Transient slag behaviour in the DRI and scrap based EAF process: Case study for high and low grade DRI input

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ABSTRACT

Tata Steel Netherlands (TSN) aims to reduce its CO_2 emissions by 35-40% by 2030 and become CO_2 neutral by 2045. A first step to reach these targets is via the utilization of an EAF, which will run on a mixture of high proportion of DRI and scrap.

For an EAF operation, optimization of slag chemistry is important to achieve the right mix of basicity (for refining especially de-P), foaming, volume (rate) and refractory life. Slag composition and rate can vary widely depending on the process variables like charge mix, charge composition, feeding rate, oxygen lancing, external carbon injection/addition, fluxing and refractory erosion/corrosion. Moreover, it is important to note that the slag composition and rate are ‘transient’ parameters and change throughout the heat. This makes all the dependent phenomena and/or outcomes transient as well. To describe all these effects simultaneously and be able to realistically simulate the EAF operations, a validated dynamic process model is important in the absence of real plant data.

In this study, a validated dynamic EAF process model based on the concept of Effective Equilibrium Reaction Zone (EERZ) has been utilized to analyse the impact of high DRI industrial scale EAF operations on the transient slag characteristics – including slag volume (rate), composition, phases, solid fraction and viscosity. Simultaneously, the model is able to predict the impact on steel and off-gas characteristics. Case studies were performed with 70% DRI:30% scrap mix considering both low and high grade DRI. Both melting and refining aspects of the process including continuous feeding, arcing program, carbon addition, fluxing and oxy-lancing were considered.

INTRODUCTION

The EU has embarked on a route to reduce its greenhouse gas (GHG) emissions in 3 steps – 20% by 2020, 55% by 2030 and 100% by 2050, compared to the 1990 levels. While the 2020 target was achieved in 2019, achievement of the 2030 target looks challenging due to the post-COVID industrial bounce-back. Industrial processes in the EU contribute 9.1% of its GHG emissions. The iron and steel industry is a major contributor, generating ~2 tonnes CO_2 for each tonne of crude steel produced; most of it comes from the Blast Furnace (BF) ironmaking step.

Tata Steel Netherlands (TSN) is an integrated steel producer using the Blast Furnace (BF) – Basic Oxygen Furnace (BOF) route to produce variety of steel products, including automotive and packaging grades. It emits 12.6 mtpa CO_2 which is ~8% of the total CO_2 emissions in the Netherlands. It aims to reduce the emissions by 4-5 mtpa (35-40%) by 2030, and become CO_2 neutral by 2045. It also aims to increase its utilization of scrap to 30% and maximize slag valorisation by 2030.

In order to meet these targets, TSN has decided to replace one of its existing Blast Furnaces (BF) with a combination of Direct Reduction Plant (DRP)-Electric Arc Furnace (EAF). Along with scrap addition, the Direct Reduced Iron (DRI) coming out of the DRP will be fed into the EAF.

Numerous integrated steel producers such as POSCO, Salzgitter, ArcelorMittal Dofasco, Voestalpine have opted for the EAF route (for their 1st phase of transition) charged with a high proportion of virgin iron units (VIU). Although scrap input is important from the circularity standpoint, tramp elements such as Cr, Ni, Mo, Cu and Sn in the scrap can have adverse effects on the mechanical properties of the steel product [Memoli, Jones and Picciolo, 2015]. Hence, high % scrap based EAF route is unable to produce the high-grade steel products that are typically made via the BF-BOF route [Mandal et al., 2018]. In order to control the tramp element levels and address circularity at the same time, the charge material into an EAF needs to be a combination of scrap with a VIU, such as DRI. This strategy should also help in addressing the problem of producing the high-quality steel grades through the EAF route.

However, DRI comes with its own challenges. Factors such as chemical composition (gangue, C, S, P), metallization degree and temperature of the DRI are critical as they greatly impact the EAF process parameters such as yield, fluxes, slag weight, energy, carbon, oxygen consumptions and raw material feeding rates [Memoli, Jones and Picciolo, 2015].

In this work, a dynamic EAF process model has been used to analyse the impact of DRI quality (high-grade vs low-grade) on the following factors of a continuously charged EAF process:

- Product composition (liquid steel and slag)
- Productivity (liquid steel and slag)
- Yield and specific consumptions

In terms of refining, the concept of controlling slag FeO and decarburisation rate by controlling oxygen lancing and carbon injection have been described under the section 'DYNAMIC PROCESS CONTROL FOR TRANSIENT SLAG CONTROL'. This knowledge has been applied during the simulations to optimize the slag FeO & decarburisation as shown in Fig. 7f.

IMPACT OF USE OF DRI ON THE EAF PROCESS

The following characteristics of the DRI greatly impact the EAF process performance:

- **Type of green iron-ore pellet**: The green pellets (raw unreduced) are classified into two types: DR-grade pellets and BF-grade pellets. The DR-grade pellets contain 67%+ Fe whereas the BF-grade pellets typically contain 65% Fe or less [Midrex, 2021]. The higher the iron content, the lower the gangue content, notably acidic components like SiO_2 and Al_2O_3.
- **Acidic Gangue content**: The gangue (SiO_2, Al_2O_3, etc.) present within the green pellets becomes concentrated within the DRI - as it is not ejected into a liquid slag phase (like in a BF). The presence of a higher amount of acidic gangue in the DRI pellet necessitates higher electrical power and flux consumptions in the EAF – leading to a larger slag volume, higher iron loss to the slag and lower productivity. The gangue content also affects the degree of

reduction or metallization within the DRP, which also affects the electrical power consumption in the EAF process.

