# 6. Conclusions

A dynamic model for the EAF was developed and validated for a two buckets AC furnace. The amount of carbon input was varied significantly in order to test the model accuracy and its physical consistency regarding the kinetics of carbon oxidation, phosphorus oxidation and iron oxide reduction. The optimized results were in reasonable agreement with analyzed slag and metal phases.

The model and the optimized parameters used in the model gave interesting insights into the furnace operation. These included:

#### **Decarburization:**

- i) The decarburization efficiency in the EAF was at least as good as in a BOF. The decarburization rate constant normalized to oxygen flow rate was higher than for BOF. It was found 0.74 [min<sup>-1</sup>], for carbon content lower than 0.14%wt. This estimate is valid when at least 60% of the charge is melted.
- ii) Compared to BOF, the present data is pointing out that the product " $m_c$ .A" increases faster than oxygen flow rate  $Q_{O_2,t}^{L^*}$ , resulting in lower critical carbon content. Higher values for both  $m_c$  and A could be attained when the turbulence is enhanced by numerous lancing injectors and larger reaction surface is created in EAF. In contrast to BOF, the longer co-existing solid ferrous materials submerged in the hot heel of EAF could also work as additional interface for reaction.
- iii) The estimated rate parameter ratio  $k_{C2}/k_{Si2}$  of 0.81, for carbon and silicon mass transport models below their critical contents, is in good agreement with observed ranges in the literature.
- iv) Only a moderate accuracy was found for soluble carbon prediction in the metal phase. The premise of metal phase homogeneity seemed to be not fulfilled. In the beginning of meltdown, distinct pools of liquid steel may form in the hot heel, separated partially by solid scrap barriers. Encapsulated pig iron and random coke penetration in the metal phase can make it worse.

- v) Dispersive behavior of carbon content occurred more frequently in the heats with pig iron charge higher than 30% and, mostly in the beginning of the meltdown step.
- vi) The melting rate of pig iron and the carbon availability in the metal phase may not be following the melting rate model for every heat. The way the buckets are layered and the job procedures for charging definitely contributes for different distribution of pig iron the EAF vessel.

## **Dephosphorization**

- vii) The model prediction is in reasonable agreement with the phosphorus content in metal phase. Phosphorus and carbon content in the metal phase together worked well as tracer elements supporting the calculation of the pig iron melting rates.
- viii) The product  $m_p A$  was presumed to increase slightly with the processing time, but an almost constant value fitted better instead. The present study estimates for " $m_p A$ " are in agreement with other of experiments conducted in industrial scale.
- ix) The rate parameter decreases with time and a good correlation was found for the rate parameter ratio  $k_{C2}/k_p$  of 5.06, for carbon and phosphorus mass transport models. However, considering the diffusivity coefficients of both species in liquid iron, the estimated rate parameter ratio seems to be 3 to 6 times higher than expected for a reaction essentially presumed to be controlled by phosphorus mass transfer.
- x) Assuming that the interface of reaction is the same for both reactions, the difference found in  $k_{C2}/k_P$  cannot be explained by the available data in this study.
- xi) The empirical model which estimates the partition of phosphorus in slag and metal phases may be overestimating the phosphorus partition in the slag-metal interface. Rephosphorization conditions were predicted by the model, but somehow delayed in time.

#### Iron oxide reduction

- xii) The rate constant estimated for the reduction of FeO in slag by solid carbon was evaluated. The proposed empirical model attained good correlation around 0.9 with the measured %wt FeO content in the slag phase.
- xiii) Based on the results, about 15-35% of the injected solid carbon leaves the furnace un-reacted.
- xiv) The rate constant seemed to increase with the increase of FeO activity. It may imply that increasing FeO activity, the reaction at carbon source interface creates higher CO flow rate, and the evolution of CO bubbles is presumed to accelerate FeO mass transfer to the slag-gas interface.
- xv) The slag viscosity increases almost four times when wt% FeO drops from 45% to 10%. The present empirical model does not include any mass transfer function of slag viscosity, despite the possibility that the FeO mass transfer coefficient may increase when viscosity decreases.

## **Recarburization**

- xvi) The current model failed to start the recarburization algorithm, maybe due to: (i) the Fe-C-O equilibrium curve is underestimating the FeO content in equilibrium, and recarburization could occur at higher FeO content; (ii) part of the injected carbon that did not reacted with slag, could penetrate and dissolve in the metal phase directly; (iii) in the slag-metal interface, dissolution of carbon in metal phase is more favorable than the iron reduction rate due to an increase in slag viscosity, as well because of lower FeO content (driving force for iron reduction is decreased).
- xvii) The direct dissolution of carbonaceous materials appears to be more realistic in consequence of operational issues related to unexpected submergence of consumable pipes in the metal phase. Carbon could have been dissolved faster in metal phase than in slag phase.
- xviii) In contrast to high productivity EAF (ton/h), deep carbon injection for not less than 10 minutes, not assisted by any oxygen lancing injection

conducted in low productivity EAF, could bring soluble oxygen and carbon closer to the presumed equilibrium curve. Under this condition, when FeO was lower than 15%, recarburization could take place. Therefore, the departure from Fe-C-O equilibrium observed for %wt FeO vs. C maybe related to kinetic issues.

# Oxygen Injection

xix) Oxygen feed by post combustion injectors may contribute to iron oxidation in a higher degree than expected. Estimated averages of 31% and 26% of the injected oxygen may have been addressed to iron oxidation and wasted through off-gas, respectively.

# Melting Rates

- xx) Despite of a lower melting point, the pig iron was estimated to melt at a lower rate than scrap, most likely due to its low area to volume ratio and the possibility of encapsulating effect.
- Pig iron melting rates were estimated to be equivalent to heavy scrap grades, like big cylinders and sphere-type geometries.
- xxii) Encapsulating effect, or chilling effect, presumes that a solidified shell from surrounding liquid metal phase is created when submerging solids in liquid metal phase with short available enthalpy. The shell covers heavy scrap and pig iron surfaces, preventing them to melt or even when melted, to escape to the liquid phase. Pig iron encapsulating effect seems to be more realistic, since slopping events cannot be neglected in industrial scale and they take place more frequently when pig iron charge exceeds 20-25%.
- xxiii) Increase of pig iron melting rate trend was found when the EAF hot heel size is increased.

### **Future Works**

- Develop new metal phase sampling procedures to minimize the interference of carbon and oxygen lancing injection.
- Develop freezing procedures for slag samples in order to measure the un-reacted carbon wasted during slag-off.
- iii) Investigate the role of metallic iron in the slag samples, as well the ferric and ferrous phases at higher temperatures. They may be departed from equilibrium.
- iv) Improve empirical model for phosphorus partition estimates.
- Implement off-gas volume and chemical composition analyzer in order to calculate the carbon mass balance in real time. In addition, slag weight in real-time will allow the basis to estimate Fe losses.
- vi) Investigate the correlation between the estimated slag chemical composition and its viscosity with foaming ability.
  Later, electrical circuit response could be connected to the thermal losses through water cooled panels in real time.
- vii) Investigate the (Fe,Mg)O magnesia-wustite equilibrium and the estimates of the solid phase present in slag phase for viscosity estimate.
- viii) Investigate the effect of (Fe,Mg)O magnesia-wustite in the iron reduction rate.
- ix) Develop the energy balance algorithm
- x) The model framework is a promising tool to work preliminarily in "what-if" process scenario builder as an static model, later, after further developments, it could be attached to a real time network.
- Evaluate the influence of more robust sequential quadratic programming and other optimization algorithms on the quality estimate of the model parameters and the magnitude of the computational effort.

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