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LATEST TRENDS IN EAF OPTIMIZATION OF SCRAP-BASED MELTING PROCESS: BALANCING CHEMICAL AND ELECTRICAL ENERGY INPUT FOR COMPETITIVE AND SUSTAINABLE STEELMAKING*

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Abstract

The present work analyzes the latest results achieved in scrap based EAFs in terms of application of chemical energy, starting from the observation that the general trend is a reduction of oxygen utilization. Consequently a review is needed about criteria for evaluation of melting process efficiency and equipment design. If from one side the maximization of productivity remains one of the major goals, from the other side some aspects of present market situation, included price of raw materials, are requiring the maximization of process yield. Based on achieved performance figures of selected plants and theoretical considerations, the effect of chemical energy input intensity is analyzed focusing on transformation cost, productivity and total energy input. The effect of present practices with lower oxygen utilization is considered also in terms of global CO2 emissions. Finally, the latest Danieli concepts and technological tools for optimization of chemical input are presented.

Keywords: EAF; Chemical energy; Optimization; Yield; Injection; Emissions.

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1 INTRODUCTION

One of key aspects of scrap-based EAF process optimization is the balance between electrical and chemical energy input. When the target is the productivity maximization, extensive use of chemical energy is adopted to decrease melting time, especially when it is not possible to get more electric power by the installed transformer. On the other side, when highest productivity is not required, steelmakers pay much more attention to reduce transformation cost; therefore it is important to understand the effect of chemical energy intensity on OPEX. For sure, there is a lower limit for oxygen utilization, below which process is no more feasible; this is mainly due to the need to obtain the final bath target chemistry and to obtain adequate foamy slag. Anyway, additional oxygen utilization has to be evaluated in terms of thermal efficiency and effect on process material yield.

On the basis of selected results of scrap-based EAFs supplied by Danieli, indication is given regarding the effect of low vs. high oxygen process on productivity, transformation cost and on global CO2 emissions.

2 PERFORMANCE FIGURES OF SCRAP BASED EAFs

With the target to obtain indications on thermal efficiency of chemical energy, recent average production data of several scrap-based EAFs (bucket charge, carbon steel) were analyzed. The main process figures are reported in Tab.1. for each plant, the chemical energy input was calculated considering:

- Fuel (natural gas for all plants)
- Carbon (charged and injected)
- Charge oxidation: oxidation of Fe, C, Si, Mn, Al, Cr, P, hydrocarbons, contained in metallic charge
- Electrodes oxidation
- Other sources: slag-forming reactions, Fe3C decomposition (pig iron), carbonates dissociation (slag builders – this input having negative sign)

Regarding carbon oxidation, the energy input considered is the one related to complete combustion to CO2.

Tab. 1 – Average production data of scrap based EAF (bucket charge).

PLANT		CHARGE			PROCESS DATA												ENERGY INPUT		
Plant	Shell	Buck.	Scrap	Pig I.	TtT	Pon	Tapped	Tap T	Yield	EE	O2	Fuel	C inj	C ch	Lime	Dolo	Electrical	Chemical	Total
[#]	[m]	[#]	[%]	[%]	[min]	[min]	[ton]	[°C]	[%]	[kWh/t]	[Nm3/t]	[Nm3/t]	[kg/t]	[kg/t]	[kg/t]	[kg/t]	[kWh/t]	[kWh/t]	[kWh/t]
A	5,8	4	100		64	48	78	1621	92,1	402	28,7	6,7	11,9	1,9	22	10	402	274	676
A	5,8	4	100		63	47	77	1610	91,9	386	34,8	8,2	10,9	5,5	23	10	386	314	700
B	6,1	2	100		46	34	104	1646	87,5	378	40,6	0,0	17,1	1,1	45	7	378	305	683
B	6,1	2	100		45	33	107	1627	91,0	417	28,0	0,0	12,9	1,5	34	7	417	257	674
C	7,5	2	98	2	47	35	162	1634	92,3	380	34,5	5,6	9,4	6,3	38	6	380	307	687
C	7,5	2	98	2	50	38	163	1631	93,0	403	25,4	4,5	8,1	3,1	35	6	403	253	656
D	6,5	2	100		51	39	103	1610	88,6	409	25,3	2,5	10,0	4,0	18	24	409	248	657
E	7,4	2	92	8	48	36	146	1580	88,2	375	37,0	4,6	12,0	7,0	45	4	375	367	742
F	9,4	3	89	11	52	38	251	1618	88,2	371	36,3	4,3	10,0	3,2	38	0	371	335	706
G	7,5	2	90	10	54	42	170	1645	90,7	378	37,0	4,3	11,2	5,5	49	0	378	351	729
G	7,5	2	87	12	50	40	160	1647	91,3	399	32,2	5,5	8,0	0,0	55	0	399	293	692
H	7,0	2	100		55	43	155	1636	92,9	404	22,3	3,7	7,8	7,4	31	0	404	247	651

As it can be seen in Fig.1, the increase of chemical energy input results in an increase of total required energy input (chemical and electrical). The overall thermal efficiency, intended as ratio between steel enthalpy and total energy input, decreases along with chemical energy increase.