- **Metallization degree**: The metallization degree is defined as the percentage of metallic iron in the reduced pellet divided by the total iron in the reduced pellet. The amount of unreduced iron oxide depends on the degree of metallization achieved during the direct reduction step.
- **Carbon content**: Carbon has multiple roles in the EAF process:
  - Adds chemical energy to the system
  - Reduces the remaining FeO in DRI: around 1 wt% C can reduce 6 wt% FeO in the DRI pellet
  - Leads to slag foaming: Carbon, when present at sufficient levels within the DRI, yielded substantial improvements in slag foaming in the EAF process, by the promotion of carbon boil [Erwee and Pistorius, 2012]. Slag foaming helps in shielding the bath from the atmosphere which reduces radiation loss, electrode loss and nitrogen absorption.
  - Enhances nitrogen removal from the liquid steel bath via carbon boil.
- **Sulphur and phosphorus levels**: The presence of sulphur and phosphorus in DRI may require different slag practices in the EAF to remove these contaminants.
- **Temperature**: the initial temperature affects the energy balance and thus electrical power consumption and power-on-time.

IMPORTANCE OF EAF SLAGS AND SLAG ENGINEERING

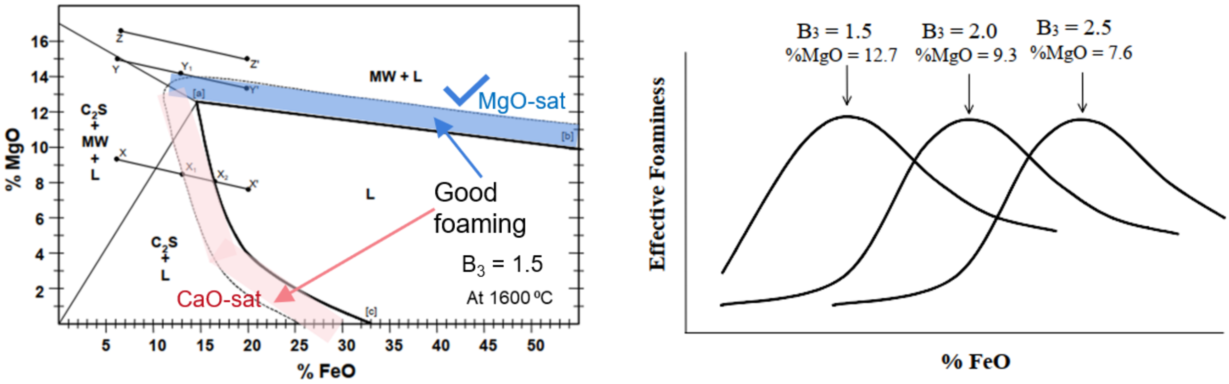
The importance of slag foaming in EAF operations is well understood [Pretorius, 2023], including decreased heat loss from electric arc, improved heat transfer to bath, higher rate and magnitude of power input, increased arc length without increase in flare, reduced power and voltage fluctuations, reduced electrical and audible noise.

Attainment of a good foaming slag necessitates the right combination of slag basicity, FeO and MgO levels at any fixed temperature [Pretorius and Carlisle, 1998]. A target EAF slag should have the following characteristics [Pretorius, Oltman and Jones, Pretorius, 2023]:

- **$1.3 < B_3 < 2$**: the EAF slag should have a proper balance between basic and acidic oxides. Higher B_3 values are needed in case of stronger dephosphorisation. Note that B_3 = %CaO / (%Al_2O_3 + %SiO_2) and B_2 = %CaO / %SiO_2. The results are discussed in terms of B_3 as it includes both the acidic components (Al_2O_3 and SiO_2), unlike B_2. However, the variation of B_2 is also shown for convenience.
- **Presence of 2nd phase (solid or solid solution) particles**: slag saturation with respect to CaO (Ca_2SiO_4) and/or MgO (MgO-FeO wustite) should be aimed. A solid solution is a phase where the secondary components (for e.g., FeO, CaO, etc.) are dissolved in the crystal structure of the main component (for e.g., MgO). These solid particles dispersed in the slag serve as gas nucleation sites, which lead to a high amount of favourable small gas bubbles in the foaming slag.
- **CO gas bubbles**: lifts the slag phase and increases the effective volume of the bubbling slag layer.
- **Slag FeO**: FeO in slag generates CO bubbles by reacting with injected carbon, but it should not be too high as it decreases the slag viscosity and promotes refractory wear.
- **Slag MgO**: Slag should be just saturated with MgO so as to prevent refractory wear.
- **Slag viscosity**: A highly fluidic slag (Al_2O_3, SiO_2 and FeO) attacks the refractories. As the effective slag viscosity (liquid slag + solid particles) is increased, the residence time of the gas bubbles in the slag is prolonged, extending the stability and the subsequent life of the foam. However, too high viscosities (high CaO and MgO) hamper refining and make the slag useless.

- **Minimum slag volume**: is necessary to cover the steel melt as well as the arc.

