FUEL-RATE AND DOWNSTREAM POWER CO-GENERATION IN A TECNORED IRONMAKING PLANT – A STRATEGIC ANALYSIS USING A HYBRID MODEL[1]

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Abstract

The Tecnored process is very flexible with regards to the selection of carbon units both as fuel and as reductant. However, the choice of a specific carbon unit for a given location can effectively be done only after a thorough evaluation of the various technical, economic, strategic and environmental aspects involved. This paper discusses the impact and implications of the use of different carbon units in the Tecnored process over the fuel-rate and power co-generation potential, using a Hybrid model specifically developed by Tecno-Logos and DCMM/PUC-Rio for the Tecnored ironmaking furnace, derived from a variety of sources including thermochemical and actual operating data from both blast furnace and Tecnored furnace operations

Key words: Tecnored; Ironmaking; Environment; Co-generation.

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1 INTRODUCTION

The unrelenting pressure to produce steel at competitive costs and with a low environmental footprint, especially those related with the emission of green house gases, is a strong driver for the optimization of energy use in the modern steelmaking industry.

Within the ironmaking step of steel production, one can suggest that greater energy optimization can be achieved by:

- dismissal of raw material treatment steps like coking and sintering;
- reduction of thermal losses and;
- recovery of the energy contained in the top gases both sensible and chemical.

These actions are effectively accomplished with the Tecnored ironmaking process in the following manner:(1-3)

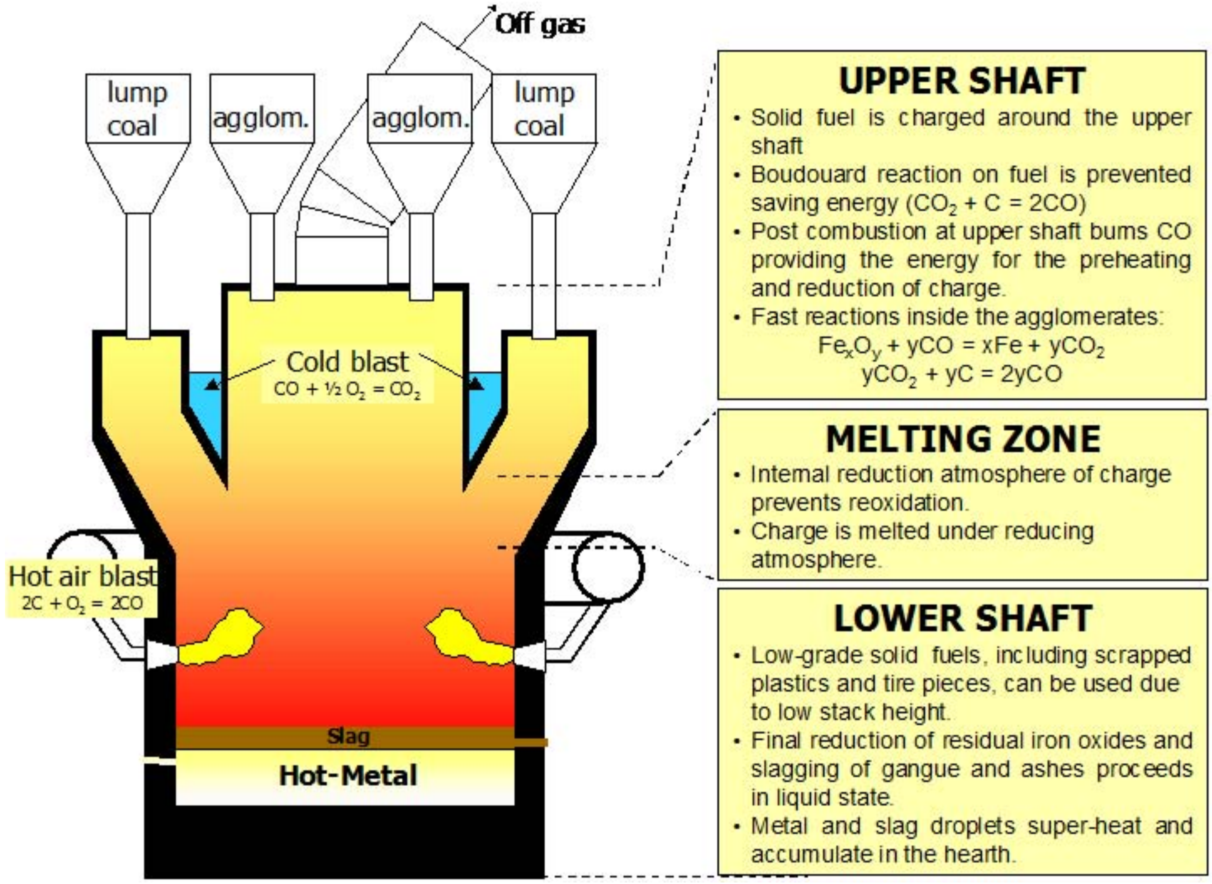
- use of cold bonded, self-reducing agglomerates, hence dismissing the need for induration furnaces;
- use of low shaft furnace, hence allowing the use of non-conventional solid fuels and, due to the lower furnace wall area, lower thermal losses to the exterior;
- low top gas temperature and downstream use of the chemical energy for air pre-heater and power co-generation.