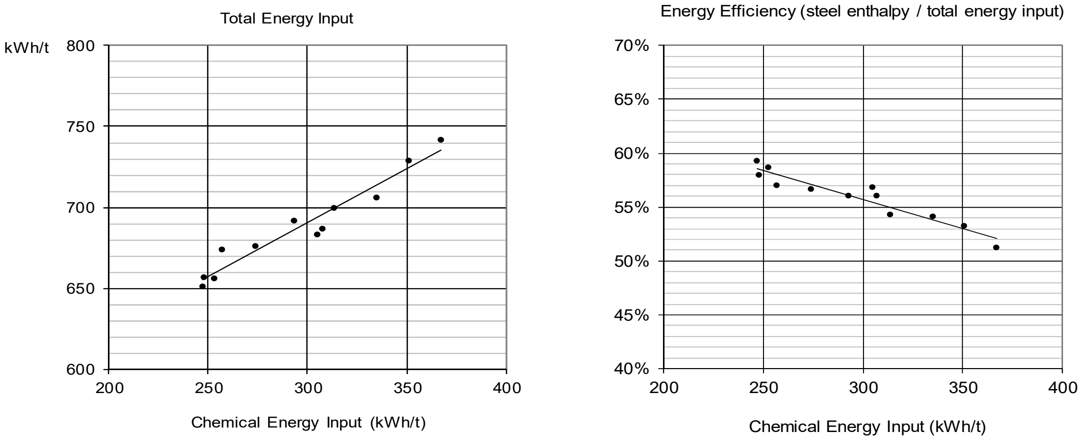

Fig.1 -Effect of chemical energy input on total energy input and energy efficiency (ref. Table I)

From Fig. 2 it can be observed that the adoption of increasing chemical energy input is mainly achieved by the increase of fuel and carbon input.

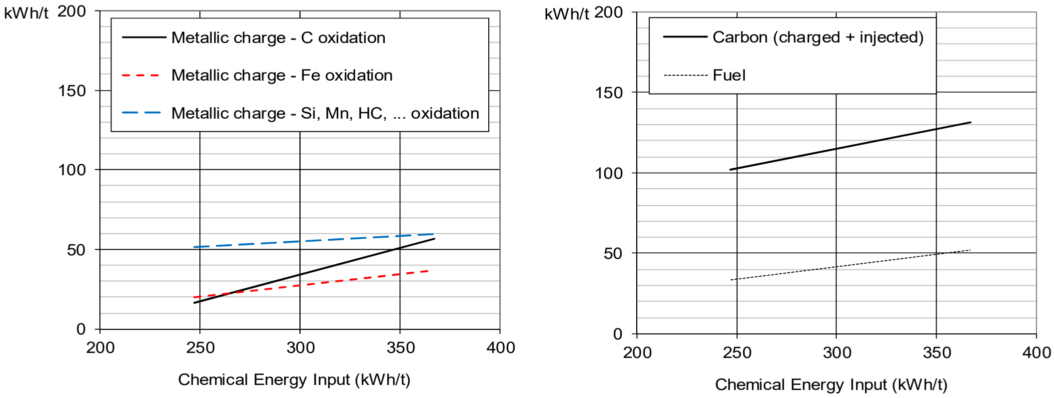

Fig.2 – Trends of chemical energy sources for EAFs of Tab.1

THEORETICAL ASPECTS OF CHEMICAL ENERGY THERMAL EFFECT

The evaluation of thermal efficiency of fuel and carbon oxidation is of primary importance, since these two energy sources are mainly employed in high chemical energy input practices (Fig. 2).

Carbon. The factors to be considered are both material yield and net heat effect. The reaction energy input considered in the graphs above is related to complete combustion to CO2, whereas CO is predominant in the gases leaving the molten bath (or residual scrap during bucket melting), meaning that the reaction energy has not been completely exploited inside EAF. The completion of reaction to give CO2 (post-combustion: CO → CO2) occurs in the first part of fume treatment plant, when gases cannot exchange useful heat with the melt.

In Fig.3 the net heat available for bath heating due to pure carbon oxidation is reported as a function of post-combustion degree and off-gas exit temperature.