Thus, it is important to understand the relative phase stabilities to better control slag foaming in an EAF operation. Typically, the phase stabilities are obtained from Isothermal Stability Diagrams (ISDs), which are plots between %MgO and %FeO at a constant B_3 and temperature. A sample ISD at a B_3 of 1.5 and temperature of 1600 ºC is shown in FIG 2 (a) [Oltmann and Pretorius 2002, Pretorius, 2023]. The highlighted regions in colour are the inferred regions of good slag foaming – due to the presence of second phase particles. The blue-highlighted region indicates the MgO-saturation conditions while the light red-highlighted region the CaO-saturation conditions. Due to better refractory compatibility and flexibility over FeO levels, the MgO-saturated region is preferred over the CaO-saturated region.



(a) Sample Isothermal Stability Diagrams (ISD) (b) Possibilities for good slag foaming

FIG 2 – Slag foaming requirements [Oltmann and Pretorius 2002, Pretorius, 2023].

In reality, various EAF operations have been able to achieve good foaminess under various combinations of B_3, FeO and MgO contents (FIG 2 (b)). However, this choice depends on tap steel quality requirements, e.g.:

- For low-C heats, higher FeO content will be reached. This needs a high B_3 (FIG 2 (b)), based on which the MgO content can be targeted.
- For high dephosphorisation requirements, high B_3 and high FeO content must be aimed.
- For not so low-C heats, the slag FeO content will be lower. In this case, it is possible to work under low B_3 values.

Present Study

In the present study, a low-C heat has been considered which is likely to result in relatively high FeO content in slag. Assuming a FeO content of ~30 wt%, it is possible to select different B_3 values and still remain in the region of good foaming and MgO saturation. This is shown schematically in FIG 3. With decreasing values of B_3, lime requirements decrease – however, it increases the dololime requirement due to an increase in the MgO saturation point. This increases the risk of refractory wear.

Moreover, the use of a very low B_3 is restricted by the minimum slag volume requirement for steel bath coverage and foaming. Thus, a B_3 value of 1.8 was selected which is more of an average value observed in real operations. From FIG 3, it can be observed that the MgO saturation is obtained at ~10 wt% MgO and the minimum FeO content is ~22 wt% at this B_3. These values are good starting points for comparison to the model simulation results presented later.

Since slag foaming is not part of the current version of the model (described later), it had to considered indirectly. In the simulations, an average B_3 value of 1.8 and continuous MgO saturation throughout the heat were ensured. While the B_3 value was controlled by flux addition, MgO saturation was controlled by ensuring the presence of MgO solid solution. The assumption is that there is a good foaming slag during the process just by ensuring these two conditions.

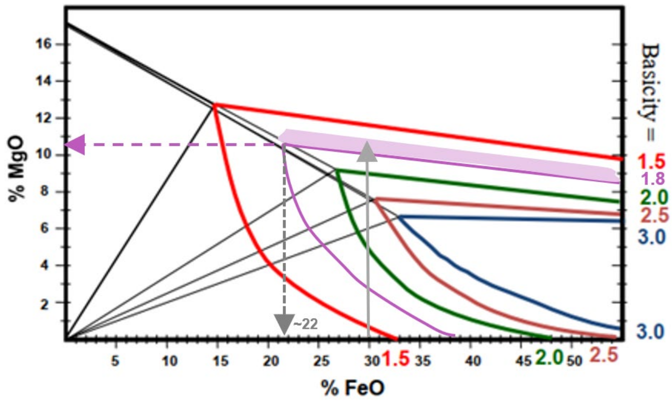


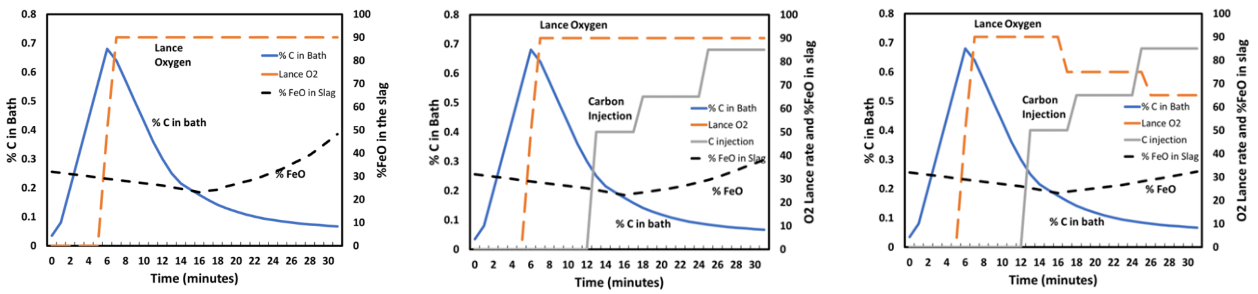
FIG 3 – ISD at different B_3 values [adapted and reprinted with permission from Pretorius, 2023].

DYNAMIC PROCESS CONTROL FOR TRANSIENT SLAG CONTROL

Sustenance of a good foaming slag throughout the power-on-time could be challenging due to the transient nature of the process [Oltmann and Pretorius, 2002]. The slag foam can collapse due to increase in the slag FeO levels and bath temperature or decrease in the CO gas evolution rate. An imbalance between the feeding/melting rates of input materials (scrap, DRI, flux, carbon), oxygen and carbon injection, FeO formation or MgO dissolution from refractories can lead to transient changes in the composition and hence basicity and viscosity of the slag.