This paper specifically addresses the last item, i.e., the use of the chemical energy in the top gases for heating of the process air with the surplus energy used in the production of electricity. A few cases were simulated varying both the fuel type and hot blast equipment.

2 TECNORED PROCESS

The Tecnored Process is a new approach to ironmaking technology that uses cold bonded self reducing agglomerates (pellets or briquettes), produced from iron ore fines or iron bearing residues, plus fines of pet coke, coal, charcoal, or carbon bearing residues 1. These materials, mixed with fluxing and binding agents, are agglomerated and cured in purpose designed dryers, producing briquettes/pellets that have sufficient strength for the physical and metallurgical demands of the Tecnored process. The agglomerates produced are smelted in a shaft furnace of high efficiency and unique design, the Tecnored furnace, that due to its short stack height, uses low cost solid fuels, such as green petroleum coke briquettes, coal or semi cokes (Figure 1).

Tecnored produces blast furnace type hot metal and slag and a top gas that is slightly richer in calorific value than the conventional blast furnace ironmaking. The top gas, after cleaned, is used for air pre-heating with the surplus used for co-generation of electricity, in quantities higher than the internal use, therefore, producing an excess of electricity that can be sold for third parties.(4-5)



UPPER SHAFT

- Solid fuel is charged around the upper shaft
- Boudouard reaction on fuel is prevented saving energy ($CO_2 + C = 2CO$)
- Post combustion at upper shaft burns CO providing the energy for the preheating and reduction of charge.
- Fast reactions inside the agglomerates:

$$Fe_xO_y + yCO = xFe + yCO_2$$

$$yCO_2 + yC = 2yCO$$

MELTING ZONE

- Internal reduction atmosphere of charge prevents reoxidation.
- Charge is melted under reducing atmosphere.

LOWER SHAFT

- Low-grade solid fuels, including scrapped plastics and tire pieces, can be used due to low stack height.
- Final reduction of residual iron oxides and slagging of gangue and ashes proceeds in liquid state.
- Metal and slag droplets super-heat and accumulate in the hearth.

Figure 1 – Cross sectional of the Tecnored Furnace

3 DESCRIPTION OF THE HYBRID MODEL

For the simulation of the cases considered in this work a hybrid model, specifically developed for the Tecnored Process, was used. The mathematical model was developed by Tecno-Logos S/A, owner of the technology, and by the department of materials science and metallurgy of the Catholic University in Rio (DCMM/PUC-Rio), long time partner in the development of this novel technology.

The Tecnored ironmaking process oriented thermo-chemical model was built after a thorough assessment of the process phenomena considering the peculiarities of the reactor and a number of applicable thermodynamic and operational aspects.

In spite of being a thermo-chemical model, bench scale and pilot plant based kinetic considerations have been taken in account in order to estimate the extension of the main reactions in different parts of the furnace. The framework involved in the division of the furnace in three main zones, namely Solid-state Reduction Zone (SRZ), Softening and Melting Zone (SMZ) and Dripping and Hearth Zone (DHZ). In each of the zones the existing chemical processes and overall process phenomena have been evaluated conditional to the global mass balance ruling the process. The model developed is now extensively used to predict the behavior of the process under different conditions of raw material usage and operational modes. Moreover, the model can be applied to compare the results of the industrial plant (under construction) with the available bench and pilot plant data, with the intention of gathering information to be used in the optimization of the model and subsequently the process.

Figure 2 shows a schematic view of the furnace as considered in the model, detailing the main inputs and outputs considered.

