THE PRACTICE OF CARBON INJECTION AND POST COMBUSTION IN ORDER TO ACHIEVE A METALLIC YIELD RECOVERY IN THE ELECTRIC ARC FURNACE: THE EXPERIENCE OF AMSTEEL MILLS (MALAYSIA)[1]

Loh Fook Guan[2]
Pong Chung Kuan[3]
Cheong Wai Meng[4]
Francesco Memoli[5]
Ovidiu Negru[6]

Abstract

Amsteel Mills Sdn Bhd is a 800,000 tpy capacity Steel Plant, located in Klang, Malaysia. Its scrap-based EAF of 87 tons heat size capacity has been equipped in the end of 2005 with a modern oxy-carbon injection system and an additional pc-burner system. Besides the expected benefits coming from the reduction of power on time and overall energy consumption, Amsteel has experienced a constant and consistent metallic yield recovery through a very efficient carbon powder injection practice. This paper describes the results achieved over a year of production and the operational practices that take into account a very careful analysis of the EAF slag, monitoring its composition on the beginning and on the end of the flat bath period. The results in yield recovery are thus related to the reduction of the iron oxides in the slag and the amount of carbon powder used for the injection.

Key words: Carbon injection; Metallic yield; Foamy slag; Iron oxide; Post combustion; Oxygen injection

A PRÁTICA DE INJEÇÃO DE CARBONO E PÓS COMBUSTÃO PARA A RECUPERAÇÃO DE RENDIMENTO METÁLICO NO FORNO ELÉTRICO A ARCO: A EXPERIÊNCIA DA AMSTEEL MILLS (MALÁSIA)

Resumo

A Amsteel Mills Sdn Bhd é uma usina com capacidade de 800.000 t/ano, localizada em Klang, Malásia. Seu FEA a base de sucata de 87 t de capacidade foi equipado no final de 2005 com um moderno sistema de injeção óxi-carbono e um sistema pc-queimador adicional. Além dos benefícios esperados na redução do tempo de power on e consumo global de energia, a Amsteel obteve uma constante e consistente recuperação do rendimento metálico através de uma prática muito eficiente de injeção de carbono pulverizado. Este trabalho descreve os resultados alcançados em um ano de produção e as práticas operacionais que consideram uma análise bem cuidadosa da escória do FEA, monitorando sua composição no início e no fim do período de banho plano. Os resultados na recuperação do rendimento são então relacionados com a redução dos óxidos de ferro na escória e na quantidade de carvão pulverizado utilizado na injeção.

Palavras-chave: Injeção de carbono; Rendimento metálico; Escória espumante; Óxido de ferro; Pós combustão; Injeção de oxigênio

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[1] *Tecnhical contribution to XXXVIII Steelmaking Seminar – International, May 20th to 23rd, 2007, Belo Horizonte, MG, Brazil.*

[2] *Director, Steel Meltshop, Amsteel Mills SDN BHD, Klang, Selangor, Malaysia*

[3] *General Manager, Steel Meltshop, Amsteel Mills SDN BHD, Klang, Selangor, Malaysia*

[4] *Assistant General Manager, Steel Meltshop, Amsteel Mills SDN BHD, Klang, Selangor, Malaysia*

[5] *Area Manager North and South America, Tenova (Techint Group), Metal Making, Milan, Italy*

[6] *Senior Product Applications Engineer, Tenova Goodfellow (Techint Group), Mississauga, Canada*

1 INTRODUCTION

Amsteel Mills Sdn Bhd, one of the four Steel plants of the Lion Group, operates today two steel mills, in Klang and Banting, both in Selangor, which are equipped with modern facilities of Electric Arc Furnaces, Continuous Casting Machines and Ladle Furnaces to produce billets for rolling into bars and wire rods. The Banting mill produces special grade bars and wire rods for automotive parts, mattress and mechanical springs, turning parts, wire ropes and other speciality uses. Antara Steel Mills Sdn Bhd, the sister-mill in Johor State, produces billets and bars including angle bars and U-channels.

Amsteel products are hot rolled flat and concrete reinforcement bars, low carbon steel wire rods also for fine drawing, wire rods for core wire of covered electrode, high carbon steel wire rods, carbon steel for cold heading, free cutting steel - leaded rephosphorised and resulphurised carbon steel.

Amsteel Meltshop in Klang was established in 1982 with a Tagliaferri EAF, subsequently upgraded to 100-ton, and a 6-strand billet Continuous Casting Machine. The Ladle Furnace was installed in 1985 as part of the mills' quality improvement programmes to produce high grade billets. The steel making facility in Klang has enabled Amsteel to achieve a billet production of 800,000 tonnes per annum. Amsteel's new meltshop in Banting under the name of “Amsteel II” comprises a 160-ton Direct Current EAF, LF, Vacuum Oxygen Degassing and a 6-strand CCM capable of producing 1.25 million tonnes of billets per annum.