In a recent study [Kirschen, Hay and Echterhof, 2021] that analysed data from multiple EAF plants, it was observed that the slag FeO control was poorer in case of high DRI charged EAFs compared to scrap heats. The standard deviation of FeO was found to be 4.1 - 9.6% for heats based on >50% DRI (remaining scrap) heats, while it was in the range of 3.9 - 5.5% for 100% scrap heats. This was attributed to poor operational control of the furnace.

Hence, it is critical to analyse and control the transient changes in the process in order to obtain favourable outcomes. An example [Pretorius, 2023] showing the impact of dynamic operational control (oxygen lancing and carbon injection) on the slag FeO levels is shown in FIG 4. In this example, the tap [C] requirement is around 0.04-0.06 wt%. With a constant oxylancing throughout the refining cycle (FIG 4(a)), the slag FeO reaches 50 wt%.



(a) No FeO control: Final FeO ~ 50 wt%

(b) FeO control by carbon injection: Final FeO ~ 40 wt%

(c) FeO control by carbon injection and oxylancing: Final FeO ~ 30 wt%

FIG 4 – Slag FeO control by controlling process conditions dynamically [reprinted with permission from Pretorius, 2023].

As shown in FIG 4(b), injecting carbon in the bath appropriately (time and rate) can reduce the slag FeO levels (to ~40 wt% in this example) since the injected carbon reduces slag FeO and increases the Fe yield. The starting point and rate of carbon injection need to be decided based on the slag FeO and bath [C] profiles.

The FeO levels can be further reduced (to ~30 wt% in this example) by controlling the oxylancing. This is because beyond the critical carbon value, the rate of decarburisation shifts from oxygen flow rate control to mass-transfer control. Under this regime, the oxygen reacts more with Fe to form FeO instead of taking part in the de-C reaction. Hence, a reduction of the oxylancing rates beyond the critical carbon value results in a decreased slag FeO.

Both the concepts of dynamic process control and slag engineering (discussed above) have been utilized in the present case study.

In this paper, it was decided not to discuss the slag refining capabilities and the concentration profiles of other elements such as S, P, Mn, Si, etc. The scope of this study is limited to the influence of the DRI grade on the main process conditions to obtain a final steel with a target temperature and carbon content and slag with adequate foamability during the EAF process.

EAF MODEL DESCRIPTION

A dynamic process model based on the concept of Effective Equilibrium Reaction Zone (EERZ) has been utilized to carry out the case study in the present work. EERZ (Effective Equilibrium Reaction Zone) is a concept [Ding et al., 2000, M.-A. Van Ende et al., 2011] that has been successfully applied to other industrial processes such as BOF, EAF, LF and RH. Under this concept, mass and heat transfer are coupled with thermodynamic databases to simulate chemical reactions in the reaction zones (volumes). A schematic diagram of the 11 different reaction zones of the EAF dynamic model is shown in FIG 5. The EAF model employed in the present study is an extension of the model described in [M.-A. Van Ende, 2022], in which the addition of hot metal, DRI and hot briquetted iron (HBI) and their reactions in the EAF have been included. This model has been validated for various cases such as 100% scrap, up to 30% hot metal and up to 40% DRI inputs. However, it is yet to be validated for a high (~70%) DRI input. Hence, the results for the 70% DRI + 30% scrap case (present work) should be considered as logical extrapolations between the validated extremes.

