THE EOF STEEL PLANT - A NEW AND PROVEN TECHNOLOGY FOR OXYGEN STEELMAKING[1]

Paulo Alves Dutra Nicácio[2]
Dev Dyuti Sen[3]
Luiz Rogério Colombo Souza[4]

Abstract

Born in Brazil to replace outdated open-hearth furnaces, the EOF technology has grown and is now starting vigorously to fight for its place in the world's steel industry, facing the classical processes of the Electric Arc Furnace and the BOF Converter. In spite of 24 years of success as the exclusive steel making unit of the Gerdau Divinópolis plant, now producing 600.000 tpy at a rhythm of 38 to 42 heats per day, the EOF is little known. This paper aims at presenting the technology as per its present status, incorporating the latest improvements. Actually the EOF has experienced a great evolution, with two new units operating in India since the turn of the century. With these two units the new technology has become a reference also in the production of quality steels, e.g. for die forging and seamless pipe, having its products approved by the most stringent costumers worldwide. One of the striking aspects in this regard is the extra-low (<0,01 %) phos content, consistently obtained at a rhythm of 27 to 30 heats per day. Today the EOF presents itself as a dynamic furnace, with a high level of automation, combining two factors which use to be strongly opposed: high productivity, essential for any steel process, and extraordinary quality, fundamental for the production of special steels. Energy optimization, which lends the name to the process ("Energy Optimizing Furnace"), allows the EOF to operate with up to 40 % solid charge, added to 60 % hot metal, with energy consumption for the entire EOF unit below 40 kwh/t. This gives the EOF its great flexibility in regard to burden composition. Evolution of the equipment goes on: new engineering solutions are ensuring ever-higher operational availability and ease of maintenance. Such is the case of the new 65/70 t unit presently under installation, again in India.

Key words: EOF; Melting shop; Mini steel plant; Energy optimizing.

ACIARIA EOF - UMA NOVA E COMPROVADA TECNOLOGIA DE PRODUÇÃO DE AÇO A OXIGÊNIO

Resumo

Nascida no Brasil em substituição aos fornos Siemens Martin, a tecnologia do EOF cresceu e começa agora a buscar com vigor seu lugar na siderurgia mundial, em disputa com os processos já consagrados do Forno Elétrico e do Convertedor BOF. Apesar dos 24 anos de sucesso como base exclusiva de produção da usina da Gerdau Divinópolis, com suas atuais 600.000 t/ano ao ritmo de 38 a 42 corridas por dia, o EOF ainda é pouco conhecido. O presente trabalho objetiva mostrar esta tecnologia como hoje se apresenta, com as últimas inovações. Realmente o EOF experimentou uma grande evolução, com duas novas unidades em operação na Índia desde a virada do século. Com estas unidades o EOF se firma também como referência na produção de aços de qualidade, como, por exemplo, para forjamento em matriz e tubos sem costura, vendo seus produtos aprovados pelos clientes mais exigentes do mundo. Um dos aspectos marcantes nesse sentido é o baixíssimo teor de fósforo (<0,01 %), obtido consistentemente ao ritmo de 27 a 30 corridas por dia. O EOF de hoje se apresenta como um forno dinâmico, com alto nível de automação, aliando dois fatores muitas vezes antagônicos: alta produtividade, essencial em qualquer processo siderúrgico, com extraordinária qualidade, fundamental na produção de aços especiais. A Otimização de energia, que dá o nome ao processo ("Energy Optimizing Furnace"), permite ao EOF operar com até 40 % de carga sólida, adicionada a 60 % de gusa líquido, com um consumo total de energia dos equipamentos periféricos inferior a 40 kWh/t. Essa característica confere ao EOF grande flexibilidade na composição da carga. O equipamento continua evoluindo no tocante às soluções de engenharia, que vêm lhe conferindo alta disponibilidade operacional e facilidade de manutenção. Tal é o caso da nova unidade de 65/70 t, presentemente em instalação, também na Índia.

Palavras-chave: EO; Aciaria; Mini usina; Otimização de energia.