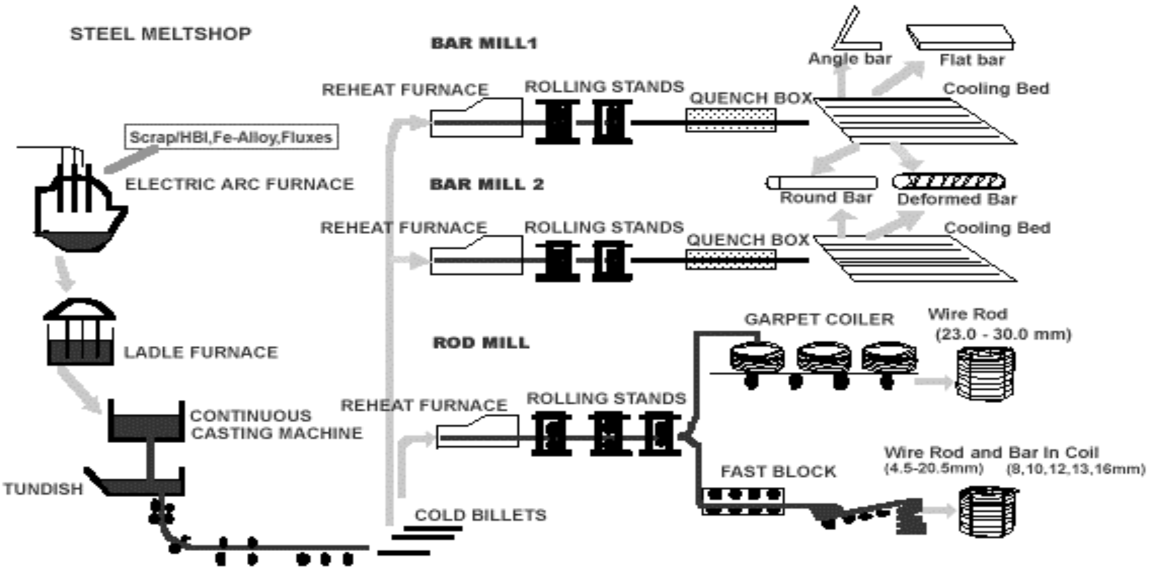


Figure 1 - Amsteel SDN BHD production process [1]

2 RAW MATERIAL CONSTRAINS IN MALAYSIAN STEEL INDUSTRY

The shortage and higher price of steel scrap in the international market affected the iron and steel industry in Malaysia. Considered as one of the East Asian Tiger Countries, Malaysia suffered a period of economic unrest that started in July 1997 for all South East Asia. Steel Companies were also hit by the slump and they had to recover year by year struggling in a market whose conditions were more and more difficult because of the strong position of China, which was actually starting the rise during those years.

The Country produces less than 5 Mt/yr of crude steel, but consumes about 7-8 Mt/yr, according to Malaysian Iron & Steel Industry Federation; the shortage of crude steel is today met by imports.

Table 1 - Apparent Steel Consumption in Malaysia (2000-2005).

Year	Longs	Flats	Total	%change
2000	3,018	3,837	6,855	13
2001	3,115	4,207	7,322	7
2002	3,555	3,307	6,862	-6
2003	3,281	3,393	6,674	-3
2004	3,761	3997	7,758	16
2005	3,419	3,705	7,124	-8

The steel industry in Malaysia is considered a policy-driven industry; certain production and products are regulated through import and export procedures and also price control mechanisms are set. In efforts to balance the national budget, one of the measures undertaken by the Malaysian Government was to reduce the expenses on civil works and this had resulted in the negative performance of the construction sector in both 2004 and 2005. Consequently, the demand of steel products and other building materials domestically had declined, and 2005 recorded negative consumption growth of – 8% in 2005, although 2004 recorded a robust 16% consumption growth. Other than slow domestic demand, the Malaysian steel industry was affected by severe fluctuations of prices of materials and products during the last years. This impact was felt all around the region with cooling down of prices particularly during the third and fourth quarters of 2005.[2] The situation was due to Asian oversupply, rising China exports and high inventory control and this had thus required steel producers to step up on export activities and as a consequence of that to look at their international competitiveness and production efficiency.

Due to escalating crude steel and steel scrap prices on the international market, Malaysia's steel semi-manufacturing producers have been operating below their designed output capacities. The major steel producers, besides Amsteel Mills and the whole Lion Group, are Perwaja Steel, Malayawata and Southern Steel. The industry's capacity utilization has been about 60% during the past years. Imports of billet were regulated by the Government and were allowed only when there was a shortage of billet to meet domestic demand or certain grades of billet were not produced locally.[3]

In response to concerns over a tightening availability of raw material supply in the domestic market, by the end of 2004, Amsteel competitor Perwaja Steel started to return to full capacity, expanding direct reduced iron (DRI) capacity at its Kemaman works from 1.2 to 1.8 million. Meanwhile Lion Group's Amsteel Mills had already decided to expand its hot briquette iron (HBI) facility on Labuan island, Sabah state.[4] Malaysia imports high-grade iron ore from Brazil, Canada, Chile and Bahrain.