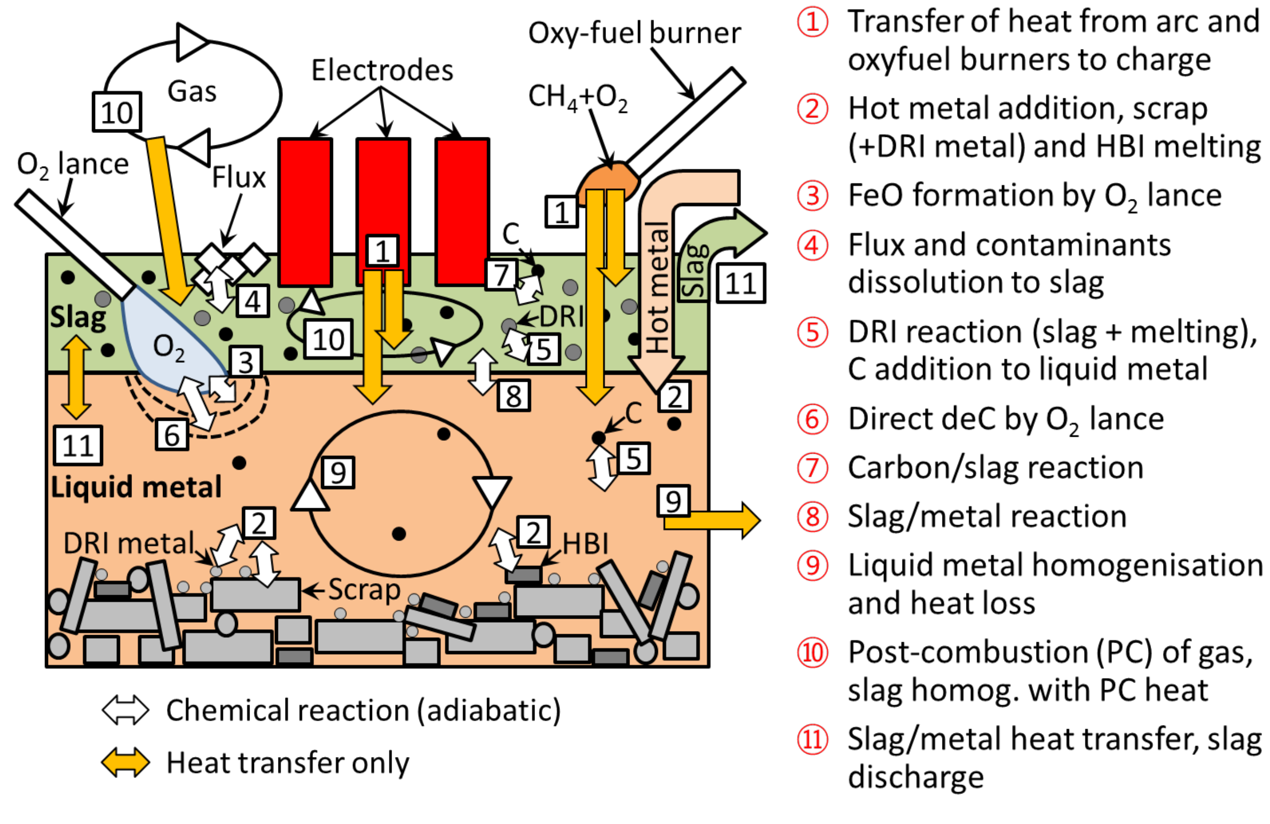


FIG 5 – Schematic representation of the reaction zones of EAF dynamic model (adapted from [M.-A. Van Ende, 2022]).

The most important DRI reactions in the EAF process model are explained below. The DRI charged in the EAF will mainly undergo reactions in the EAF slag due to its relatively low density (Reaction 5 in FIG 5). In this reaction, heat is extracted from the slag to heat up the DRI and possibly melt the gangue and metallic fraction of the DRI. The C from the DRI reacts with the DRI gangue and the surrounding EAF slag to reduce FeO and other reducible components and produce CO bubbles in the slag. After the reaction, the oxide products are dissolved into the slag, while the metallic products (solid and/or liquid) travel through the slag to the liquid metal bath. The liquid metal products will mix with the liquid metal bath, whereas the solid metallic products will sink and continue to melt in the liquid metal bath (similarly to scrap, Reaction 2 in FIG 5). All heat transfer requirements associated with the above phenomena are considered in the model. In this way, imbalance in the amount of heat provided to the slag during DRI charging, which will result in the solidification of the slag (ferrobergs) and the accumulation of solid unmelted DRI metal in the liquid bath, can be identified during the simulations.

CASE STUDY SETUP

A case study was performed with an input mix of 70% DRI and 30% scrap into a continuously fed EAF. The objective of this work was to estimate some of the unknowns using process modelling. The EAF model inputs and outputs for the case study are shown in FIG 6 and the other important considerations are provided in Table 1.