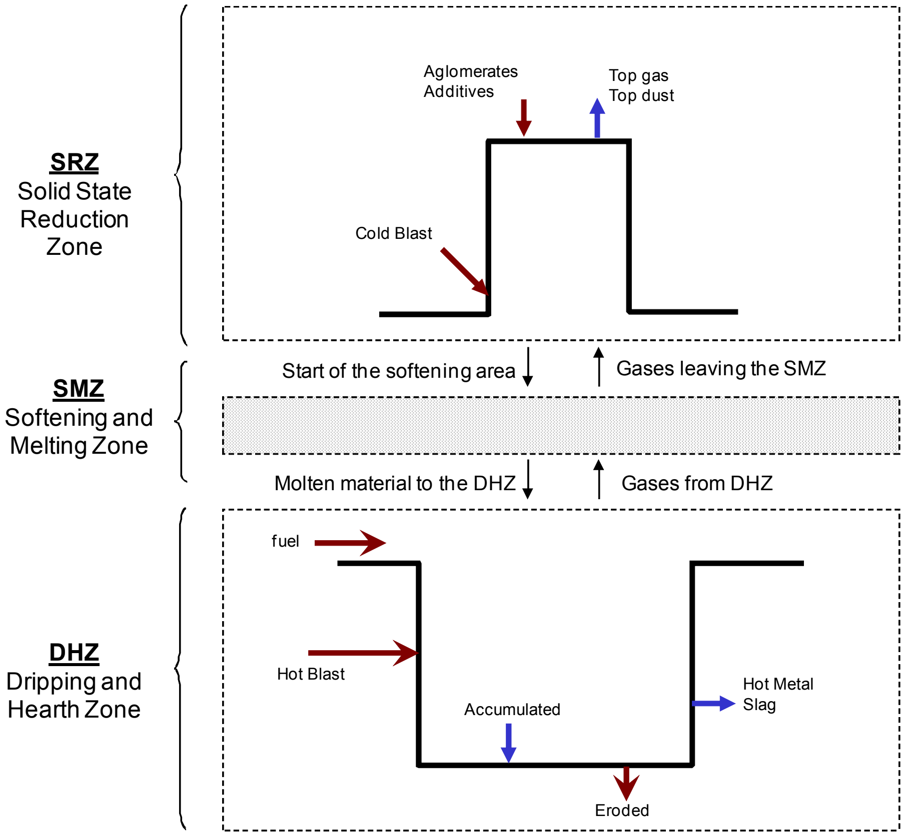


Figure 2 – Main inputs and outputs considered in the model

Stepwise, the hybrid model performs the following subroutines:

0. Boundary conditions are defined by the user, as follows:
    a. Agglomerate data (Carbon:Oxide ratio, Binder content, Moisture, etc.)
    b. Operational data (Post combustion model, internal pressure, metallization degree at the softening zone, shift reaction inside the agglomerates, etc.)
    c. Hot metal characteristics (Iron yield, Titanium behavior, etc.)
    d. Slag characteristics (Sulfur partition between slag and hot metal, Alkali retention in the slag, etc.)
    e. Top gas characteristics (Dust content and composition, etc)
    f. Thermal parameters (Temperatures of the various inputs and outputs, thermal losses, reference temperatures, etc.)
    g. Other technical data (Erosion of refractory lining, hot blast heater outlet temperature and efficiency, etc.)
    h. Economic data for OPEX calculation purposes
1. Calculation of the agglomerate composition, after selection of the raw materials in the model's databank
2. Selection of the solid fuel in the model's databank
3. Calculation of the global mass balance (balance is closed by the fuel rate)
4. Calculation of the global energy balance (Top gas temperature closed the balance)

5. Calculation of the mass balance for each of the three zones, including the various interface streams (composition of primary slag and metal, process gas composition in the different frontiers, etc.)
6. Calculation of the energy balances for each of the three zones, hence defining the interface temperatures
7. Final check of the results and adjustment of the input variable if needed.

Also, using the output data generated by the internal calculations, an Operational Cost of a virtual or existing installation can be estimated. Moreover, the anticipated slag chemistry allows its evaluation using ternary diagrams that are automatically plotted (Figure 3).