Nevertheless Amsteel management has been also very concerned about energy savings and strongly looked at technologies with proven capabilities to reduce variable costs.[5] As a matter of fact during those years, Amsteel Mills was facing an energy consumption account between 15-20% of the total production cost,[6] which is the second item of cost after raw materials, which for the Meltshop rises up to 65-70%. In all Malaysia steel plants were also studying on the same basis energy reduction techniques. In fact Perwaja Steel in Jan. 2003 decided the revamping of its furnace No. 4 – one of the two operating DC EAFs 75 tons/heat DRI based – with the chemical package KT Injection System. One of the main results achieved in that plant has been an average DRI feeding rate of 40 kg/min/MW, a value certainly high for a DRI-based furnace. The key of that result has been the very efficient powder carbon injection, considered the main driver for better foamy slag and yield increase.[7] So, besides the clear advantages of a multipoint injection package, the KT System was showing capabilities to increase the efficiency of Carbon Injection, which is a distinctive point for this system in comparison to other modern oxygen and carbon injection systems.

Therefore, the raw material constrains, the market situation requiring higher production efficiency and the good results shown by the KT system in Malaysia were the main drivers for the installation of that system on the Amsteel Mills scrap-based Electric Arc Furnace.

3 THE KT PROJECT AND EAF EQUIPMENT IN AMSTEEL MILLS SDN BHD

The cooperation between Amsteel and Tagliaferri, the Italian EAF main supplier acquired by Techint Group of Companies in 1996 and now become Tenova Melt Shops, started in the late '70s with the first project of the EAF. The relations between the two companies have always been very close. The project of the KT injection system, which is only one of the state-of-the-art technologies of Tenova, started in early April 2005, after a long series of revamping to the EAF, including the installation of the TDRH digital Electrode Regulation System. The EAF, previously equipped with conventional burners and a water cooled supersonic lance from the slag door, has been then equipped with three KT Oxygen Lances, three KT Carbon Injectors and 8 KT Post-Combustion Burners.

Amsteel EAF equipment details:

• Furnace type	Tagliaferri EAF (1993)
• Furnace diameter and volume	6,100 mm – 90 m^3
• Tapping system	EBT – swivelling flap
• Platform type	Tagliaferri conventional half-platform
• Roof swinging system	rail and pivot on independent foundation
• Electrode Arms	Tagliaferri Copper Auto Conductive
• Charging system	conventional – by buckets
• Transformer:	80 MVA Tamini (33kV 950-850-650V)
• Reactor:	0-2 Ohm (33kV)
• Regulation System:	TDR-H with harmonics control, 2003
• Oxygen Multipoint Lances:	3 KT Oxygen Lances, 2004
• Carbon Injectors:	3 KT Carbon Injectors, 2004
• Burners:	8 KT Post Combustion Burners, 2004

The Amsteel KT Oxygen and Carbon Injection System is an evolution of the typical KT Injection System[8] due to the implementation of the KT PC Burners. As a matter of fact these are special burners that mount a special nozzle which is capable of a double function: high efficiency flame and oxygen low-flow for an optimized CO post combustion.

Referring to the Amsteel EAF layout, it is interesting to see that the furnace has the possibility to have up to eleven flame points during scrap melting operation, three KT oxygen lances used as burners (up to 5 MW each) plus the eight burners (up to 2.5 MW each).

Once the furnace is ready, the KT Oxygen lances start with supersonic oxygen injection and the PC Burners start to act as low-flow oxygen injectors in order to burn the CO generated in the low section of the EAF, since PC burners are located one to two feet higher respect to the lances nozzles.

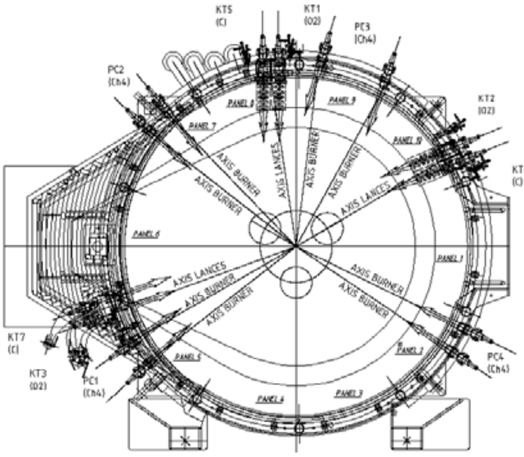


Figure 2 - KT Lances and burners layout

Amsteel chemical package can be considered then one of the most advanced and complete multipoint injection systems installed in an Electrical Arc Furnace of the last years. [9,10]

4 POST COMBUSTION PRINCIPLES AND ITS APPLICATION IN AMSTEEL

Before the analysis of the results achieved in Amsteel, it is important to define the parameters that should be taken into account talking about Post Combustion and Decarburization. Almost all modern Electric Arc Furnaces use oxy-fuel burners to assist the electric power in melting. It is well known that these burners increase the production rate, decrease electric energy consumption, and reduce undesirable delays caused by late melting of scrap in the cold spots. In the literature there are several heating models that have been developed in order to simulate these effects of Chemical Energy for the Electric Arc Furnaces, the most interesting models combine the effects of heating by burners and arc heating.

The phenomena that occur during the melting of the scrap include: (1) heating of the scrap by the oxy-fuel burners, (2) melting of the scrap by the electric arcs, (3) liquid slag formation, (4) oxygen and carbon injection for foaming of the slag, (5) movement of the scrap pieces during melting, (6) chemical reaction between slag and metal, (7) post-combustion of the CO evolved from the reactions is practiced. [11] Important exothermic reactions and the heat of reaction (ΔH) are listed on Table 2.

