ONSITE RESIDUES RECYCLING AND EFFICIENCY IN A DR-EAF BASED STEEL PLANT: ANALYSIS BY A VALUE-IN-USE MODELS[1]

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The introduction of a new ironmaking technology (TECNORED) for onsite recovery and recycling of the steelmaking residues generated at a typical DR (direct reduction) integrated mini-mill has been simulated by "Value In Use" models, followed by an assessment of the pros and cons of this approach. The idea in this preliminary study was to optimize overall production cost, ensure a stable supply of high-quality and low cost virgin iron units to the melt-shop and avoid any residues disposal. To achieve these goals, a Tecnored plant has been considered "over-the-fence" the steel plant, receiving all iron and carbon enriched residues from both the DR plant and the melt-shop operations, then supplying hot metal to be used as part of the metallic charge input of the EAFs. Different scenarios have been envisaged.

Key-words: DRI, EAF, tecnored

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1 INTRODUCTION

In 2002, dictated by the expressive production of some countries in Asia, specially China, the world crude steel production crossed the limit of 900 Mt (million tons), figure well ahead of the most optimist forecasts of only 1 year ago(1). As far as the routes of production are concerned, the shares of the BOF and EAF routes remained about the same as in 2001, with 60 and 34% percent respectively(2), with both routes raising the same 7% between 2001 and 2002. Nonetheless it is likely to change in the future with the EAF route increasing his shares in many parts of the world.

In this scenario the steel production via the gas based DR-EAF route may represent a cost effective technological alternative to be regarded specially in locations plenty of natural gas and scarce of both steel scrap and electricity. To date annual production of DRI/HBI, although far away from the total production of pig iron, increased over 10% (from 40 to 45 Mt) corroborating that the educated use of DRI/HBI in iron and steelmaking operations is gaining more adepts every year.

Continuous optimizations of such steelmaking route have been deserving particular attention, aiming at overall steel operating cost reduction as well as the attainment of better environmental patterns. At the same time, new ironmaking technologies, fitting the mini-mills capacity requirement and more flexible in the use of alternative raw materials have been coming out successfully and the first tonnages of hot metal production via these emergent processes on industrial basis are expected to occur very soon. These factors combined may represent a true spin-off in the sector leading to the ***integration of the mini-mills*** by these new ironmaking technologies, ensuring stable supply of low-cost high-quality iron units, specially hot-metal(3,4).

This paper simulates an interesting way in which an existing DR integrated mini-mill can derive the benefit of reducing crude steel operating cost and optimizing environmental performance through the introduction of one of these new ironmaking technologies viz: the Tecnored process. In this simulation, the Tecnored process has been considered to make hot-metal from all the in-plant iron and carbon enriched residues from the DR plant as well as the melt-shop, then supplying hot metal as part of the metallic charge of the EAFs. This simulation can be extended in the future to optimize the economics of the entire steel plant operations.

Also in this simulation, the steelmaker would make no investment on the Tecnored plant but buys the hot-metal on a long-term “take-or-pay” contract. This model makes it possible and interesting for third parties to become hot-metal providers “over-the-fence” within a steel mill environment.

2 VALUE IN USE MODELS

Value-In-Use (VIU) models are considered nowadays as a powerful tool to assist the decision making process for new investments, marketing strategies, etc. In brief, **VIU express the relative price difference between two materials that can be applied to achieve the same end cost of a product made in a specific process.**

The basis of the concept of VIU is that, in any steelmaking process, so is the EAF, the type of raw materials used strongly affects process efficiency, yield and energy consumption due to their intrinsic characteristics. Traditionally, the EAF metallic charge has been 100% cold scrap with few exceptions but, the use of scrap substitute material is growing since a few years ago to a point where there is an overall consensus that hot-metal is the premium metallic source, with the highest VIU among all options, with its use in EAFs becoming every day more popular worldwide.

By using VIU models, EAF operators are able to predict both the operating norms of the EAF with a specific set of raw materials and the final steel production cost.