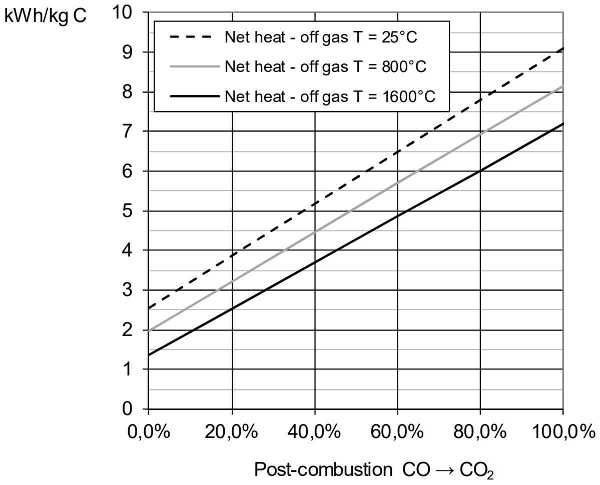

Fig. 3 – Net heat of pure carbon oxidation

Fuel. The heat released by complete combustion is 10 kWh/Nm3 of natural gas. Main factors affecting efficiency of fuel utilization are off-gas temperature and not complete combustion to CO2 + H2O. The off-gas analysis during burners' utilization always shows a certain amount of un-burnt CO and H2 ([1]).
Thermal efficiency of fuel combustion is higher compared to carbon oxidation. In fact, during burner phase off-gas temperature is "low" due to significant amount of not melted scrap. On the opposite, carbon oxidation is obtained by oxygen and carbon injection after burner phase, up to the end of refining, when the temperature of product gases is higher. Also, the high temperatures during oxygen injection stage do not allow high post-combustion near bath level, whereas the residual CO in off-gases during burner phase is lower.

Metallic elements. An increase of chemical input by charge oxidation can be achieved by using pig iron or cast iron as a part of charge mix, or by increasing oxygen utilization. In the first case, the additional energy is released by reactions of C, Si, Mn, whereas in the second case the chemical energy is obtained by Fe oxidation, with subsequent yield loss. Focusing on iron oxidation, iron is present in EAF slag both as FeO and Fe2O3 form. The theoretical reaction energies (at 25°C) are 1.32 and 2.03 kWh/kg of Fe respectively. Anyway, given a fixed amount of tapped steel, the oxidized Fe has to be compensated with additional charge and the reaction product (FeO or Fe2O3) exits EAF at around 1600°C in the slag, lowering the net available heat for bath heating.

REAL EFFICIENCY OF CHEMICAL ENERGY

The trend observed in Fig. 1 is related to several EAFs with different size, melting practice and process time. A proper simulation model was used for mass and energy balances to evaluate thermal efficiency of single energy sources. The tuning of simulation model allowed estimating the real efficiencies of single energy sources, which are reported in Tab.2.
Regarding carbon oxidation, the reported values are related to typical observed ranges of 15%-22% post-combustion and 800°C-1600°C off gas exit temperature.

For added carbon (charged and injected) the heat efficiency takes into account an average material yield of 75%.

Iron oxidation energy is referred to 1.5 average ratio FeO / Fe2O3. Average exit temperature of Fe, Si, Mn oxides is then considered 1600°C.
In Tab.2, the net heat available (which corresponds to the expected electric energy saving) is also indicated as kWh/Nm3 of oxygen involved in the single oxidation reactions.

Tab.2 – Real efficiency of chemical energy sources

ENERGY SOURCE	THEORETICAL HEAT	EFFICIENCY (net / theoretical)	OXYGEN DEMAND	NET HEAT referred to O2
Natural gas	10 kWh/Nm3	45-55 %	2.06 Nm3/Nm3	2.2-2.7 kWh/Nm3 O2
Carbon in charge	9.1 kWh/kg	24-37 %	1.06-1.13 Nm3/kg	2.1-2.9 kWh/Nm3 O2
Carbon added	7.7 kWh/kg	18-28 %	0.68-0.72 Nm3/kg	2.1-2.9 kWh/Nm3 O2
Fe oxidation	1.6 kWh/kg	60 %	0.24 Nm3/kg	4.0 kWh/Nm3 O2
Si oxidation	8.7 kWh/kg	86 %	0.79 Nm3/kg	9.5 kWh/Nm3 O2
Mn oxidation	1.9 kWh/kg	68 %	0.20 Nm3/kg	6.6 kWh/Nm3 O2

In Tab.3 the results of low chemical energy input practices are reported, for plants where it was possible to select sufficiently long periods for each melting practice (low-high oxidation), adopting same charge mix.