Table 2 - Exothermic reactions and the heat of reaction (ΔH); 1kg O2 = 26.6 scf O2

Reaction at 1650°C (3000°F)	ΔH (kWh/kg of first specie)	ΔH (kWh/scf of O2)
$Fe + ½ O_2(g) = FeO$	-1.275	-0.167
$Si + O_2(g) = SiO_2$	-9.348	-0.308
$4Al + 3O_2(g) = 2Al_2O_3$	-8.650	-0.365
$C + ½ O_2 (g) = CO(g)$	-2.739	-0.077
$CO(g) + ½ O_2(g) = CO_2 (g)$ – POST COMBUSTION	-2.763	-0.182
$C + O_2(g) = CO_2(g)$	-9.184	-0.129
$H_2(g) + ½ O_2(g) = H_2O(g)$	-34.614	-0.164
$CH_4(g) + 2O_2(g) = CO_2(g) + 2 H_2O(g)$	-13.994	-0.132

It is interesting to see that, given the same quantity of Oxygen, the so called Post-Combustion reaction at 1650°C is 2.5 times more exothermic than the simple combustion of Carbon into Carbon Monoxide and even 40% more exothermic than the complete combustion of carbon into Carbon Dioxide. The right and appropriate use of this potential heat is crucial for the EAF energy efficiency.

If then it is calculated the amount of oxygen required to combust Carbon or Carbon Monoxide:

Reaction	Amount of specie reacting	Amount of Oxygen required
$C + ½ O2 (g) = CO(g)$	1 kg of Carbon	1.33 kg Oxygen
$C + O2(g) = CO2(g)$	1 kg of Carbon	2.66 kg Oxygen
$CO(g) + ½ O2(g) = CO2 (g)$	1 kg of Carbon Monoxide gas	0.57 kg Oxygen

Generically, post combustion refers to the burning of any partial combusted compounds. In EAF both CO and H2 are present. A high degree of CO PC corresponds to high H2 PC. CO is produced in large quantities in the EAF both from O2 lancing and slag foaming activities. Thermodynamically it is not possible for CO to burn into CO2 into the steel bath, so that CO is the gas that can be developed in the liquid steel. If there is sufficient Oxygen present outside the bath, both CO and H2 will evolve into CO2 and vapour. The necessary oxygen can only be supplied by additional injections, since there would not be enough O_2 for the total combustion of these species.

If these species are burned into the EAF shell when solid scrap is till present, this can have two consequences: a lower Electrical Energy required for scrap melting and a lower heat load of the off gasses, since the latent heat would be used in the EAF and not developed into the off-gasses dedusting system.

In terms of energy savings, according to literature,[12] Post Combustion reactions can give about 3 kWh/Nm^3 of Oxygen. Some technologies have claimed in the past to be capable to develop more efficient PC reactions into the slag, up to 4.5 kWh/Nm^3 O2, injecting Oxygen at low flow in the same slag in order to catch the CO bubbles coming from the steel bath and coming from the Iron Oxide reduction into the slag.

Nevertheless, considering the high amount of iron oxide formed in the slag of those furnaces equipped with that technology, it is difficult to classify the heat proceeding from PC reactions and the heat coming from Iron re-oxidation, which is another very exothermic reaction. So the use of PC oxygen inside the slag it is mostly not recommended if one has to take care of metallic yield.

From a global energy and economical point of view PC reactions developed outside EAF slag are preferable. As a matter of fact also literature confirms this hypothesis, considering the amount of 15 Nm3/tonne for PC Oxygen as the limit that can create excessive yield losses due to scrap over-oxidation.

In the case of Amsteel, the PC Oxygen is delivered by PC Burners that have double function of conventional burner and PC injectors. It is well known that once scrap reaches a temperature of about 800°C, the burner heating efficiency decreases and the over-stoichiometric oxygen and other combustion products react with iron to form FeO. The yield loss can reach percentages up to 2 to 3% if the burner combustion ratio is widely over-stoichiometric and the flame or oxygen speed is high and clearly directed toward the scrap.

At this point there are several options for the use of the burners after scrap reaches 800°C, which commonly happen about 50% of the meltdown time: (1) one possibility is to stop the burners in order not to oxidize the scrap, (2) another possibility is to stop the Natural Gas flow and reduce the amount of oxygen flow in order to reduce speed and using that oxygen to catch the CO and produce the post-combustion reactions, (3) an additional possibility is to force the effect of Fe-burning, in order to increase the chemical energy developed by these reactions, shorten the scrap melting time and even cutting the scrap with the oxygen flow, but then trying to reduce the FeO created in this way with a very efficient carbon injection inside the slag.

The chemical devices installed in Amsteel are capable to act in all the three different manners, having a special nozzle that can provide efficient low-flow oxygen, but that can act as scrap cutters if used at high flame speed and high oxygen flow.

Based on the heats of reaction previously indicated, and typical EAF efficiencies, according to literature an iron yield loss of 1% equates to a power input of 13.2 kWh/tonne. This matter is very important when one has to analyse the consumption figures of the EAF. As a matter of fact sometimes very low energy consumptions are fictitiously indicating that the furnace is efficient, so the yield should always be considered in the overall picture for the evaluation of EAF results, as done in this article.