2.1 THERMO-CHEMICAL MODELS

To carry-out the simulations, three different thermo-chemical models have been used:

2.1.1 EAF model

Developed under Visual Basic® environment by RS Consultants, this tool was acquired by Samarco Mineração S.A. in 2002 to be utilized in technological assessments jointly to its customers. This thermo-chemical model consists basically of a group of mathematical equations which interactively solve mass and heat balances. All major chemical reactions and phenomena present in EAF operation have been considered in this model. Since this is non-dynamic tool, variations on tap-to-tap times (TTT) are determined in relation to a built-in case.

Main Inputs: Metallic charge mix characteristics, Fluxes and Carbon bearing materials characteristics, Dimensions of the EAF, Electrical energy supply conditions, Cooling water flow inlet and outlet temperatures, Process parameters (power-off time, aimed temperature and composition of the steel and slag, off-gases temperature, fumes generation rate and composition, refractory and electrodes consumption, post-combustion ratio, air leakage, partition coefficient, etc.).

Main Outputs: hourly production, TTT, electricity consumption, slag weight, volume of off-gas generated, oxygen and fluxes consumption, crude steel characteristics (temperature, chemistry) and production cost[7].

2.1.2 DR Shaft furnace model

This model has been developed by Catholic University (PUC-Rio) and was used in this work only to simulate the standard DR operation of a natural gas-based shaft-furnace.

Main Inputs: iron burden characteristics (blend, chemistry, fines charged and generated in the process), bustle gas (flow-rate, temperature and chemistry), top gas parameters (temperature, chemistry and fines content) and cooling characteristics (cooling gas analysis, DRI discharge temperature and carburization).

Main Outputs: productivities and specific consumptions using the following pre-fixed conditions: metallization and total production.