Tab.3 – Effect of decreased chemical energy input

		EAF #A	EAF #B	EAF #C
Oxygen	Nm3/t	-6.1	-12.6	-9.1
Fuel	Nm3/t	-1.5	0	-1.1
Charged carbon	kg/t	-3.6	+0.4	-3.2
Injected carbon	kg/t	+1.0	-4.2	-1.1
Electric Energy	kWh/t	+16	+39	+23
Yield	%	+0.2	+3.5	+0.7
Electric Energy increase per reduction of 1 Nm3/t O2	kWh/Nm3	+2.6	+3.1	+2.5

For plants #A and #C the chemical energy decrease is mainly achieved by fuel and carbon addition, whereas for plant #B the charge oxidation practice was abandoned, with significant yield increase. This is in agreement with overall thermal effect of oxygen utilization. The effect on electric energy for plants #A and #C (2.5-2.6 kWh/Nm3 O2) is closer (compared to plant #B) to the one associated to fuel and carbon oxidation reported in Tab.2, since for these plants the yield variation (iron oxidation) is limited. For plant #B the contribution of iron oxidation is higher, this resulting in 3.1 kWh/ Nm3 O2.

INFLUENCE OF CHEMICAL ENERGY INPUT ON RAW MATERIALS CONSUMPTION

For plants reported in Tab.3 the decreased oxygen utilization was associated to increase of charge material yield.

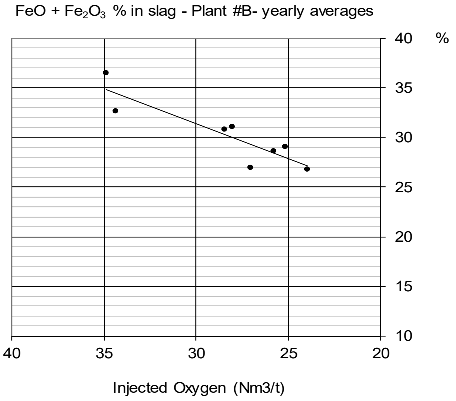

Fig. 4 – Trend of iron oxide in slag for EAF #B

This is due to decrease of iron oxide generation. An example of iron oxides decrease adopting lower oxygen consumption is reported in Fig.4 for EAF #B (yearly averages).

In order to limit iron loss it is necessary to balance oxygen and carbon addition. Data were analyzed for a series of plants related to increased chemical energy utilization practice. For each plant, two parameters were identified as associated to the increased oxidation practice.

The first parameter is the specific yield decrease; the second parameter is the specific increase of carbon addition, both parameters being referred to 1 Nm3/t of additional injected oxygen. The relation between the two parameters is reported in Fig.5.

Referring to Tab.2, if we consider the utilization of 1 Nm3/t of additional oxygen without compensating with carbon, the expected iron loss is 4.2 kg/Nm3. If average scrap yield is 90%, this corresponds to a yield loss of 0.38% (see point A in Fig. 5).

On the opposite, if we consider the utilization of 1 Nm3/t of additional oxygen completely compensated by carbon addition, the required additional carbon is 1.35-1.47 kg/Nm3 (point B in Fig.5).

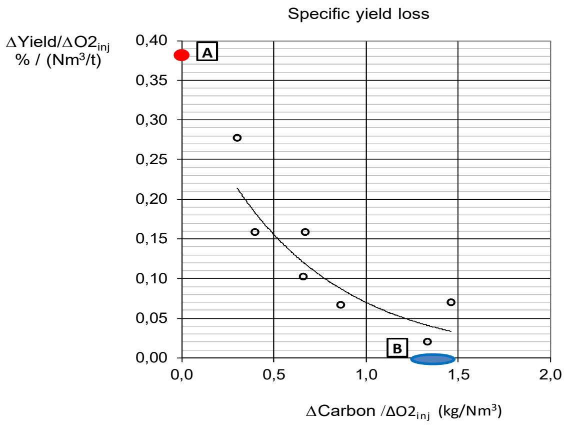

Fig.5 – Metallic charge yield variation for each Nm3/t of additional oxygen, as a function of carbon/oxygen addition

The trend in Fig. 5 shows that it's difficult to avoid a residual loss of yield even at high ratios between carbon and oxygen addition. This is because the reduction kinetics by injected carbon is not as fast as iron oxide generation. The result is a residual yield loss.

Based on same considerations, with higher oxygen blowing intensity, higher steel oxidation will be obtained. Trend of oxygen steel activity increase as a function of carbon-oxygen balance is reported in Fig. 6, for the same plants of Fig. 5, for which measurement at the end of heat was available.