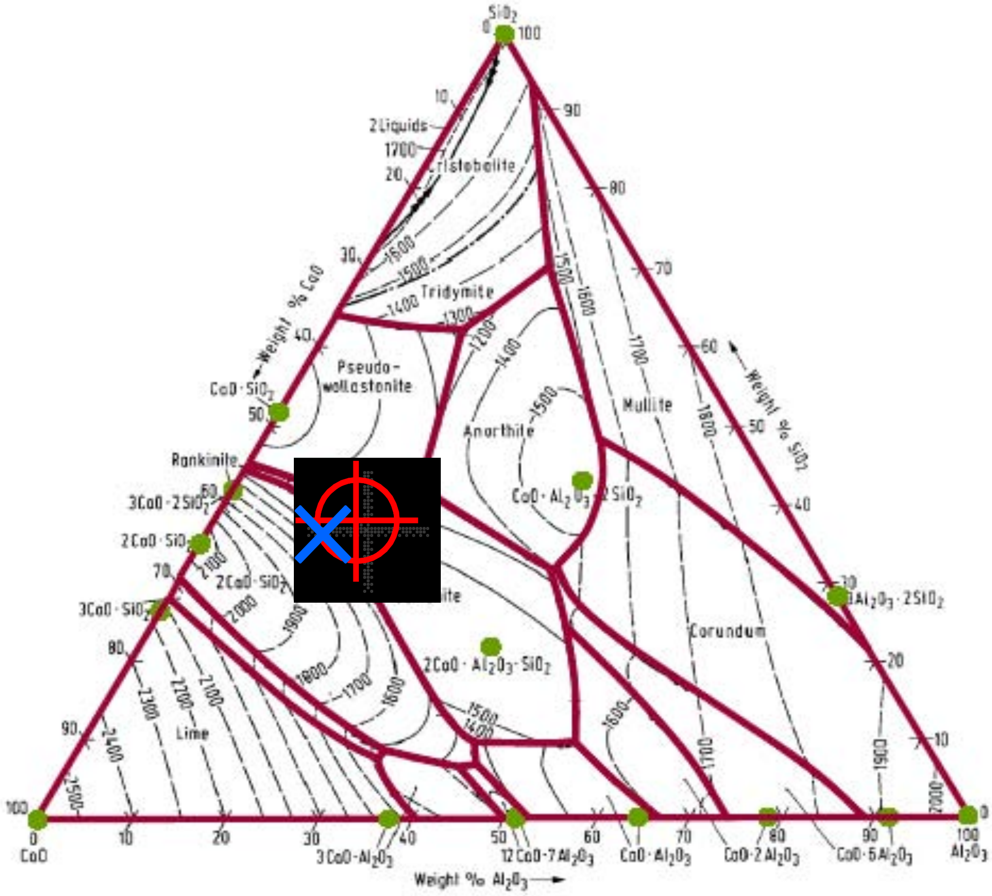


Figure 3 – Slag ternary diagram (red circle is the Tecnored slag while the blue cross indicates a typical BF slag)

Obviously the routine described earlier is rather simplified since the model allows for a number of adjustments and simulation of different conditions. Figure 3 shows the main screen output of the model.