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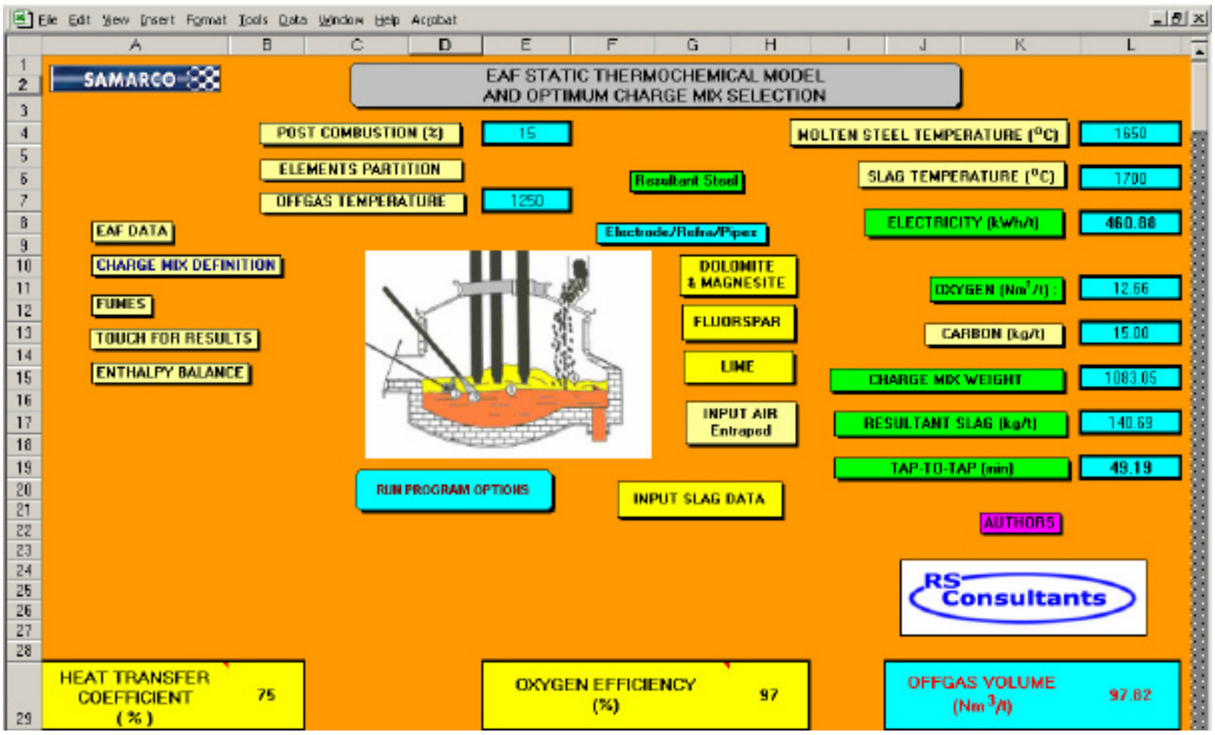
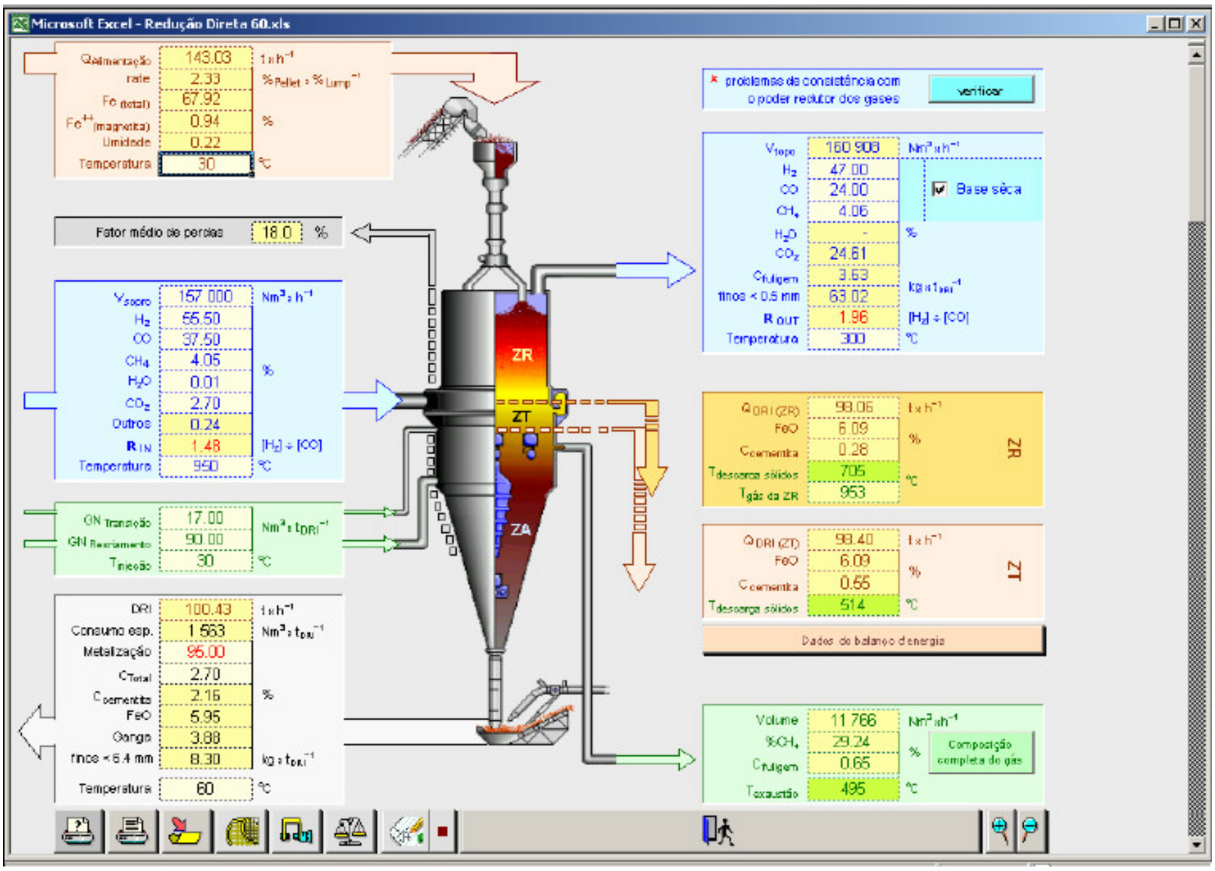
[7] This cost represents the metallics and conversion costs since labor, overheads, capital, etc., have not been included in the analysis.