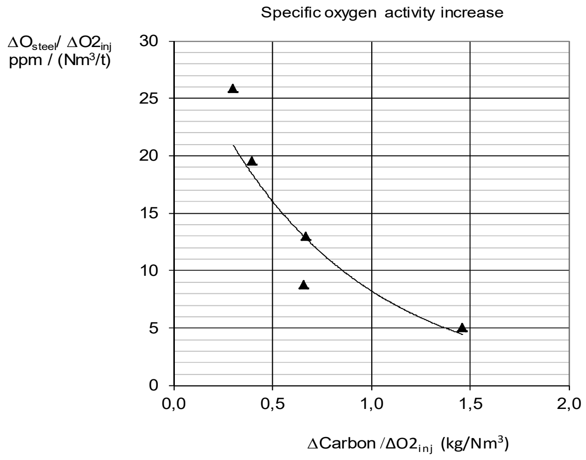

Fig. 6 – Steel oxygen content variation for each Nm3/t of additional oxygen, as a function of carbon / oxygen ratio

Increased oxygen activity results in higher consumption of ferroalloys for steel desoxidation, moreover it can have negative effect on steel quality.

OPEX COMPARISON OF HIGH vs. LOW CHEMICAL ENERGY INPUT PRACTICES

With the target to evaluate convenience of high vs. low oxygen utilization for a given target productivity, process simulation was performed considering a reference EAF of which main data are reported in Tab.4. The simulation model was tuned on the real recorded data reported in previous paragraphs.

Tab.4 – EAF data for process simulation

Bottom shell diameter	m	6.1
Upper shell diameter	m	6.2
Tapped steel	t	100
Tap to tap	min	47
Power on	min	35
Charge practice	#	100% scrap, 2 buckets
Scrap density	kg/m3	600
Electrodes	mm	610
Oxygen injection capacity	n° x Nm3/h	4 x 2100
Burner phase capacity	n° x MW	6 x 4.0
Carbon injection capacity	n° x kg/min	3 x 40
Transformer size	MVA	115
Tapping conditions	°C - %C	1620 – 0.06

The simulation was then performed to compare the process figures of 2 different processes, maintaining same productivity:

- High oxygen practice
- Low Oxygen practice (by decreasing oxygen and carbon consumption)

The comparison of process figures and transformation cost is reported in Tab.5.

Tab.5 – Comparison of process figures and OPEX

	High oxygen practice	Low oxygen practice		Unitary cost
	Figures	Figures	Cost difference	
Total Energy Input	726	683		
Chemical Energy Input	351	292		
Yield	89.7%	90%		
Scrap	1.1148 t/t	1.1111 t/t	- 0.63 €/t	170 €/t
Electric energy	375 kWh/t	391kWh /t	+ 0.96 €/t	0.06 €/kWh
Oxygen	36 Nm3/t	30 Nm3/t	- 0.36 €/t	0.06 €/Nm3

Fuel	4.5 Nm3/t	4.5 Nm3/t	0 €/t	0.25 €/Nm3
Charge carbon	9 kg/t	6 kg/t	- 0.45 €/t	0.15 €/kg
Injected carbon	14 kg/t	10 kg/t	- 0.60 €/t	0.15 €/kg
Lime/dololime	34 kg/t	32 kg/t	- 0.14 €/t	0.07 €/kg
Electrodes	1.23 kg/t	1.21 kg/t	- 0.06 €/t	3 €/kg
			- 1.28 €/t	

As it can be seen, for a given productivity it is convenient to decrease chemical energy input. A part from cost of oxygen, lower OPEX is mainly due to the cost savings related to carbon and metallic charge. The economic convenience of low oxygen practice can be extended for electrical energy unitary cost up to 0.14 €/t.

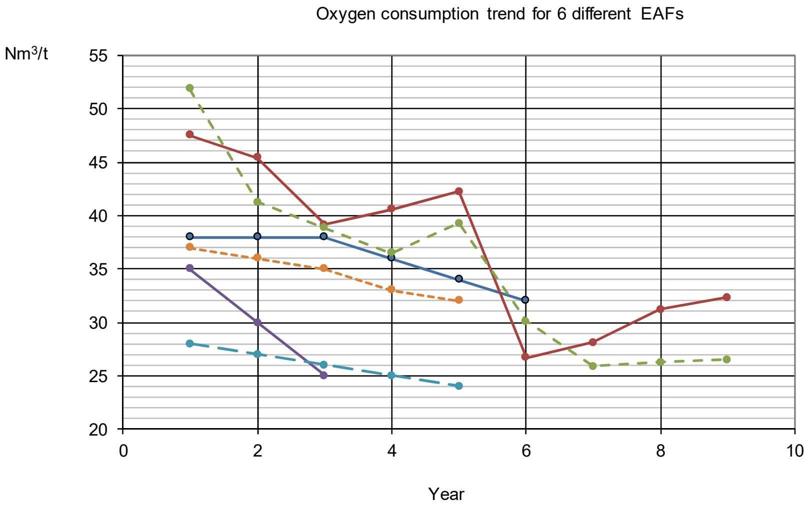

Fig.7 – Trend of EAFs oxygen consumption for bucket process

The trend of average oxygen consumption for a series of 6 EAFs during observation period (Fig.7) highlights the progressive decrease chemical energy. This is in accordance to consideration made above: during last years, the maximization of productivity is not main target; therefore cost optimization is being pursued.