A typical modern Electric Arc Furnace should be equipped at least with 0.133 MW of burner rating per ton of furnace capacity. In the case of Amsteel, the nominal burner capacity is much higher than that. As a matter of fact the burner power that can be applied is higher than 30 MW and the actual burner power applied is reaching 25 to 27 MW as peak during meltdown time.

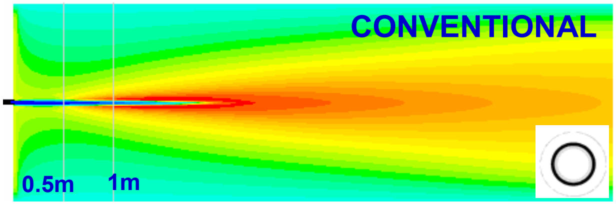
A review of the calculated energy values from the major chemical reactions associated with burners, lancing and post combustion in the EAF shows good agreement with the reported actual benefits of chemical energy, which are typically about 3.5 kWh/Nm3 O_2 (about 0.1 kWh/scf).[13]

Since there is no off-gasses chemical composition measurement system in Amsteel, the PC practice is not performed on a real-time basis, but PC set-points have been calculated in order to optimize the electrical energy savings and yield savings.

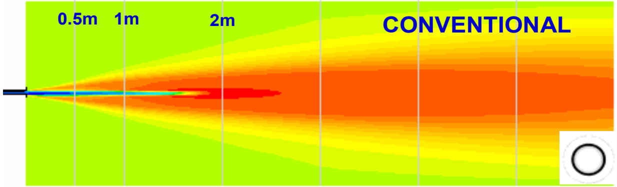
The characteristics of the KT Post Combustion Burners have been studied on a CFD simulator in order to verify the design of the burners and in order to be capable to set the appropriate flow rates in each scrap melting condition.

No further details will be given in this article about the shape and geometrical characteristics of the burner nozzles, but just for reference it can be said that oxygen and natural gas are flowing through a complex geometry of straight and helicoidal channels. Figure 3 indicates the main differences between the conventional burner previously installed at Amsteel and the new KT Post Combustion Burners.

Burner Mode: looking at the gas burning efficiency, the new optimized KT PC burners clearly reaches higher temperatures than a conventional burner and actually this is due to a much better combustion efficiency of the natural gas (35%).



Post Combustion Mode: in PC mode O2 is injected at low flow in order to burn CO generated into the EAF. It is easy to see from the simulations how the new nozzle can guarantee a higher temperature profile