EAF STATIC THERMOCHEMICAL MODEL
AND OPTIMUM CHARGE MIX SELECTION

POST COMBUSTION (%) 15
OFFGAS TEMPERATURE 1250
MOLTEN STEEL TEMPERATURE (°C) 1650
SLAG TEMPERATURE (°C) 1700
ELECTRICITY (kWh/t) 460.88
OXYGEN (Nm^3/t) : 12.66
CARBON (kg/t) 15.00
CHARGE MIX WEIGHT 1083.05
RESULTANT SLAG (kg/t) 140.69
TAP-TO-TAP (min) 49.19
HEAT TRANSFER COEFFICIENT (%) 75
OXYGEN EFFICIENCY (%) 97
OFFGAS VOLUME (Nm^3/t) 97.82

Figure 1 – Main screen of the EAF thermo-chemical model.



$Q_{alimentação}$ 143.03 $t \times h^{-1}$
rate 2.33 $\%_{Pellet} \div \%_{Lump}^{-1}$
$Fe_{(total)}$ 67.92
$Fe^{++}_{(magnetita)}$ 0.94 %
Umidade 0.22
Temperatura 30 °C

Fator médio de perdas 18.0 %

V_{sopro} 157 000 $Nm^3 \times h^{-1}$
H_2 55.50
CO 37.50
CH_4 4.05
H_2O 0.01 %
CO_2 2.70
Outros 0.24
R_{IN} 1.48 $[H_2] \div [CO]$
Temperatura 950 °C

$GN_{Transição}$ 17.00 $Nm^3 \times t_{DRI}^{-1}$
$GN_{Resfriamento}$ 90.00
$T_{injeção}$ 30 °C

DRI 100.43 $t \times h^{-1}$
Consumo esp. 1 563 $Nm^3 \times t_{DRI}^{-1}$
Metalização 95.00
C_{Total} 2.70
$C_{cementita}$ 2.16 %
FeO 5.95
Ganga 3.88
finos < 6.4 mm 8.30 $kg \times t_{DRI}^{-1}$
Temperatura 60 °C

* problemas de consistência com o poder redutor dos gases

V_{topo} 160 908 $Nm^3 \times h^{-1}$
H_2 47.00
CO 24.00
CH_4 4.06
H_2O - %
CO_2 24.61
☑ Base sêca
$C_{fuligem}$ 3.63 $kg \times t_{DRI}^{-1}$
finos < 0.5 mm 63.02
R_{OUT} 1.96 $[H_2] \div [CO]$
Temperatura 300 °C

ZR
$Q_{DRI (ZR)}$ 98.06 $t \times h^{-1}$
FeO 6.09 %
$C_{cementita}$ 0.28
$T_{descarga\ sólidos}$ 705 °C
$T_{gás\ da\ ZR}$ 953

ZT
$Q_{DRI (ZT)}$ 98.40 $t \times h^{-1}$
FeO 6.09 %
$C_{cementita}$ 0.55
$T_{descarga\ sólidos}$ 514 °C

Volume 11 766 $Nm^3 \times h^{-1}$
$\%CH_4$ 29.24 %
$C_{fuligem}$ 0.65
$T_{exaustão}$ 495 °C

Figure 2 – Main screen of the DR thermo-chemical model.