INFLUENCE OF LOWER CHEMICAL INPUT ON PRODUCTIVITY

Referring to Tab.1 we can analyze the effect on productivity in plants B and G, where along the years the chemical input has been progressively reduced.

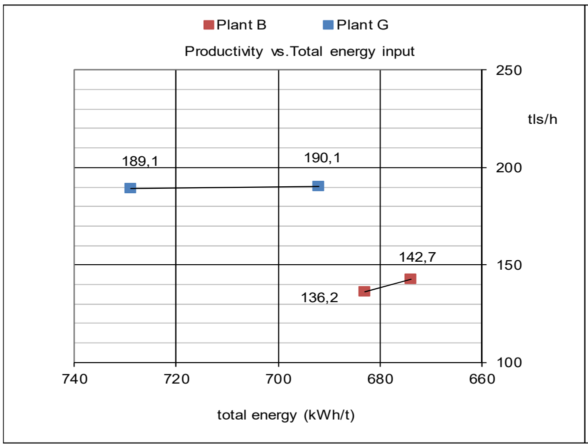

Fig. 8: productivity vs. total energy

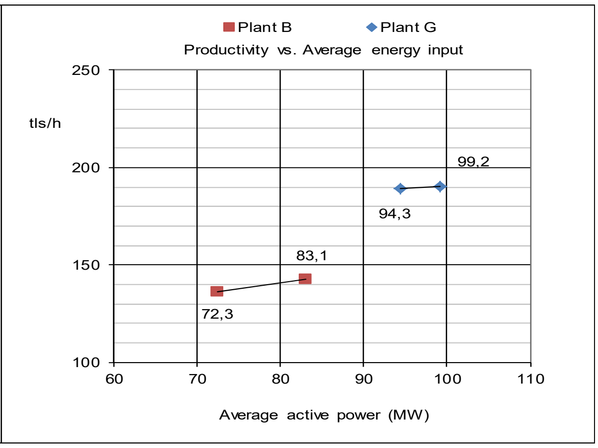

Fig. 9: productivity vs. average power input

The driving factor for the change in the operative practice has been as first step the reduction of the chemical input due to the lower OPEX. Consequently the increase of the electrical power has been pursued to increase productivity.

From Fig.8, it can be observed how despite the reduction the total energy input (due to reduction of the chemical input), productivity has been kept at the same levels, as for plant G, or increased as for plant B. The increase of the average power input in both cases allowed compensating the lack of power input: in plant B the electrical average power input was increased by 10.8 MW, while in plant G it was increased by 4.9 MW, see Fig.9.

The utilization of higher power input means utilization of more aggressive electrical working points with higher RWI, see Fig.10. The need of higher slag freeboard to cover longer arcs is a direct consequence of this change of practice and as a result the slag door breast was increased by 50 to 100 mm with respect the original level.

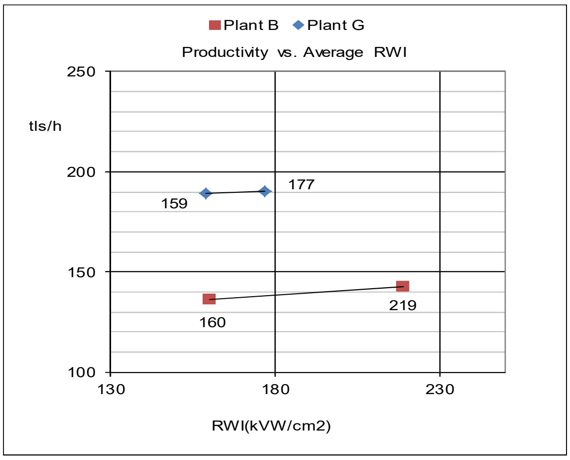

Fig. 10: productivity vs. refractory wear index

In addition the slag foaming practice is improved thanks to the reduction of FeO content in the slag, as reported in Fig.4 for Plant B, from 35% to 26%. Its reduction allows the reduction of the amount of liquid phase in the slag increasing the viscosity: the final result is a slag less aggressive towards refractory and more efficient to transfer heat from arc to bath.