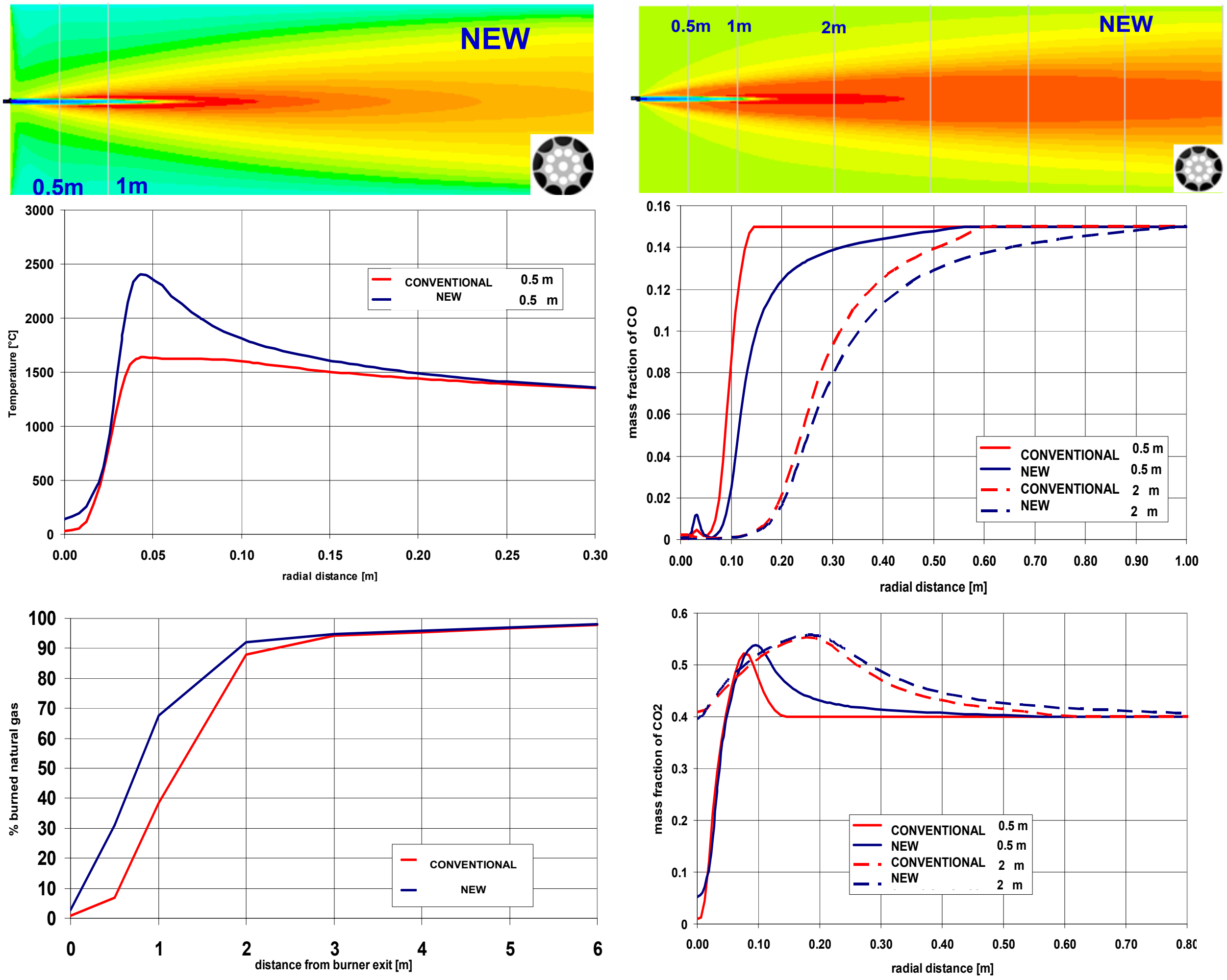


Figure 3 - Main differences between conventional burners and new KT pc-burners.

Of course the excellent characteristics of the KT PC Burner should be utilized in the right way, and this is why the layout position of the burners and the relative position to the oxygen lances is a main parameter to be carefully analyzed case by case.

5 FOAMY SLAG PRINCIPLES AND ITS APPLICATION IN AMSTEEL

One area in which steelmakers have invested significant resources over the past several years to improve steel quality and lower total costs is slag foaming in the EAF. Although efforts have been consistent, some steelmakers have met with less than consistent results in achieving and maintaining a good foamy slag practice, and this has been caused by many reasons. One of the best ways to maximize the effectiveness of a process is to provide general training and process knowledge in conjunction with tools for process monitoring. The tools need to be efficient, effective and user friendly.[14]

Improved foaming (extent, time and consistency) can significantly increase the energy efficiency and reduce electrode and refractory consumption. Time and thus productivity is affected by energy input and efficiency, but potentially also by decarburization and the balance with FeO-content of the slag. The increased use of oxygen to decrease electrical energy consumption, as said in the previous chapter, can lead to excessive FeO content in the slag. The FeO-content and volume of the slag directly affect the Fe-yield and the significant cost penalty of yield losses should be carefully weighed up against energy and productivity gains.[15]

Maintaining a predictable and foamy slag for every heat has eluded steelmakers for a long time. Mostly, adequate slag foaming occurs at the beginning of the refining but then decreases towards the end of the heat. This variability in the foaming behaviour has forced many steelmakers to melt to a "generic" low C heat for every grade of steel, regardless of final carbon specifications. The loss in the iron yield that results from this practice is somewhat offset by a more predictable arc furnace foaming practice and melt down time.[16] Endpoint control in an EAF is then a balance between reaching the desired tap %C and temperature while controlling %FeO in the slag. The relationship between %FeO in the slag and %C in the metal is clearly influenced by the supply of oxygen and carbon rate and timing of injections.[17]

Efficiency of the Carbon Injection into the slag should be divided in two parts:

- A “mechanical” efficiency, meaning how much carbon that we have injected is entering into the slag
- A “chemical” efficiency, meaning how much on the carbon entered into the slag takes part to the desired reactions

The total carbon injection efficiency is the product of the two factors.

The KT Carbon Injector is installed right on the slag line; the tip of the injector is always submerged by the EAF slag so that the “mechanical” efficiency of carbon injection when KT technology is used can be considered 100%.

For what concerns the “chemical” efficiency, this depends on various factors. First of all, the reactions that can take place, considering the ΔG_0 potential, are the FeO and MnO reduction and CO formation; chemical efficiency then will depend on: (1) FeO activity, (2) MnO and other oxides activity, (3) Oxygen activity, (4) Reaction Time, (5) Slag Temperature, (6) Carbon Type and quantity, (7) Presence of solid particles in the slag solution that can enucleate CO bubbles.

Referring, for instance, to Carbon type and quantity, several studies have been done to clarify this matter; high-temperature visual observation of the slag-carbon interfacial reaction, showed larger slag volumes for the graphite reactions compared with coke, suggesting a better slag foaming performance with the use of graphite, while higher level of carbon contributes to smaller gas bubbles in the slag and enhances slag foaming in the slag/graphite system.[18] The two reactions that have to be taken into account are:

$$FeO + C_{(s)} \Rightarrow Fe + CO_{(g)}$$

$$\mathrm{C} + \tfrac{1}{2} O_2 \Rightarrow CO_{(g)}$$

Both reactions of FeO reduction and CO formation are responsible for slag foaming. In brief, the injection of Carbon into the EAF slag is responsible for Foamy slag formation and for yield recovery. Both reactions help to reach these two targets. FeO reduction is directly responsible for the recovery of iron to the steel bath, creating CO as second product of the reaction, while CO formation is directly responsible for slag foaming, while helps Fe recovery because that reaction is subtracting oxygen for iron oxidation. Then a proper system for powder carbon injection, as it is the KT System, will enhance these two reactions. The conclusion of this short description of the relation between carbon powder injection and foaming slag formation is that a good foamy slag can drive towards iron reduction and thus yield recovery.