2.1.3 TECNORED Furnace model

This model has been developed by Tecnored, considering the specific features of self-reducing technology, to simulate the process. The calibration of the model has been made based on actual production data from Tecnored pilot-plant and probing the inner of the furnace during the trials or after furnace quenching.

Main Inputs: Raw material mix and chemical composition, hot and cold blast parameters, heat losses, charge moisture.

Main Outputs: Fuel-rate, top gases characteristics, slag-rate, hot-metal and slag characteristics.

3 CASE STUDY

3.1 BASE CASE

The starting point of the analysis was to devise a base case, called as “current scenario”, to allow for further comparisons. Such a case considers a generic steel plant (GSP) producing up to 3 million tons (Mtpy) of crude steel on a electric arc furnace (EAF) based melt shop fed by a 2.4 Mtpy captive DR plant. The metallic charge is complemented by home and purchased scrap. Home scrap is generated at a rate of 100 kg/tls.

The melt shop of the GSP is equipped with 3 EAFs of 160 t each (heat size) with individual 110 MVA transformers. This simulation considered all EAF’s charge mix even. Future analysis may simulate different charge mixes for each furnace.

3.1.1 Charge Mix

Since the GSP is a mini-mill integrated with a gas based DR, the EAF charge mix in the current scenario is composed basically by cold DRI (73%) complemented by home scrap (9%) and market scrap (18%).

3.1.2 Virgin Iron Units Supply

The captive DR plant is composed by 3 gas based DR shaft furnaces, charging 100% pellets as iron ores burden, producing 0.8 Mtpy of cold DRI each. The DRI produced presents the following characteristics:

- Metallization: 94%
- Carbon content: 2%
- Fe_{tot}: 92.28%
- Gangue content: 4.14%

This DR plant presents 3 screening stations that will provide part of the iron units to the new ironmaking process. In the current scenario these units operates as follows:

Unit	Material	Size range (mm)	Efficiency (%)	Destination
1st	DR Pellets	+6.3	70	+6.3mm: follow to DR reactors - 6.3mm: follow to 2nd screening unit
2nd	DR Pellets	-6.3+3	50	-6.3+3 mm: return to process -3mm: sold to the cement market
3rd	DRI	+3	100	+3mm: follow to EAF -3mm: briquetted before EAF

The operating norms of the DR reactors considered in this first round of simulation and used to run the respective model, represent a world class practice reported by some operators worldwide. This practice have not been discussed neither modified in this scope, although there is a strong belief that further improvements on the DR reactors operation shall result after the various scenarios are applied, mainly due to less fines in the charge.

3.1.3 Melt-shop Operation

Based on a literature review of world-class EAF operations(5,6,7), all input data required have been provided to the thermo-chemical model. The following table shows the typical furnace performance in the current scenario:

Table I – Typical melt-shop norms

Power consumption	502 kWh/tls
Power off time	15 min
Tap-to-tap time	72 min 48”
Productivity	123.6 t/h

Oxygen consumption	14.5 Nm^3/tls
Refractory consumption	2.0 kg/tls
Electrodes consumption	4.0 kg/tls
Transformer usage	97.7 MVA

3.1.4 Economics of the Current Scenario

In the current scenario the crude steel production cost predicted by the thermo-chemical model was 136.13 US$/tls. This low figure results from the low cost production of high quality DRI. Table II shows the costs considered for the various metallics as well as for the consumables of the EAF.

Table II – Unitary cost of metallics and consumables.

DRI (transferred cost)	80 US$/t
Home scrap	140 US$/t
Market scrap	140 US$/t
Power	0.035 US$/kWh

Oxygen	0.070 US$/Nm^3
Refractory	1 US$/t
Electrodes	2 US$/t
Dolomite	25 US$/t

4 ALTERNATIVE SCENARIOS / RESULTS

Assisted by the thermo-chemical models, 3 alternative scenarios have been devised and simulated, followed by an overall assessment of the role of the new ironmaking technology into the production flow.