INFLUENCE OF CHEMICAL ENERGY ON CO2 EMISSIONS

The impact of EAF practice on CO2 emissions can be evaluated with reference to melt shop only or on global basis. The calculation of EAF CO2 emissions at stack depends on quantity of injected fuel and carbon present in the charge. For example, the CO2 generated by 1 Nm3 natural gas is 2.06 kg, whereas CO2 output of 1 kg pure carbon is 3.67 kg.

Adoption of low chemical energy process (lower carbon and fuel) thus results in lower meltshop emissions. From environmental point of view it has to be evaluated the global emissions of EAF process, considering also the CO2 associated to the production of electric energy and oxygen used in EAF.

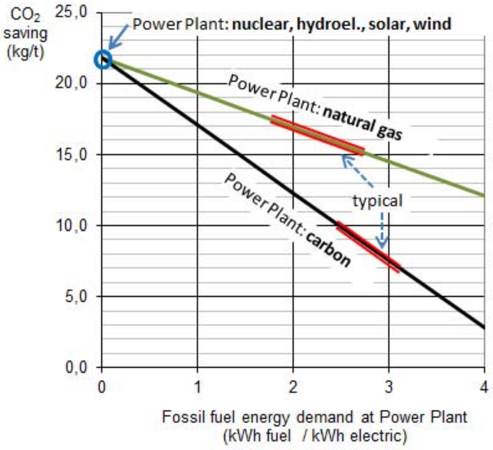

Fig.11 – Global CO2 emission decrease of Low Oxygen EAF practice vs. High oxygen practice

The carbon footprint of electric energy production depends on the technology adopted and primary energy source employed at local power-plants. Regarding oxygen generation, considering an air separation plant, the electric energy to produce and deliver to EAF 1 Nm3 of oxygen is around 0.7 kWh.

A comparison was made on the global variation of CO2 emissions for the 2 processes previously evaluated (high and low oxygen practices, based on different carbon addition, see Tab.5), taking into account the variation of carbon consumption and electric energy consumption (at EAF and at air separation plant). The power-plant technology was defined by the fossil fuel energy which is necessary to generate 1 kWh of electric energy. In case of nuclear, solar, wind and hydroelectric plants the ratio is close to zero, whereas for plants powered by fossil fuel, 2 cases were considered: natural gas and carbon plants.

As it can be seen in Fig.11, considering the typical efficiencies of power plants [2], the low oxygen practice at EAF always results in lower global CO2 emissions. On the other hand, due to higher thermal efficiency of gaseous fuel compared to carbon oxidation (see Tab. 2), and lower CO2 generation of natural gas combustion compared to carbon combustion, EAF practices with lower natural gas consumption are beneficial in terms of global CO2 emissions only in case of zero CO2 power-plants (-2 kg/t CO2 for each Nm3/t natural gas decrease at EAF) and in case of natural gas power plants (-0.1/-0.9 kg/t CO2 for each Nm3/t natural gas decrease at EAF).

In case of carbon-fed power plants, the global emissions by decreasing fuel at EAF are higher (in the range 1.5-2.2 kg/t CO2 for each Nm3/t natural gas decrease at EAF), and in principle it would be beneficial to avoid reduction of fuel utilization at EAF.

RECENT DEVELOPMENTS IN CHEMICAL ENERGY OPTIMIZATION TECHNOLOGY

The discussion so far has pointed out that high chemical energy practices generally result in lower thermal efficiency, lower charge material yield, and higher CO2 emissions, both on local and global scale. Increase of chemical energy efficiency is therefore one of the main targets to be pursued.

Latest Danieli concepts for chemical input optimization are related to both design criteria and process control.

Injectors' installation. Special attention is given to minimization of oxygen injector's distance from steel to bath. Short oxygen jet lengths allow for higher penetration efficiency, this resulting in better decarburization rate and at the same time lower bath oxidation. The adoption of deep bulged blocks adequately protruding inside the furnace allows obtaining short jet lengths with injection angles of 43-45°, maintaining suitable distance of injection point from refractory. A typical installation is reported in Fig.12.

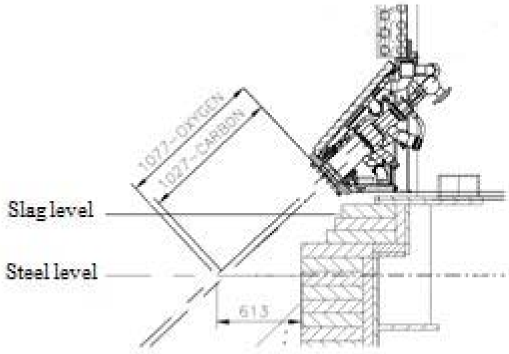

Fig. 12 – Typical injector installation

Injectors' typology: The need to couple oxygen and carbon injection in a unique tool brought to the development of M-One injector. The target is not only to reduce the distance from oxygen to carbon but also to keep the carbon injection tip clean, thanks to the surrounding flame. In this way carbon build-ups in front of the injector are avoided and the efficiency of injection is increased.