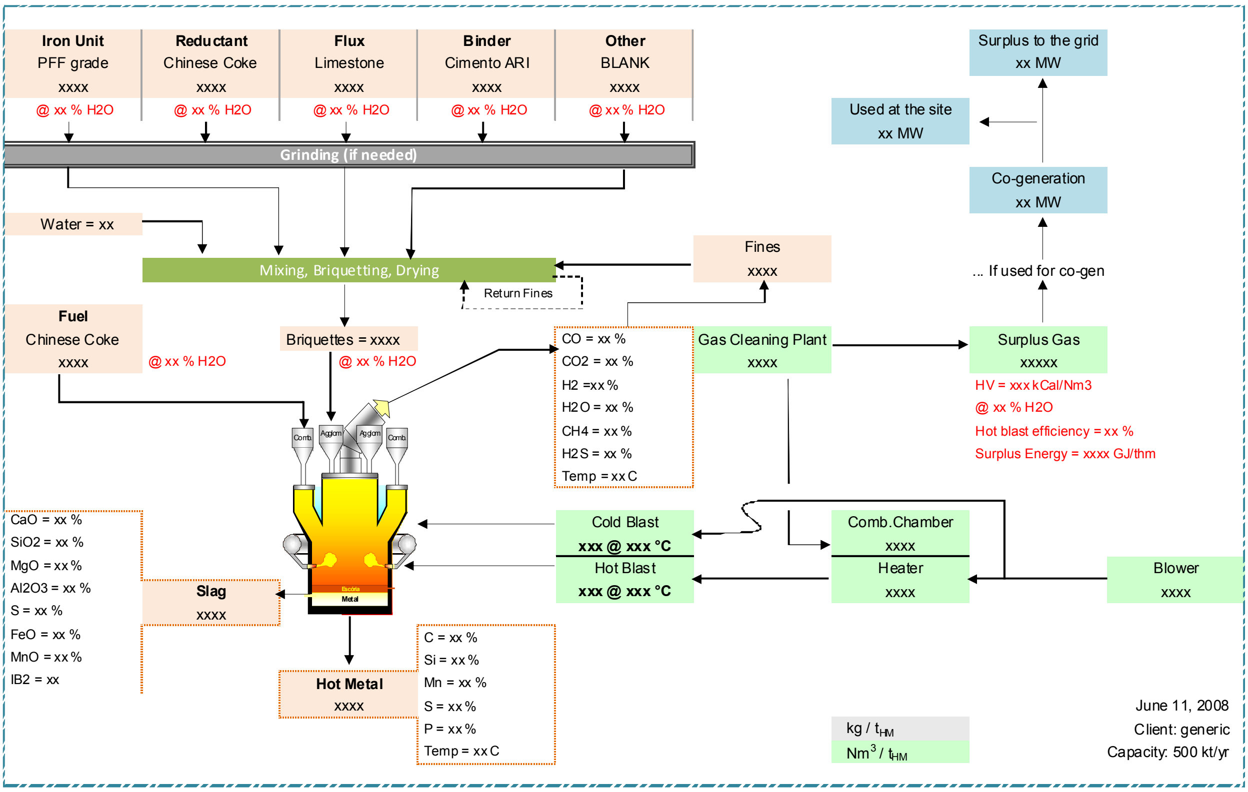


Figure 4 – Screen output of the model

As far as the present work is concerned, it can be noted from the Figure 3 above that the model automatically calculates the fuel rate along with the volume of process air used and the top gas generated. These numbers are then considered in the calculation of the electricity that can be generated in a downstream co-gen plant.
In the next section the cases simulated in this work are presented.

4 CASE STUDIES

In order to perform a strategic analysis on the evaluation of fuel-rate and downstream power co-generation in a Tecnored ironmaking plant as a function of both, type of solid fuel used and technical solution for process air pre-heating, the following cases were simulated.
The following conditions were kept constant for all cases simulated:

Iron Units = PFF (66% Fe)
Binder = Cement
Fluxes = Limestone
$CO:CO_2$ dictating the Carbon / Oxide ratio in the agglomerates = 80:20 (%vol)
Agglomerates moisture = 2%
Solid fuel moisture = 5%
No variation between fuel and reductant

Table 1 shows the 6 cases simulated.

Table 1– Cases simulated in this study

Case	Hot blast		Carbon Unit (Fuel / Reductant)
	Equipment	Temperature (°C)	
1	Glendon	850	Coke (83% FC, 15% Ashes, 2% VM)
2	Stove	1,200	Coke (83% FC, 15% Ashes, 2% VM)
3	Glendon	850	Mineral Coal (75% FC, 12.4% Ashes, 12.6% VM)
4	Stove	1,200	Mineral Coal (75% FC, 12.4% Ashes, 12.6% VM)
5	Glendon	850	Green Pet Coke (87% FC, 1% Ashes, 12% VM)
6	Stove	1,200	Green Pet Coke (87% FC, 1% Ashes, 12% VM)

As shown in Table 1 above, two hot blast heating systems were considered, i.e., Glendon type pre-heaters widely used in the charcoal based pig iron production in Brazil and Stoves that are the classical equipment used in the blast furnace integrated plants worldwide. Apart from the enormous differences in design (one is based in indirect heat exchange using metallic serpentines while the other heats-up the air by passing cold air in extremely hot checker bricks), two main different features between the Glendon and the Stoves considered in this work were the yield (30% and 78%, respectively) and the resulting hot blast temperature (850°C and 1.200°C, respectively).