6 RESULTS OF YIELD RECOVERY AND EAF FIGURES IMPROVEMENTS

The results on table 3 have to consider some Meltshop restrictions. First of all it should be clarified that these results have been reported bases on same conditions of scrap mix: 97.3% of scrap, typically national scrap and imported shredded, 1.2% of HBI and 1.5% of Pig Iron.

Table 3 - Results of yield recovery and EAF figures improvements

ITEM	Metric Units	Monthly Figures 2005	Monthly Figures 2006	Major Benefits	Weekly Figures 2006
Scrap weight	t/heat	99.0	98.48		98.40
Billet weight	t/heat	87.3	87.64		90.93
Billet yield	%	87.0	89.00	+ 2.0	92.40
Productivity	t/h	79.03	102.78	+ 23.75	111.34
Tap to Tap	Min	54.32	51.16	- 3.16	49.0
Power On	Min	41.78	38.66	- 3.12	37.0
Melting	Min	-	24.60		23.54
Refining	Min	-	14.06		13.43
Power Off	Min	12.54	12.50		12.0
Electrical Energy	kWh/t	446.21	388.17	-58.04	365.51
Electrodes	kg/t	1.8	1.47	-0.33	1.47
Total Oxygen	Nm3/t	45.83	46.71		44.88
Diesel Oil	Kg/t	9.43	-		-
Natural Gas	Nm3/t	-	11.54		12.19
Coke Breeze 0.5-3	kg/t	16	16		16
Charge Coke 5-15	kg/t	24	24		24

The two columns referring to 2006 are indicating results that Amsteel has obtained on a weekly averages and results obtained on a monthly averages where on a weekly basis it is possible to reach productivity rates of about 10 metric tons per hour higher than on a monthly basis, due to scrap availability, market demand and LMF/CCM restrictions that may impede to run on a monthly basis at that level of hourly productivity. Anyhow, for the calculation of the efficiencies and the chemical parameters of the new KT System installed, the reference results should be the ones of the weekly averaged.

For what concerns the major benefits achieved with this project it should be clarified that since the beginning both Amsteel and Techint were conscious that the old EAF figures were far to an optimized situation and clear advantages in terms of reduction of Power On time and Electrical Energy were expected. It was also clear that an important improvement on the metallic yield could be obtained through a practice of carbon injection following the procedures set for the KT System. Anyhow the result obtained on a monthly basis of more than 2% recovery in the yield has been remarkable.

Considering then that the oxygen usage has not suffered any strong variation, the reasons for the yield recovery has to be found in the post-combustion, carbon injection and foamy slag theories stated here in the previous chapters. The most important literature parameters related to PC and yield recovery, well accepted by the international steelmaking community, are:

- Post Combustion reactions can give about 3 to 4.5 kWh/Nm^3 of Oxygen
- 15 Nm3/tonne for PC Oxygen as the limit that can create excessive yield losses
- A 1% of metallic yield loss can give 13.2 kWh/ton

Given a stoichiometric ratio of 2.19 for the type of diesel oil, which was the combustible previously used by Amsteel, the oxygen available in Amsteel for the supersonic injection trough the door lance before the installation of the KT lances was:

Old situation	New Situation
Oxygen Used for Oil Burners:	Oxygen used for KT burners:
$11.23 \times 2.19 = 24.59 Nm^3/t$	$11.54 \times 2 = 23.08 Nm^3/t$
Oxygen for PC & injection:	Oxygen for PC & injection:
$45.83 - 24.59 = 21.24 Nm^3/t$ Previous PC oxygen usage $= 0 Nm^3/t$	$46.71 - 23.08 = 23.63 Nm^3/t$ PC oxygen usage $\cong 9 Nm^3/t$
Oxygen injected into the bath $= 21.24 Nm^3/t$	Oxygen injected into the bath $\cong 14.63 Nm^3/t$

Considered that the yield recovery has been 2% on a monthly basis, and considering that each point of yield corresponds to 13.2 kWh/ton the EAF has in the new situation about 26.2 kWh/t less energy proceeding from the iron oxidation.

Considering the difference in terms of combustibles:

Old situation (considering 8.81 kWh/kg nominal for diesel oil):

$$9.43 \frac{kg}{t} \times 8.81 \frac{kWh}{kg} = 83.07 \frac{kWh}{t}$$ (34 including η)

New Situation (considering 9.6 kWh/Nm3 nominal for NG):

$$11.54 \frac{Nm^3}{t} \times 9.6 \frac{kWh}{Nm^3} = 110.78 \frac{kWh}{t}$$ (72 including η)

Than it is possible to calculate the difference:

$$110.78 \frac{kWh}{t} - 83.07 \frac{kWh}{t} = 27.71 \frac{kWh}{t}$$

So therefore the balance is that in terms of energy the usage of Natural Gas instead of Diesel Oil as combustible for burners almost compensates at the nominal combustion rates the less energy input proceeding from iron oxidation:

Saving: $$27.71 \frac{kWh}{t} - 26.20 \frac{kWh}{t} = 1.51 \frac{kWh}{t}$$

Then considering that the new burners have been calculated to be 35% more efficient (41% for the old burners and 65% for the new burners as overall efficiencies during the whole burners meltdown time), there are:

Saving:

$$(110.78 \times 0.65) \frac{kWh}{t} - (83.07 \times 0.41) \frac{kWh}{t} - 27.71 \frac{kWh}{t} = 10.24 \frac{kWh}{t}$$

So part of the 58 kWh/ton saved with the KT Injection System will then be 1.51 kWh/t and 10.24 kWh/t

Consequently considering that the reduction of Power Off time has not been important, so the time in which the EAF roof is open is almost the same, only the reduction of 3 minutes in Power On time lead to a better energy efficiency of the EAF. So part of the 58 kWh/t saved with the new system proceed from this efficiency improvement, which can be estimated as about 9 kWh/t.

So the additional benefit that can be explained as heat recovered from post combustion reactions and better usage of the oxygen into the flat bath will be:

$$58\frac{kWh}{t} - 10.24\frac{kWh}{t} - 1.51\frac{kWh}{t} - 9\frac{kWh}{t} = 37.25\frac{kWh}{t}$$

So the efficiency of the PC trough the KT PC-burners can be calculated as:

$$37.25\frac{kWh}{t} \Big/ 9\frac{Nm^3}{t} = 4.14\frac{kWh}{Nm^3}$$ of PC Oxygen

REFERENCES

1 http://www.tradenex.com/sites/amsteelmills/f_main.htm

2 Malaysian Iron & Steel Industry Federation, http://www.misif.org.my/index.php?navi_id=29

3 Pui-Kwan Tse, “The Mineral Industry of Malaysia”, *U.S. Geological Survey Minerals Yearbook – 2004*, pp.15.2

4 Wong, K L “Perwaja and Amsteel react to scrap shortages”, Metal Bulletin , no. 8836, pp. 25. 5 Apr. 2004

5 D. Aaager, D. Madsen, M.D. Madsen, J. Steinhausen, “Mechanisms for energy efficiency in the manufacturing industry of Peninsular Malaysia”, *Rapportserien No.90 Jan. 2000*, Institut for miljø, teknologi og samfund, Roskilde Universitetscenter (DK), Jan. 2000, pp.81/121

6 *idem*, pp.66/121

7 A. Malek Omar; T. Appasamy; F. Memoli, “DC EAF with high DRI Feeding Rates trough Multipoint Injection”, *Metallurgical Plant and Technology MPT (Germany)*, Feb. 2004, pp. 58-67

8 V. Köster, F. Memoli, “The advanced KT injection system for high-productivity EAFs”, *AISE Steel Technology* (Usa), Mar. 2002, Vol. 79, no. 3, pp. 28-35.

9 F. Memoli, C. Mapelli, P. Ravanelli, M. Corbella, “Simulation of Oxygen Penetration and Decarburisation in EAF Using Super-sonic Injection System”, *ISIJ International* (Jap), Vol. 44, May 2004, No. 8, pp. 1342-1349

10 F. Memoli, C. Mapelli, P. Ravanelli, M. Corbella, “Evaluation of the Energy Developed by a Multipoint Side-wall Burner-Injection System during the Refining Period in a EAF”, *ISIJ International* (Jap), Vol. 44, May. 2004, No. 9, pp. 1511-1516

11 Guo, D; Irons, G.A “Modeling of Scrap Melting in an Electric Arc Furnace”, *AISTech 2005 Volumes I & II and ICS 2005 Conference Proceedings*; 2005, pp. 441-448.

12 E. Pretorius, H. Oltmann, J. Jones, “EAF Fundamentals”, http://etech.lwbref.com/Home, pp. 12-25

13 S. Jepson, “Chemical energy in the EAF: benefits and limitations”, *58th Electric Furnace Conference and 17th Process Technology Conference Proceedings* (Usa), Nov. 2000, pp. 3-14

14 E. Pretorius, R.C. Carlisle, “Foamy slag fundamentals and their practical application to electric furnace steelmaking”, *Iron and Steelmaker* (Usa), Oct.99, Vol.26, n.10, pp. 79-88.

15 H. Oltmann, E. Pretorius, “Improvements in EAF operation by the use of refining simulation tools and mass-balance programs for foaming slag”, *60th Electric Furnace Conference Proceedings* (Usa), Nov. 2002, pp. 13

16 V. Sahajwalla, M. Rahman, L. Hong, N. Saha-Chaudhury, D. Spencer, “Influence of Carbonaceous Materials on Slag Foaming Behavior during EAF Steelmaking”, *AISTech 2005 Vol. I & II and ICS 2005 Conference Proceedings*, 2005, Vol. I & II, pp. 639-650.

17 M. Rahman, V. Sahajwalla, R. Khanna, N. Saha-Chaudhury, D. Knights, P. O'Kane1, "Fundamental Understanding of Carbonaceous Materials' Influence on Slag Foaming Behavior during EAF steelmaking", *AISTech 2006 Volumes I & II Conference Proceedings*, 2006, Volume I, pp 491-497

18 H. Oltmann, E. Pretorius, "Simulation of the EAF Refining Stage", *AISE Steel Technology*, Mar 2003, Vol. 80, no. 3, pp. 25-33