Injectors' layout: Homogeneous distribution of injectors allows better control of bath oxidation. In particular, for practices with low injected oxygen, it is preferable to maintain the number of injection points, reducing their size rather than using few injectors with higher flow rate. The target is pursued by optimizing the installation of the injectors in the cold area of the furnace, especially the EBT area.

Slag freeboard: Since in any case the reduction of iron oxide in the slag by means of carbon injection is a relatively slow reaction compared to iron oxidation by oxygen blowing, the maximization of material yield can be obtained also by proper design of slag freeboard. Higher slag freeboard allows for higher slag retention time, this meaning higher available time for FeO reduction. The slag freeboard height has to be chosen based on process timing and arc power applied.

Process control: The development of process control is of primary importance to enhance efficiency of chemical energy. The installation of LindarcTM off gas analysis system [1] allows obtaining information on the oxidation state inside the furnace. The laser technology allows immediate, reliable and accurate measurement of O2, CO, CO2, H2O. The information received during the heat is used to correct set-points of injectors in order to control the oxidation state inside EAF (closed loop control – CLC). During burner stage, according to the measured ratio CO/CO2 the stoichiometry of fuel oxidation is varied by changing oxygen set points. Oxygen is increased if CO/CO2 ratio is high, in order to maximize conversion to CO2 which is beneficial for scrap heating. On the opposite, when CO/CO2 ratio is low, oxygen is decreased to avoid excessive scrap oxidation. It is clear that in this way the closed loop control has an effect both on thermal efficiency and on material yield. Besides, information about off-gas composition is useful also during refining stage in order to get information about bath oxidation. A systematic approach to process optimization is obtained with the Q-MELT Automatic EAF, a package that performs adaptive process control (by means of the Melt-Model) and operational support to enhance operational safety. With the Melt-Model, operators are guided through the furnace operation, with a system that is able to inform if the read parameters are the ones expected or if corrections are needed. More specifically, the capability of Melt-Model in chemical input optimization is due to the following:

- Q3-Intelligence Data Modeling, providing access to database of all relevant process data, included time-dependent variables
- FingerPrintTM : based on Q3-Intellgence, it classifies heats with homogeneous practice and extracts relevant information of time-dependent variables. Average and standard deviation trends are then generated, allowing a real-time comparison of trend during the heat with average historical trend;
- Utilization of FingerPrintTM trends of CO and CO2 measured by LindarcTM to evaluate deviations which are related to anomalous oxidizing state. As a consequence, oxygen injection set-points can be dynamically adjusted to match final target chemistry;
- Predictive models that allow to foresee real-time the evolution of temperature, oxygen and carbon content in the steel during refining
- Q-Reg Plus: separate control of each carbon injection flow based on arc coverage index of each electrode. Carbon injection during refining is adjusted dynamically, the target is feeding the minimum quantity necessary for slag foaming, thus resulting in carbon consumption minimization. The tool allows acting also on lime injection, in this way the slag foaming can be obtained by regulation of slag viscosity.

3 CONCLUSION

The following items can be summarized:

- Among the chemical inputs the effect of fuel and carbon combustion has been analyzed in terms of thermal efficiency here considered as the ratio between the net heat transferred to the melt and the theoretical heat. For fuel it can be reached a thermal efficiency up 55%, while for injected carbon the thermal efficiency can reach values up to 28%.
- Residual losses of yield cannot be avoided even at high ratios between carbon and oxygen addition when using high oxygen practices.
- From transformation point of view the operational practice with lower oxygen utilization is more convenient bringing to a reduction of the cost not only of the charge, approx. 50% of the savings, but also of the other process media (oxygen , carbon , lime).
- The low oxygen practice is utilized mainly in the periods where the productivity demand is low. There are anyhow examples of plants that along the years have kept or increased the productivity thanks to an increase of the electrical power input.
- The low oxygen practice leads to a reduction of the CO2 emission. Considering the typical efficiencies of power plants, the low oxygen practice at EAF always results in lower global CO2 emissions in the range of 7 to 18 kilograms of CO2/ton of steel.
- The analysis of the actual trend in the EAFs shows a reduction of the chemical input because less efficient if compared to electrical input. Danieli with the target to increase the chemical input efficiency has concentrated its efforts not only in the optimization of the equipment design, but also in the adaptive control of the main melting parameters in function of the real charge characteristics..

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