[1] *XXXVII Steelmaking Seminar – International, May 21th to 24th, 2006, Porto Alegre, RS, Brazil*
[2] *Metallurgical Engineer. Project Manager (Steel Making) at MINITEC Minitecnologias Ltda.*
[3] *Metallurgical Engineer. Deputy General Manager (Steel) at Southern Iron and Steel Co. Ltd. (Siscol) India.*
[4] *Chemical Engineer. Advisor to Minitec Minitecnologias Ltda, as well as to HOSPET STEELS and SISCOL, both in India.*

1 INTRODUCTION

The EOF - “Energy Optimizing Furnace” - is a melting/refining furnace associated with a scrap preheater for the production of liquid steel, working with combined submerged and atmosphere oxygen blow in an initial charge, containing hot metal, preheated solid scrap and fluxes for slag formation. Submerged oxygen blow reacts with the carbon from hot metal, generating CO bubbles that travel through the liquid bath to the furnace atmosphere, where CO is burnt to CO_2 by the oxygen blown through atmospheric injectors and supersonic lances. Such CO bubbling generates a very strong stirring that strongly increases bath surface, allowing the transfer of an appreciable amount of heat to the bath.

Sensible heat in the off-gas is used for preheating scrap, placed on a tilting arrangement in the flue gas uptake, above the furnace roof.

The following are some important features of the EOF:

- Combined oxygen blowing (submerged and atmospheric).
- Maximum utilization of the sensible heat from all reactions.
- Scrap preheating, using the sensible heat from the waste gases.
- Production of liquid steel combining hot metal and scrap in charge.
- Possibility of using high percentage of solid charge (≤40 %).
- Special tuyeres for submerged oxygen blowing, with long life.
- Efficient wet gas cleaning system.
- Deslagging from the beginning till the end of the process, without interruption of blow.
- Liquid steel of highest purity, with very low level of phosphorous.
- Very low noise level.
- Highest productivity - up to an average of 40 heats per day.

Combining the above features, the EOF presents a lower cost than any other route, combined with great flexibility with regard to the metallic charge mix.

2 EOF DESCRIPTION

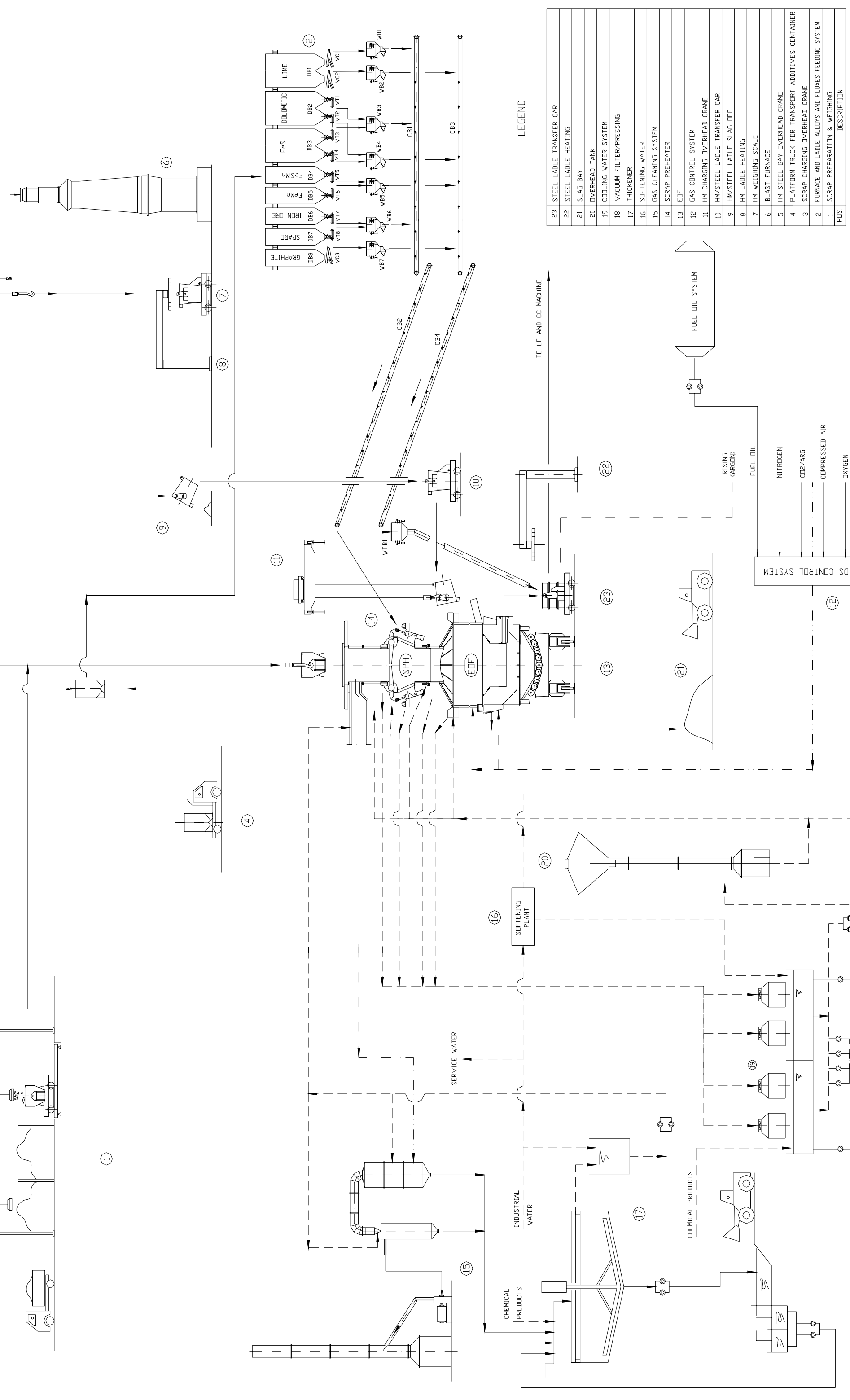
The EOF proper is a melter based on oxygen blowing - submerged and into the furnace atmosphere - in order to achieve the melting, decarburizing, dephosphorizing and desulphurizing of the charge, with the following components:

- Bottom car (2 units) of shuttle-type, to allow quick bottom exchange for a new campaign. One bottom car supports the EOF furnace in operation and the other one supports a second bottom at one or another side for relining. Both cars are equipped with roll collar tracks to tilt the furnace for tapping or deslagging. Tilting is performed by high-speed hydraulic cylinders, allowing slag-free tapping.
- EOF furnace with bottom refractory lining, split water cooled shell, water cooled roof and sealing between the furnace and Scrap Pre-heater, hot metal launder, steel tapping launder, submerged tuyeres, atmosphere injectors and supersonic lance for oxygen blowing, air-fuel burners for heating-up new bottom.
- Scrap Preheater placed immediately above the furnace, provided with water-cooled tilting fingers to support the solid metallic charges which is heated by the furnace off-gas. At the moment of charging, the fingers tilt, releasing the

preheated scrap onto the bottom of the EOF. Also provided with water-cooled inclined pipe placed below the fingers, for additions into the furnace. Further items are air injectors for post-combustion of carbon monoxide, water sprays to control the off-gas temperature before the scrap layer, off-gas uptake, water cooled sliding door and scrap charging system, both placed at the Scrap Preheater top.

- Gas Cleaning Plant (GCP), wet system, with lined downcomer duct provided with water sprays, vertical quenching chamber with water sprays, emergency stack for off-gas exhaust in case of power failure, venturi type scrubber, mist collector, ID fans with control dampers and stack, placed outside the building.
- Alloys & fluxes system, with weighing and feeding units for furnace additions during melting and ladle additions during tapping.
- Valve stand for submerged/atmosphere oxygen blowing and air-fuel burners.
- Hydraulic power pack for:
  - (a) Furnace tilting;
  - (b) All hydraulic components of the Scrap Preheater and local hydraulic pulpits/panels for maintenance; and
  - (c) Top sliding door and scrap charging system.
- Control room at working platform level, for the control of all operations of the furnace and Scrap Preheater.
- Slag pit in front of the furnace-working door and below the working platform.
- OH crane for handling of scrap buckets, alloys & fluxes bags/containers and maintenance services.
- OH crane for hot metal pouring into the furnace and maintenance services in the pouring/tapping area.
- Scrap buckets for handling and releasing the cold charge into Scrap Preheater.
- Sampling equipment for steel and slag analysis.
- Liquid steel temperature measurement equipment.
- Liquid steel carbon measuring equipment.

3 EOF FLOW DIAGRAM



4 ADVANTAGES OF THE EOF

The EOF presents some outstanding advantages:

- Extreme flexibility with regard to the metallic charge mix (up to 40% solid charge)
- No use of electrical energy for melting
- High plant productivity and availability, industrially proven
- Excellent metallurgical properties, specially with regard to dephosphorisation and desulphurisation
- Low content of tramp elements in steel
- Continuous flushing of slag during the blow; slag free tapping
- The steel tapped may be directly transferred to the continuous casting machine or undergo secondary metallurgy in ladle furnace and vacuum treatment unit
- Easy process control, fully automated
- Energy savings, due to:
    - High post combustion rate (95 %)
    - Good transfer rate of post combustion heat to the bath (30 %)
    - Scrap preheating up to 850^{o}C
    - High operational efficiency
- Constructive features, which are industrially proven for more than 20 years:
    - Horizontal submerged tuyeres for oxygen injection
    - Utilization of water cooled panels for shell walls and roof
    - Oxygen injectors and air fuel burners
    - Supersonic lances for oxygen injection
    - High efficiency Scrap Preheater, also lined with water cooled elements
    - Exchangeable bottom, in shuttle arrangement
- Operation under slightly negative pressure
    - No secondary dust emissions
- Compliance with environmental regulations, with wet gas cleaning system.
- Low noise levels and dust emission.