The following common assumptions have been the starting point for all the scenarios proposed:

- Purchase of external steel scrap has to be abolished;
- Yearly consumption of captive DRI has been unmodified (DR plant already exists and is responsible for the production of a high quality product at low costs);
- 2nd screening unit not needed since the undersize material from the 1st unit (-6.3mm) is transferred to the new ironmaking plant;
- As a result of the above the supply of DR pellets to the plant varied only to offset the screened material no longer transferred to the DR furnace;
- DRI undersize fraction from the 3rd screening unit is not briquetted but transferred to the new ironmaking plant;
- Screening units (1st and 3rd) are optimized for an efficiency of 90%.

This collection of DR pellet fines and DRI fines from the screening units targets either the supply of iron units to the new ironmaking plant and to improve the operation of the DR reactor as well as the EAF.

Since the recovering/recycling of the residues available (DR pellet fines, DRI fines, DR off-gas dust, EAF off-gas dust) does not supply all iron/carbon needed, additional pellet feed fines (PFF) and semi-anthracitic coal (lump and fines) are required. Both materials can be supplied by the DR pellets supplier.

Table III shows the chemical composition of the materials used into the Tecnored furnace to hot metal production

Table III – Chemical analysis of the iron enriched residues and PFF.

Item	%Fe total	%Fe Met	%C	$\%SiO_2$ + $\%Al_2O_3$	%CaO + %MgO	%S	%Zn
Pellet Feed Fines	66.50	0.00	0.00	2.05	0.04	0.003	0.004
DR pellet fines	67.81	0.00	0.00	1.51	1.20	0.002	0.005
DR off-gas dust	72.71	17.35	0.40	1.62	1.28	0.002	0.005
DRI fines	92.28	86.74	2.00	2.05	1.63	0.003	0.007
EAF off-gas dust	29.87	0.00	0.13	4.68	10.67	0.500	6.51

4.1.1 Scenario 1

In the scenario 1, a 0.6 Mtpy Tecnored plant is introduced. The hot metal produced is charged into the EAFs at 1320°C at a cost of 140 US$/t (sold by the owner of the Tecnored plant).

Yearly crude steel production has been kept at 3 Mtpy, and the natural shortening in tap-to-tap time due to the use of hot-metal was offset by reducing the transformer operating norm from 97.7 to 81.6 MVA.

The capacity of the Tecnored unit has been determined aiming only at to eliminate the need for purchasing external scrap.

EAF charge mix in scenario 1 is: DRI: 73% / Internal scrap: 9% / Hot-Metal: 18%.

Steel cost reference reduced from 136.13 to 133.15 US$/tls.

4.1.2 Scenario 2

Scenario 2 considers an expansion in crude steel production from 3 to 3.5 Mtpy thru simple shortening the tap-to-tap time of the EAFs due to the effects of hot-metal usage (assumed no restrictions downstream the EAFs).

Since no purchase of external scrap is allowed, the metallic demand is assured by captive DRI (2.4 Mtpy), home scrap (0.35 Mtpy) and hot-metal (1.08 Mtpy) from the Tecnored plant, hence the capacity of the Tecnored furnace is 1.08 Mtpy in the scenario 2.

EAF charge mix in scenario 2 is: DRI: 63% / Internal scrap: 9% / Hot-Metal: 28%.

In this case there was no change in the steel cost reference compared to the current scenario (136.13 to 136.38 US$/tls) even with higher proportion of hot-metal (140.00 US$/t) in the mix replacing low cost captive DRI (80.00 US$/t).

4.1.3 Scenario 3

Scenario 3 considers that the capacity of the Tecnored hot-metal plant is 0.6 Mtpy (scenario 1) and the yearly crude steel production targeted is 3.5 Mtpy (scenario 2).

No expansion of both the ironmaking plants (DR and Tecnored) and melt-shop is allowed, and the new yearly crude steel production is accomplish by purchasing market DRI at 140.00 US$/t (similar characteristics as the domestic DRI).