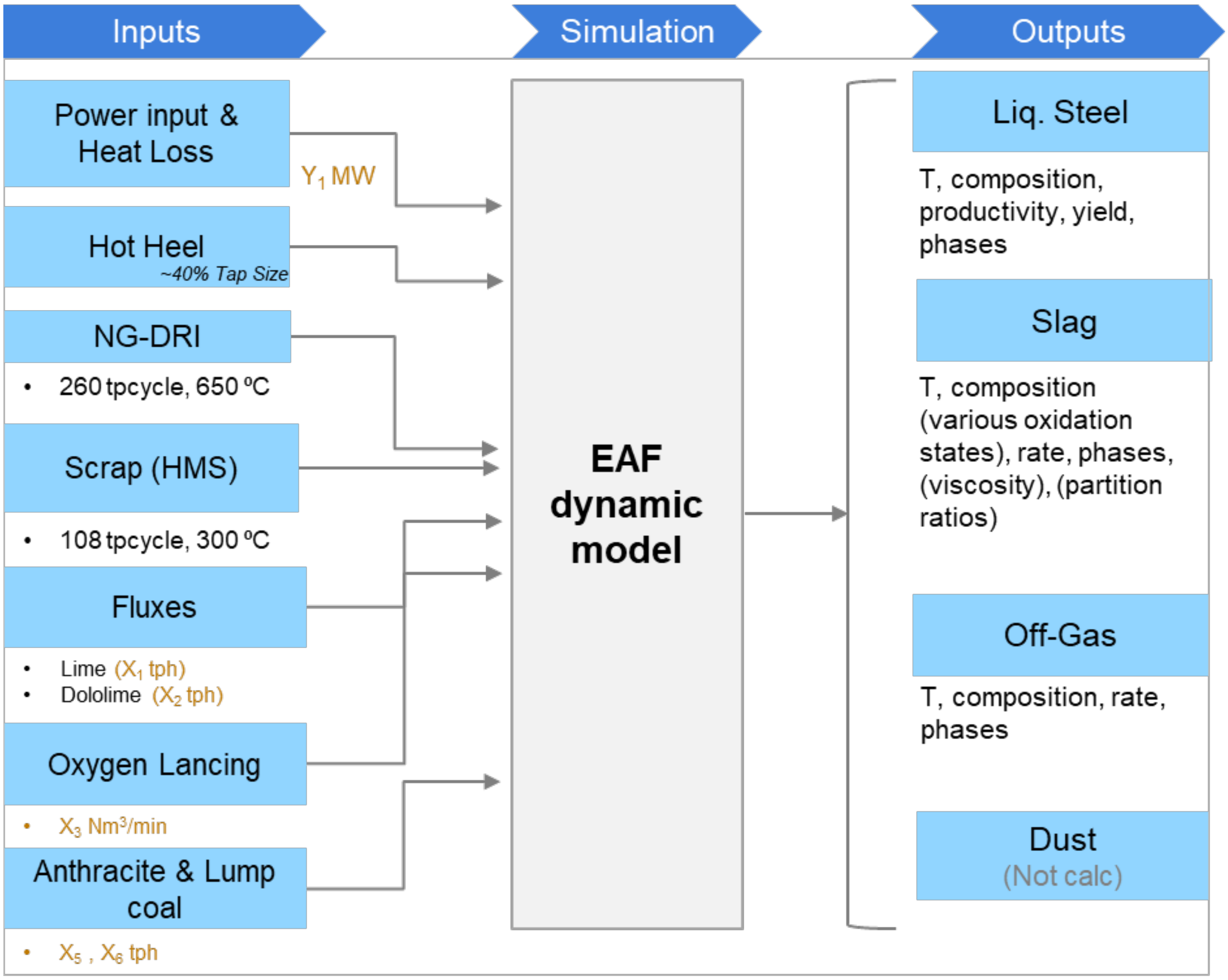


FIG 6 – Model Inputs and outputs for case study: 70% DRI + 30% Scrap into an EAF (continuous charge).

Table 1 – Other key model inputs and considerations for case study: 70% DRI + 30% Scrap into an EAF (continuous charge).

Parameter	Values/Remarks
Input charge mix	▪ *DRI pellet*: ○ T = 650 ºC ○ 12 mm size ○ *High-grade*: • Metallization = 96%, FeO ~ 4%, C ~ 2.7% • Total acidic gangue (Al_2O_3 + SiO_2) ~ 2.5% ○ *Low-grade*:

Parameter	Values/Remarks
	• Metallization = 94%, FeO ~ 7%, C ~ 2.7% • Total acidic gangue (Al_2O_3 + SiO_2) ~ 5% ▪ *Scrap*: o T = 300 ºC o No oxides considered o 0.4m x 0.15m x 0.15m
Aim LS quality	• ~ 1650 ºC • ~ 0.04 - 0.05 % C • < 0.01 wt.% P, <0.02 wt.% S
Tap-to-Tap Time	50 mins
Power on Time	40 mins
Charging Cycle	36 mins
Slag foaming	considered indirectly
Aimed slag B_3	1.8 (explained earlier)

RESULTS AND DISCUSSIONS

Through this case study, the impact of DRI quality (high-grade vs low-grade) on the following EAF process metrics will be presented:

- Product composition
- Productivity and yield
- Specific consumptions

Both the concepts of dynamic process control and slag engineering have been considered in these case studies.

The process conditions and the model simulation results are presented in FIG 7 for the high-grade (solid lines) and low-grade DRI (dashed lines) cases. The feed rates (FIG 7(a)) of scrap and DRI were ramped up (or down) based on their melting behaviour. The electrical power was scaled to match the feed rates. This was an iterative procedure to find a balance between the two parameters. Higher than necessary power would result in higher tap temperatures while an insufficient power supply is unable to melt all the feed material, fluxes or slag. Around 108 t of scrap and 260 t DRI pellets were added per cycle. Since the ratio of DRI feed rate to scrap feed rate is quite high (almost 2.5), the requirement of electrical power (and its variation with time) in order to melt all the feed material was primarily determined by the feed rate of DRI. This variation can be observed in FIG 7(a). The higher power consumption for the case of low-grade DRI input (dashed green line) is due to the extra power needed to melt the additional acidic gangue in low-grade DRI and relatively higher amount of added fluxes.

The transient addition profiles of various other inputs to the process - such as fluxes, oxylancing, carbon, burner oxygen and natural gas - are shown in FIG 7(b). The basic flux (lime and dololime) additions are matched with the incoming acidic oxides (present in DRI) as well as acidic component in scrap (Si in this case). Maintaining a MgO saturation throughout the heat was also considered a necessity in order to (i) protect the refractory wear and (ii) generate second phase particles (solid and solid solution) needed to maintain a foamy slag. As clearly observed, the flux addition amounts are significantly higher for the low-grade DRI case, having much higher acidic gangue content (twice that of high-grade DRI).

For generation and sustenance of a foamy slag, the presence of a sufficient amount of CO gas bubbles is also necessary. The amount of gas to sustain foaming is higher when the slag amount increases. Hence, the carbon and oxygen consumption should be higher for the low-grade DRI case to compensate for the higher mass of slag. However, since the effect of slag foaming is not ‘directly’ included in this version of the EAF model, the carbon and oxygen consumptions are kept the same in both cases for simplification.

As shown in FIG 7(c), the slag B3 (%CaO / (%Al2O3 + %SiO2)) was kept at ~1.8 to accommodate slag foaming requirements, as explained earlier. The slag B_2 (%CaO / %SiO_2) varied in between 2.2 to 2.4. Evidence of MgO saturation can be observed from FIG 7(d), which shows the presence of MgO solid solution throughout the process. The slag B_3 ratio and MgO saturation are controlled by adjusting the flux (lime and dololime) additions with time.

Based on the flux additions, the cumulative slag weight can be calculated as shown in FIG 7(d). The weights of total slag (black dashed line) and liquid slag (red dashed line) for the low-grade DRI case are significantly higher than for the high-grade DRI case (solid lines). On a cumulative bases, ~70 t of total slag is generated in the low-grade DRI case, compared to ~40 t in the high-grade case. Usually, the slag is discharged towards the end of the heat. However, the effect of deslagging is not considered in this study.