5 STEEL QUALITY ASPECTS

The EOF is suitable to produce all steel qualities; tapped steel presents a chemistry typical for steel obtained from combined blowing process. Due to the continuous slag flushing practice an excellent dephosphorisation (up to 0,008 %) and desulphurisation (up to 0,025 %) are attained.

Working with high percentage (>60 %) of hot metal in the charge, the EOF has as final product a steel with very low content of tramp elements, which means a great advantage when producing special steel grades such as die forging steels, specially clean steels, steels for seamless pipes etc.

The high CO partial pressure during the whole blowing period leads to very low nitrogen and hydrogen content in the steel as tapped.

Same as for all steel making routes in case of high quality and special steels, a secondary metallurgy is required, e.g. ladle refining, vacuum degassing etc.

At present Hospet Steels Plant in India is producing the following steel grades:

- Cold heading quality, such as VS14250, 10B21, 15B21, 19MnB4, 15B41, SAE4140
- Forging quality, such as SAE8620, 8627, SCM420, SAE4120, 20MnCr5, 16MnCr5, EN353, EN354, EN15A, 1045(M), 709M40(AL), SHAEM105 (DANA), 40Cr4(C), EN18, EN19, SAE4140, 42CrMoA, JIS 35 C, JIS 45 C, JIS 48 C, SAE4135 (Meritor), SAR440
- Ball bearing steel: SAE 52100,EN 31
- Free cutting steel: EN 1A,
- Semi free cutting steel: EN 8M, SAE1141
- High carbon steel: 56/60, 61/65, 66/70, 81/85, 61/65, 66/70, 78/82(V)
- Cathode bars: LER
- Special electrode: WR3
- Spring steel: 65Si7, 50CrV4, 58CrV4, 65Si7, SUP7, SUP9, SUP12V, SAE9254
- Seamless tubes: SAE1010, SAE1018, MSL-I/IA; SAE4042, SAE1541, MSL-II, MSL-IV, AP15CTQ 125, BS3059 Gr.440, MSL7, MSL8, SAE1537 (V)
- High temperature boiler: SA210 Gr.A1, SA210 Gr.C, SA192
- Applications (for BHEL): SA106 Gr-C
- Micro alloyed steel: C38+N2 for crankshaft application of Ford Motor Co, USA.

6 APPLICATION

The EOF is an economical process for all steel production routes. The advantages are greatest, however, when at least 60 % hot metal are available - either from blast furnace, cupola or from smelting-reduction processes like Corex, HiSmelt, Tecnored etc. Furthermore, in case of low availability of electrical energy the EOF becomes the solution. The flexibility regarding solid charge materials (scrap, pig iron, DRI, HBI) is a further attraction.

The ideal EOF application lies in areas with electrical energy deficit and scrap shortage. Upon availability of Hot Metal, a certain annual volume of pig iron will be produced, which, with the addition of other metallic, will allow a steel production one and a half times of hot metal availability.

A MINI STEEL PLANT of such a concept, duly equipped with a ladle furnace and CC Machine, presents the following advantages:

- It will not depend on substantial availability of electric energy
- It does not require availability of much scrap; if readily available, however, scrap may be utilized to almost 40 % of the charge
- It yields highest productivity
- It presents reduced production costs - lower than any other route
- It features improved environmental compliance - by lowering noise levels, reducing primary and secondary dust emissions
- It requires lowest capital cost
- It warrants highest cleanliness in steel

7 PERFORMANCE

The following data are characteristic for the performance of a conventional EOF:

- Furnace availability: - 340 days per year
- Charge composition: hot metal - 60 % to 100 %
  Solid charge - 40 % to 0 %
- Tap to tap time: - 30 to 50 minutes
- Oxygen consumption: - 50 to 70 Nm^3/t
- Oil consumption (heating of new bottom): - < 0,5 kg/t
- Refractory consumption: Relining - 1 to 2 kg/t
  Gunniting - 3 to 4 kg/t
- Heats per campaign: - 800 to 1.500
- Bottom exchange (between campaigns): - 12 to 24 hours.

