotata all'estremità inferiore di ugello dal quale, in prossimità della punta dell'elettrodo, vengono iniettate nella zona dell'arco-plasma, sostanze quali ad es.: idrocarburi liquidi e gassosi.

L'attività sperimentale conclusasi nel 2001 è stata condotta su di un forno pilota in CC da 1,9 MVA dotato di elettrodo da 250 mm ϕ , installato a Terni presso l'Unità di Ricerca del CSM.

I risultati di maggior rilievo sono stati:

- caratteristiche volt-amperometriche dell'arco plasma: a parità di tensione d'arco (V), di intensità di corrente (I) e quindi di potenza elettrica (P) vengono generati archi più corti, a minore irraggiamento sulle pareti del forno e quindi ad elevato rendimento termico; l'aumento di P può essere vantaggiosamente ottenuto aumentando la V, a costanza di I e di lunghezza dell'arco;
- composizione chimica dell'arco-plasma: i prodotti di demolizione molecolare, allo stato atomico o ionico, delle sostanze iniettate (ad es. metano, olio) creano una barriera all'ingresso di ossigeno ed azoto nell'arco-plasma sede preferenziale per la generazione di NOx, favorita dalle altissime temperature presenti;

- composizione chimica attorno all'elettrodo: l'iniezione modifica non solo la composizione dell'arco-plasma ma l'atmosfera attorno alla colonna elettrodica in prossimità della punta riducendone il consumo ossidativo in sinergia con l'abbassamento della temperatura media dell'elettrodo;
 - temperatura media dell'elettrodo: la presenza della lancia raffreddata riduce la temperatura sia interna che superficiale di tutta la colonna elettrodica migliorandone la conducibilità elettrica e riducendone il consumo sia ossidativo che in punta, quest'ultimo anche per l'effetto raffreddante indotto dalle reazioni di cracking;
 - composizione chimica della scoria e del bagno metallico: i prodotti di reazione che si sviluppano nell'arco-plasma interagiscono con il bagno liquido favorendo la riduzione e il recupero nel bagno metallico di ossidi di Cr, Mn etc., presenti nella scoria, le reazioni di desolforazione, denitrurazione.
- L'attività futura, ancora cofinanziata dalla CECA, di durata triennale a partire dal 2° semestre 2002, sarà condotta, con impianto dimostrativo, su forni elettrici di taglia pilota e industriale sia in CC che in CA.
- In termini più generali la tecnologia dell'iniezione nell'arco-plasma si presta a numerose applicazioni fra le quali si segnala:
- forni in CC monoelettrodo ad elevata potenza operanti ad alta tensione e con intensità di corrente nel campo di utilizzo degli elettrodi standard; forni per la produzione di acciai inossidabili dove l'accorciamento dell'arco, a parità di potenza, permette la sua schermatura anche in presenza di scorie di debole schiumosità;
 - forni per la termodistruzione di oli non riciclabili iniettati nell'arco-plasma e di rifiuti siderurgici quali: polveri FEA, scaglia di laminazione, etc. e rifiuti con essi compatibili, di derivazione anche non siderurgica;
 - reattori oxi-elettrici ad elevata flessibilità di carica (rottame e ghisa liquida) alternativi al convertitore ad ossigeno (BOF) nella produzione di acciai senza "overquality" e con minori emissioni di CO₂.