The variation of the effective viscosity (liquid + solid slag), shown in FIG 7(c), gives an idea of the foaminess of the slag (transient nature). The calculated viscosity of the liquid slag is based on a very extensive database of FactSage. The Einstein-Roscoe equation [Einstein, 1906] was then used to calculate the effective viscosity (liquid + solid slag) that considers the effect of the MgO solid fraction. The fraction of solid MgO in slag is in the range of 2-10% under the present conditions (FIG 7(d)) and therefore has only a small contribution to the effective viscosity of the slag. The calculated values range from 0.025-0.035 Pa.s under the considered conditions. These values are in the range of experimental observations [Choi et al., 2021] for similar slag composition (~30 wt% FeO slags at 1600 ºC).

The kink in the viscosity curve at ~30 mins (FIG 7(c)) is most likely due to the increase in formation of the MgO solid solution. The viscosity curve follows the pattern of the MgO solid solution throughout as this is the only solid phase present.

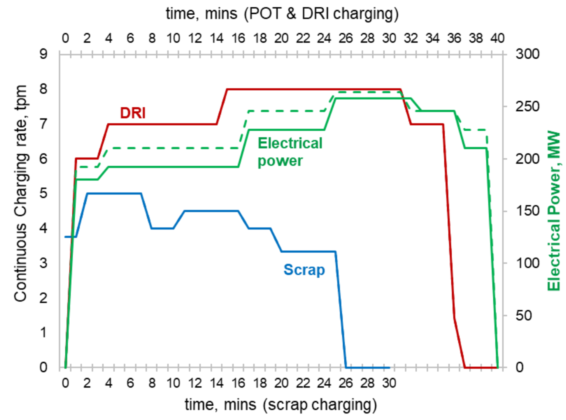
The transient melting profile of various scrap feeds are shown in FIG 7(e). As observed, there is no unmelted scrap remaining in the heat after ~35 mins.

As depicted in FIG 7(f), the bath [C] and slag (FeO_x) and (MgO) levels are comparable to those obtained from the BOF process. It is also important to check the presence and behavior of other important components such as [P], [Mn], [S] and [N]. However, they are not part of the present study. This is especially important from the product point of view as the integrated steel producers are looking to cover their current product portfolio as much as possible with the DRP-EAF route. In this study, a bath [C] level of 0.04 wt% and slag (FeO_x) of 29 wt% are obtained in the high-grade DRI case – compared to 0.04 wt% [C] and 24 wt% (FeO_x) for the low-grade DRI case. A lower (FeO_x) level in the low-grade DRI case might seem counter-intuitive at first. However this is likely the result of dilution of its concentration due to the addition of very high amounts of fluxes (lime and dololime) in the low-grade DRI case. Although its concentration is lower, the specific mass of FeO_x formed is higher due to a relatively higher slag rate in the low-grade DRI case (52 kg FeO/tLS), compared to 29 kg FeO/tLS in case of the high-grade DRI case. The slag (MgO) level for both the cases is around 8 wt%.

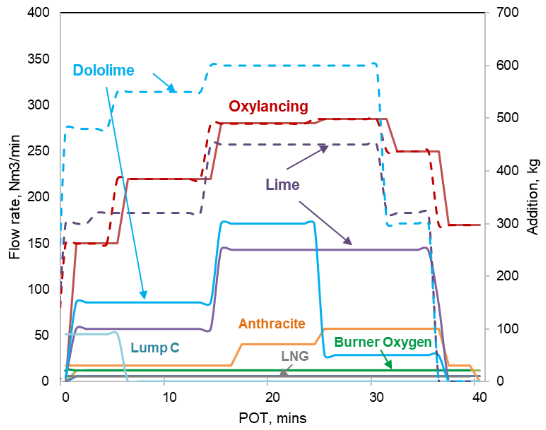
One important point to note is that the (relatively) steady variations in process outputs, such as steel and slag compositions, slag B_3, slag viscosity (foaming), are obtained after carefully manipulating the control parameters such as flux additions, feed rates, power input, oxylancing and carbon addition.

Few selected parameters are listed in Table 2 for comparing the end-point results from the high-grade and low-grade DRI cases. Few key points to note are as follows:

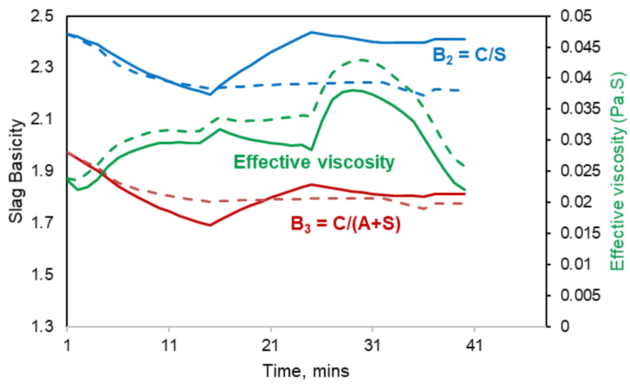
- For the low-grade DRI case:
  - Lower productivity
  - Higher electrical energy consumption
  - Higher slag rate
  - Higher flux consumption
  - The specific consumption figures can be used further to carry out cost calculations