5 RESULTS AND DISCUSSION

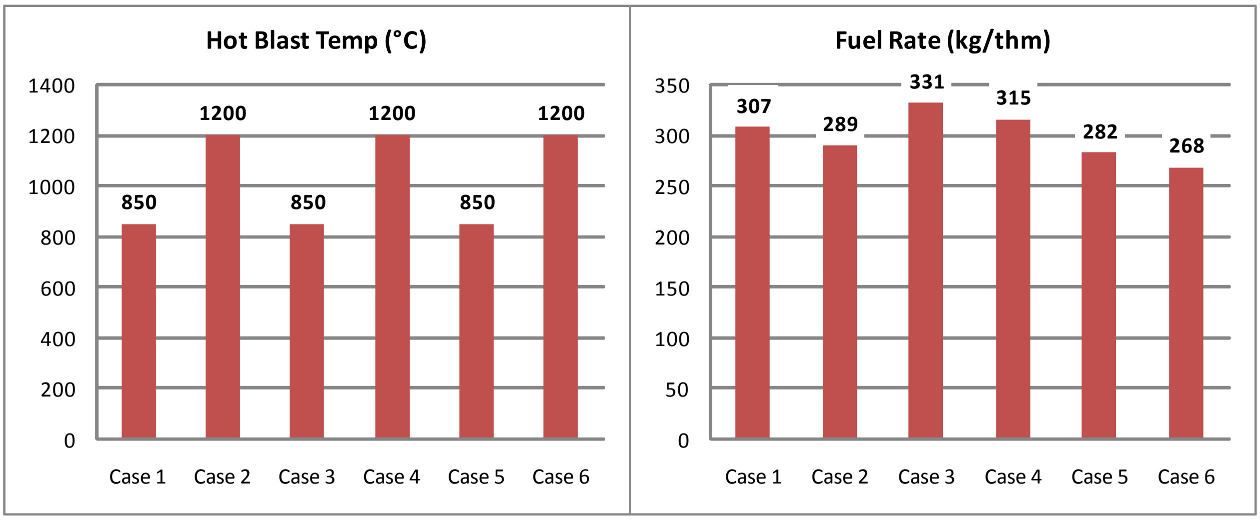


Figure 5 – Hot blast temperature (left) and calculated fuel rate (right) for the cases simulated.

The effect of the use of higher temperatures in shaft reactors is well known (5). High hot blast temperatures result in part of energy already supplied by the sensible heat of the air thus replacing part of the chemical energy to be supplied by the combustion of the solid fuel used. This behavior is also expected in the Tecnored reactor and the simulations corroborated this theory, as shown in Figure 5 above. The following savings in solid fuel can be theoretically achieved by increasing the hot blast temperature from 850 to 1,200°C:

- Coke = 307 – 289 = 18 kg_{coke}/t_{hm} or 6%
- Mineral Coal = 331 – 315 = 16 kg_{coke}/t_{hm} or 5%
- Green Petroleum Coke = 282 – 268 = 14 kg_{coke}/t_{hm} or 5%

With the current situation of high prices of raw materials, specifically coal and coke, this may represent an interesting tradeoff compromise between CAPEX (higher investment required for the stoves) and OPEX (savings in fuel rate when using Stoves and additional potential power generation).

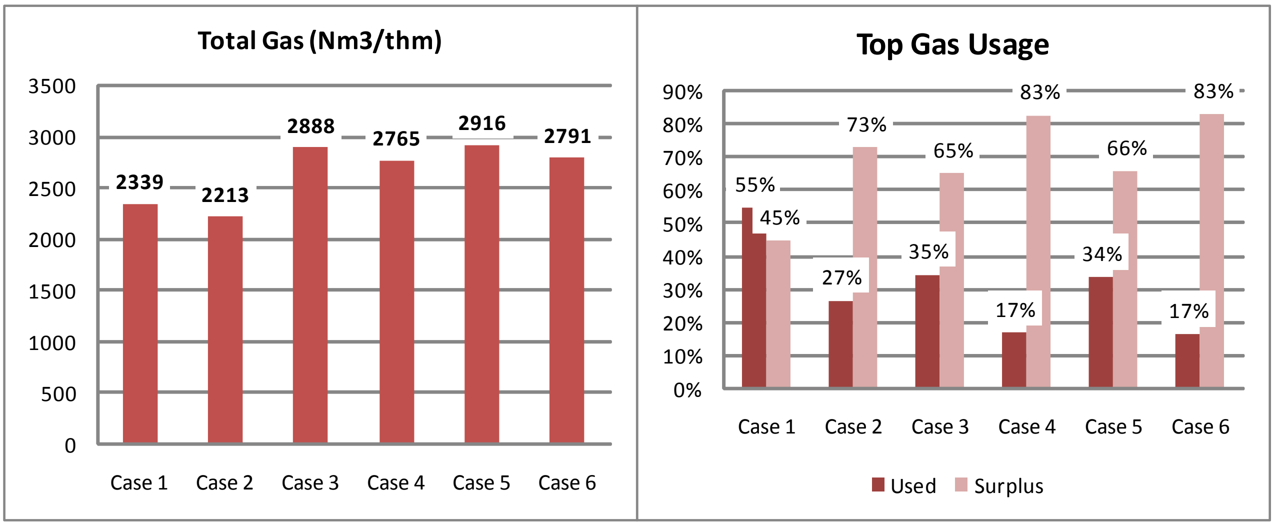


Figure 6 – Total top gas (left) and top gas usage (right) for the cases simulated.

The amount of top gas generated is direct proportional to the fuel rate. Nonetheless due to the pos-combustion of gases inside the Tecnored reactor, this statement is only valid when the same solid fuel is used, or in other words comparing Figures 5 and 6, a low fuel rate for the green pet coke (case 5) didn't lead to the minimum production of gas due to the presence of combustible gases burned at the secondary blast level.

With regards to the use of top gas used as fuel to pre-heat the air, as shown in Figure 6 above, the use of Stoves always resulted in greater amounts of surplus gases to be used for downstream uses due to a much higher efficiency of this equipment in comparison to a Glendon type heater.