8 SPECIFIC CONSUMPTION FIGURES FOR CONVENTIONAL PRODUCTION

Hot Metal (example)	- 778 kg/t (70 %)
Iron and Steel Scrap (example)	- 333 kg/t (30 %)
Metallic yield	- 87 to 89 %
Lime	- 50 kg/t (depending on P in hot metal)
O_2	- 50 to 70 Nm^3/t
N_2/CO_2	- 3 to 5 Nm^3/t
Fuel	- 3 to 5 Mcal/t
Tapping temperature	- 1700°C without ladle furnace
	- 1650°C with ladle furnace

9 CAPITAL EXPENDITURE

A standard EOF, conceived as a turn-key unit and including supplies, civil, erection etc will require a capital expenditure of the order of US$50, -/tpy rated capacity, under conditions prevailing in Brazil.

10 REFERENCE LIST AND REMARKS

Following is a reference list of EOF installations in the world with brief comments:

Nr.	Company	Country	Capacity (Heat Size – t)	Year of Installation	Remark
1.	PAINS / Pilot	Brazil	22	1982 (Apr)	(1)
2.	PAINS Nr.1	Brazil	30	1982 (Dec)	(2)
3.	PAINS Nr. 2	Brazil	32	1988 (Mar)	(3)

4.	ALIPERTI	Brazil	60	1988 (Aug)	(4)
5.	TATA Steel	India	80	1989 (Nov)	(5)
6.	AFS / Trieste	Italy	60	1991 (Oct)	(6)
7.	SISCOL	India	35 / 40	1998 (Aug)	(7)
8.	HOSPET	India	35 / 40	1998 (Sep)	(8)
9.	PT Perkasa	Indonesia	40	-	(9)
10.	SISCOL	India	65 / 70	2006	(10)

Remarks:

1. This prototype operated for only 8 months, until commissioning of the industrial unit, EOF Nr. 1.
2. Operated for 7 years, until EOF nr. 2 took over the entire production of PAINS.
3. This EOF started with a tapping weight of 32 t. Over the years capacity has been enhanced to 43 t and production reached more than 600.000 t liquid steel in 2004, corresponding to a rhythm of 42 heats per day. Production concentrates on rebar and clean carbon steels. Current charge pattern: 67 % HM; 20 % steel scrap; 13 % iron scrap and pig iron. Since 1998 the plant is called GERDAU Divinópolis.
   Note: An increase in tapping weight to 50 t is presently being considered, along with other improvements.
4. This EOF stopped operation in 1989, when the entire ALIPERTI plant was shut down.
5. This EOF, installed within existing Open Hearth melt shop SMS 3, never reached full production due to non-availability of oxygen and hot metal. Also ingot-casting facilities were missing. Operation was stopped and EOF dismantled, preceding closure of SMS 3 OH shop, in year 1993.
6. At present this plant belongs to a Russian group. Production line: wire rod, clean carbon steels. Charge mix: 60% HM, 36 % steel scrap and 4 % iron scrap.
7. Unit is operating over the last 7 years, at a rhythm of 22 heats per day, with 40 t tapping weight, due to lack of hot metal. Production concentrates on carbon steels and rebar. Recently SISCOL has been taken over by the JINDAL Group and capacity of BF has been enhanced, leading to a higher number of heats per day.
8. Unit is producing fully for the last 6 years and is now operating at a pace of 27 heats per day, with 45 t tapping weight, yielding over 400.000 tpy liquid steel. Entire production is of special steels (die forgings, seamless tube etc).
9. In years 1997/1999 PT Perkasa Indosteel had approved the installation of a mini steel plant based on the Mini Blast Furnace / EOF route. Engineering for the 40 t EOF had already been fully carried through when the project was stopped due to economic crisis.

10. JINDAL is carrying through an expansion of the former SISCOL plant, from 0,3 to 1,0 mtpy. Core of this expansion are a second BF and a new 65/70 t EOF.

10 CONCLUSION

At present the EOF is a proven technology that can compete with any other classical process to produce steel, with the strong advantage of being specifically able to produce the most stringent special steels as routine. A low investment and operational cost along with its great flexibility regarding to burden composition and low energy consumption brought the EOF to the top to be carefully considered for any new steel plant.