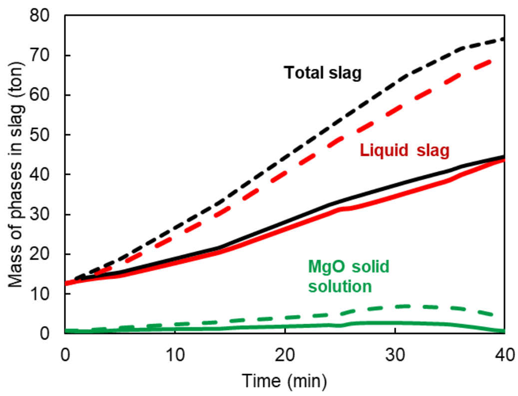
(a) Charging and Electrical power profiles



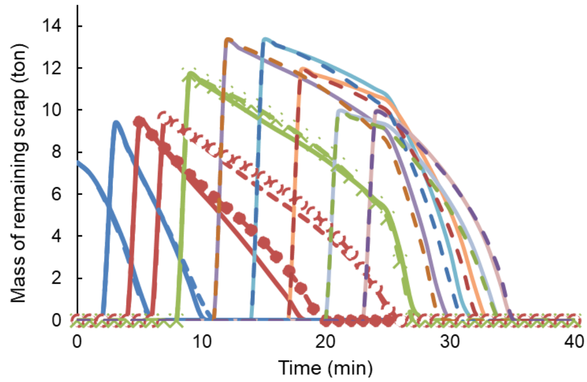
(b) Additions (flux, C, O_2, NG)



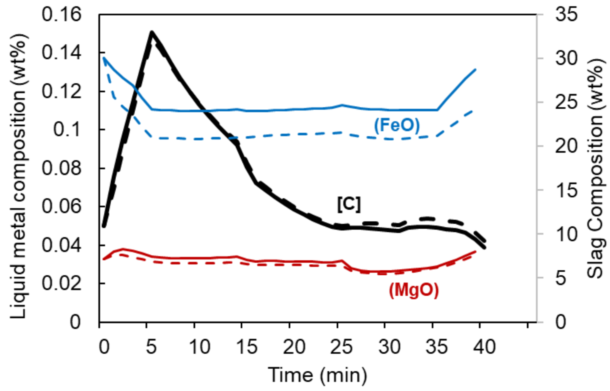
(c) Slag basicity and viscosity profiles



(d) Slag weight (no deslagging) and MgO saturation profiles



(e) Scrap melting profiles. Note: Each line shows a separate scrap feed into the furnace.



(f) Chemistry:$[C]_{LS}$, $(FeO)_{slag}$ and $(MgO)_{slag}$

FIG 7 – Model Outputs: Dynamic profiles for the high-grade DRI (solid lines) and low-grade DRI (dashed lines) cases.

Table 2 – Model simulation results (selected parameters) at LS tap

Parameter	Ore type	With High-grade DRI ~ 2.5% acidic gangue	With Low-grade DRI ~ 5% acidic gangue
LS	Composition	387 ppm C, 503 ppm O	420 ppm C, 460 ppm O
Slag	Composition	• B_3 (C/A+S) = 1.8 • FeO_x ~ 29 wt. %	• B_3 (C/A+S) = 1.8 • FeO_x ~ 24 wt. %

	Rate	92 kg/tLS	186 kg/tLS
Electrical energy consumption	kWh/tLS	417	458
Flux Consumption	Lime	20 kg/tLS	42 kg/tLS
	Dololime	17 kg/tLS	58 kg/tLS
Yield	%	93%	89%

CONCLUSION

In this work, a sample case study for a 70% DRI + 30% scrap input to a continuous charging EAF was performed using a dynamic EERZ process model. The model is not validated for this specific case, but results should be considered as logical extrapolations from the validated extremes (100% scrap and 40% DRI + 60% scrap).

Two cases, one with a high-grade DRI (~2.5% acidic gangue content) and another with a low-grade DRI (~5% acidic gangue content), were simulated. Following conclusions can be drawn from this specific case study:

For the low-grade DRI case (compared to the high-grade DRI case), the following were observed:

- 4% lower productivity of liquid steel (LS)
- 9% higher electrical energy consumption
- 51% higher slag rate
- 62% higher flux consumption
- 4% lower yield

The higher electrical energy consumption for the case of low-grade DRI input is due to the extra power needed to melt the additional acidic gangue in low-grade DRI and relatively higher amount of added fluxes. Higher fluxes are needed in the low-grade DRI case to balance the higher incoming acidic gangue. Moreover, higher fluxes also generate higher slag rates and thus reduce the liquid steel productivity and yield. The specific consumption figures can be used further to carry out cost calculations and compare between various options on a techno-economical basis.

A lot of research & technology development is now being channelized towards getting an EAF liquid steel that is as close as possible to that of BOF liquid steel. Using a high amount of DRI in EAF is one of the steps towards it, but dynamic process control and slag engineering are also very important influencing factors. Through this study, the importance of these factors has been highlighted:

1) *Slag engineering*:
    a. It is possible to operate EAFs at different B_3 (slag basicity) values.
    b. The target slag for a good EAF operation should ensure minimum volume requirement, refining requirement (dephosphorisation), slag foaming and MgO saturation.
2) *Dynamic process control*:
    a. It is important to understand the transient behaviour (and not just the end-point) of the process characteristics: steel, slag and off-gas composition, rate and temperature.
    b. Dynamic control over parameters such as carbon and oxygen injection enables hitting targets of bath [C] content, slag (FeO) content and yield.

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