One can then suggest that if there is an application for the top gases, the best technical solution for the pre-heating of process air is the Stove type heater instead of low cost/low efficiency Glendons.

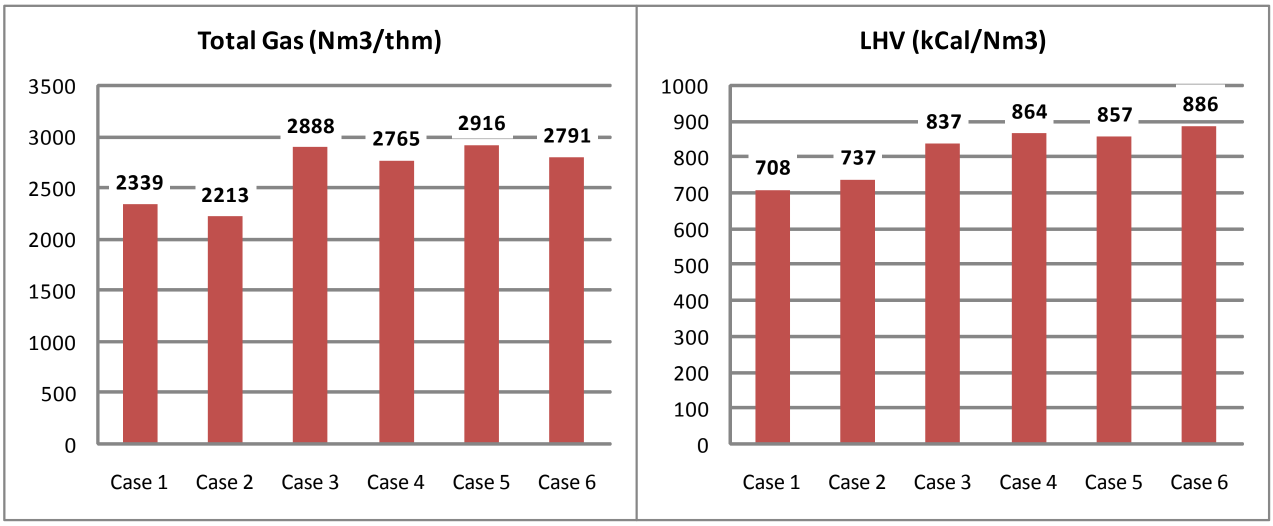


Figure 7 – Total top gas (left) and Low heat value of the top gases (right) for the cases simulated.

The higher presence of Volatile Matter in both the mineral coal and the green petroleum coke resulted in similar LHV of the top gases when these fuel sources were used. On the other hand, since coke has practically no Volatile Matter available the LHV of the top gases is projected to be much lower (Figure 7). The type and amount of hydrocarbons existing in the different fuels were obtained from the literature.(4)

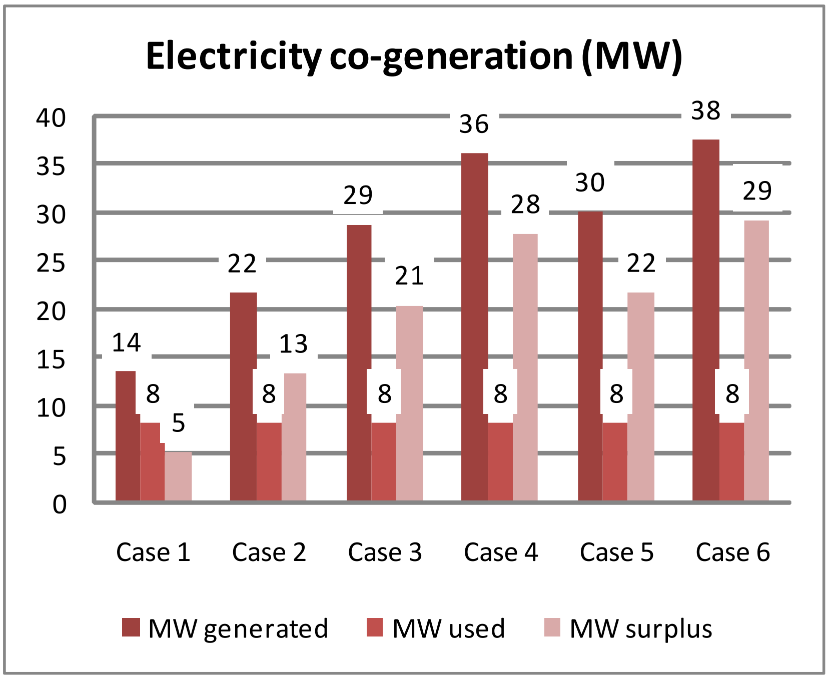


Figure 8 – Electrical energy generated in a captive power plant

The simulations presented in this work considered a Tecnored plant with a capacity of 500,000 tons per year. Considering this assumption and all the outputs given by the model, specially the top gases LHV and volume generated, used and available as surplus, the power generated, used internally and saleable were calculated (Figure 8).