EAF charge mix in scenario 3 is: Captive DRI: 63% / Internal scrap: 9% / Hot-Metal: 16% / Market DRI: 12%.

Due to the higher proportion of DRI into the charge, the transformer utilization approaches the nominal capacity (99 MVA) and the steel cost reference increased from 136.13 to 140.70 US$/tls.

4.1.4 Tecnored plant

As an indication some of the figures concerning the hot-metal production at the Tecnored plant are shown in table IV for the various scenarios.

Table IV – Tecnored hot-metal production

	SCENARIO 1 (0.6 Mtpy)	SCENARIO 2 (1.08 Mtpy)	SCENARIO 3 (0.6 Mtpy)
Iron units consumption			
PFF	59.50%	76.85%	58.63%
DR PELLET FINES	11.57%	6.43%	11.50%
DR OFF-GAS DUST	11.59%	6.45%	11.52%
DRI FINES	10.35%	5.76%	10.29%
EAF OFF-GAS DUST	6.99%	4.51%	8.06%
TOTAL in tpy (%)	**858,980 (100%)**	**1,544,140 (100%)**	**864,318 (100%)**
Carbon units consumption[8]			
Semi-anthracitic coal (fines)	353 kg/t	360 kg/t	352 kg/t
Semi-anthracitic coal (lump)	448 kg/t	449 kg/t	449 kg/t
Potential credits			
Slag-rate	248 kg/t	246 kg/t	254 kg/t
Surplus top gas	2.82 Gcal/t	2.84 Gcal/t	2.81 Gcal/t

Table V resumes the main results of the simulations.

Table V – Main results of each scenario

	CURRENT SCENARIO	SCENARIO 1	SCENARIO 2	SCENARIO 3
Steel production (Mtpy)	3.00	3.00	3.50	3.50
Crude steel cost (US$/tls)	136.13	133.15	136.38	140.7
Cost difference compared to current scenario (US$/tls)	na	- 2.98	+ 0.25	+ 4.57
Annual savings (MUS$)	na	8.9	- 0.9	- 15.9
Potential credits from Tecnored (MUS$)[9]	na	5.9	10.5	5.9
Power consumption (kWh/tls)	502	420	358	420
Power off-time (min)	15	15	15	15
Tap-to-tap time (min)	72	72	62	62
EAF Productivity (tph)	123.6	123.6	143.5	143.5
Oxygen consumption (Nm^3/t)	14.5	22.7	26.4	21.9
Refractory consumption (kg/tls)	2.0	1.67	1.42	1.67
Electrodes consumption (kg/tls)	4.0	3.34	2.85	3.34
Transformer use (MVA)	97.7	81.6	84.3	99.0

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[8] Semi-anthracitic coal: Carbon: 75%, VM: 12.50%, Ashes: 12.50%
[9] Slag credited at 5.00 US$/t and Surplus gas credited at 3.00 US$/Gcal

4.2 Remarks

All benefits of these simulations are supposed to be different case-by-case when different boundary conditions, localization and other particularities are considered.

The practice of hot-metal charging in EAF is relatively new and involves specific know-how in order to get all potential benefits

Changes in electrode consumption have been determined as a function of electrical energy consumption(7).

5 CONCLUSIONS

The final assessment of this round of simulation lead to the following conclusions:

- The alternative of use a new ironmaking technology to produce hot-metal "over-the-fence" a mini-mill, charging the product in EAF is a remarkable worth alternative to increase productivity, recover industrial residues, escape from the instability of market steel scrap supply and lay on a stable supply of high-quality iron units.
- Increase in crude steel production can be accomplished by the use of hot-metal without major investments in the melt-shop due to an observed tendency of shortening in tap-to-tap time.
- Conversion costs of steel tends to be lower when DRI and hot metal may be utilized jointly, due to lower electrical energy, refractories and electrodes consumption.

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