In this work a conversion factor of 3,25 GCal/MWh produced was employed. The internal consumption of power was calculated considering a consumption of 140 kWh/t_{hm} and the co-gen plant is expected to present an availability of 96%.

As can be seen from Figure 8, the combination of high top gas volumes (Nm^3/t_{hm}), high LHV (kCal/Nm^3) and low top gas volumes used as fuel in the air pre-heaters (Nm^3/t_{hm}) led to very high figures of power generated in some cases, especially cases 4 and 6 where high volatile matter fuels and stoves were applied. In these cases the total power generated was in the order of 36 and 38 MW respectively, enough to feed a city of 80,000 habitants each.$^{(6)}$

Since the plant capacity (500,000 t/yr) and power consumption (140 kWh/t_{hm}) were kept constant the power used internally in the plant remained as 8 MW in all cases with the surplus available for sale easily calculated as the difference between generation and use.

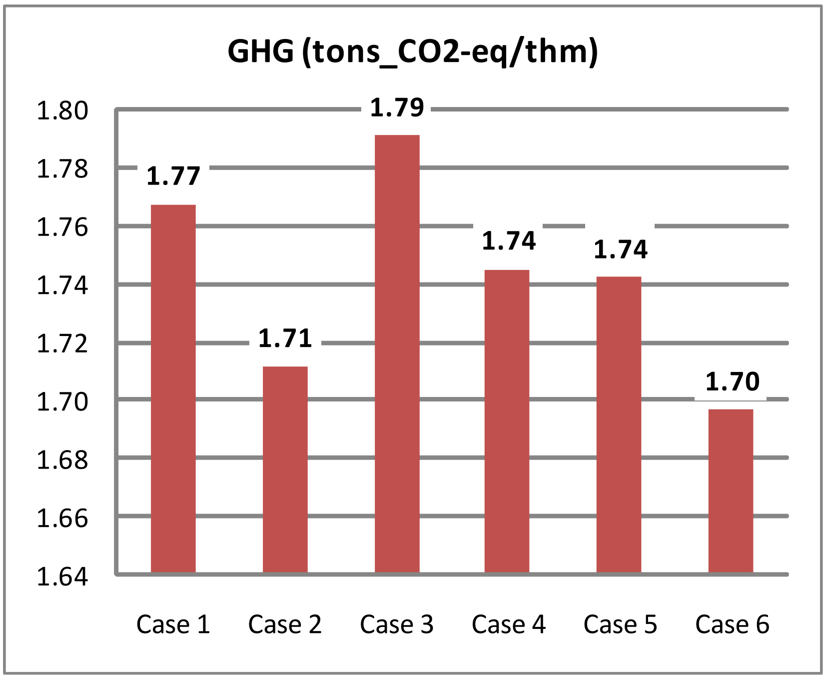


Figure 9 – Projected equivalent green-house gases emissions from the case studies

With regards to the equivalent Green-House Gases emissions projected for the 6 cases assessed in this work, the difference between the highest and the lowest figure is as low as 5%, suggesting that the total amount of Carbon consumed in all cases were very close to each other. The figures above were calculated by converting all moles of Carbon leaving the top gases as Carbon Dioxide (CO_2), i.e., the CO, CH_4 and any other form of carbon will eventually get converted to CO_2.

6 CONCLUSIONS

From the present work the following conclusions can be drawn:

- The selection of the fuel source has a major impact on the potential for power co-generation in a Tecnored based iron plant.
- Due to its ultimate flexibility in using different fuel sources, Tecnored is able to maximize the production of energy in a captive power co-generation plant, thus becoming a very interesting option for electricity short locations.

- The model developed by Tecno-Logos and DCMM/PUC-Rio proved to be a very beneficial tool for the simulation of the process in different conditions, thus anticipating different operational conditions and determining the best alternatives for a given project.
- The total power that can be generated by a 500,000 t_{hm}/yr Tecnored plant using Stove type heaters and medium vol coals can be as high as 40 MW, if desired since the internal post-combustion efficiency can be controlled to a certain extent.
- The use of coke as fuel in the Tecnored furnace, besides not attractive from an economical viewpoint results in lower potential for power cogeneration due to the low levels of volatile matter existing in this raw material.
- Although the total fuel rate varied between the six cases simulated, the total carbon rate only varied by 5% thus leading to similar CO_{2-e} emissions.

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