Optimising Consteel continuous scrap feeding with roof-fed DRI

For EAF furnaces charged jointly with scrap and with DRI through the roof, feeding the scrap via a Consteel pre-heater conveyor rather than by bucket enables a shorter power-on time, increases productivity and improves all other operating parameters, except carbon injection, resulting in a significant saving in electrical energy. By F Memoli*, J A T Jones** & F Picciolo***

WHILE some conventional EAFs use DRI as a source of iron for their charge, the use of DRI in a furnace equipped with a Consteel continuous scrap preheater has not yet been adopted on a large scale. Those plants which have started using DRI in Consteel furnaces report promising results. Process investigations, metallurgical calculations and practical tests have been carried out to determine the optimum balance between Consteel continuous scrap charging and continuous charging of DRI through the furnace roof.

The composition of the DRI is important and impacts furnace parameters such as yield, flux additions, slag weight, energy, injected carbon and feeding rates as well as oxygen use. DRI composition varies depending on the source and analysis of the ore used. The process used for DRI production and the choice of operating parameters also impact the DRI chemistry.

One of the routes for DRI production, the HYL Self-Reforming Process, enhances the carbon content of the DRI to well above 4% with the formation of iron carbide (Fe₃C) as a major component of the DRI (Fig 1). In comparison, other processes generally result in a significant portion of the carbon not combined as Fe₃C in the DRI. This difference is important when it comes to using the DRI in the EAF. It is preferable to have Fe₃C rather than elemental Fe and C, to avoid loss of free C by combustion in the EAF atmosphere [Duarte 2].

DRI produced via the HYL process has carbon that can exceed the carbon content of blast furnace pig iron (~4%), reaching values up to 6%. This carbon will yield energy by the reactions:

\[
2\text{C}(s) + \text{O}_2(g) \leftrightarrow 2\text{CO}(g) + \text{Heat} \quad \Delta H = -221.0 \text{ kJ}
\]

\[
\text{Fe(s)} + \text{C(s)} \leftrightarrow \text{Fe}_3\text{C}(s) + \text{Heat} \quad \Delta H = -21 \text{ kJ}
\]

The combination of these reactions will yield more than 37kWh/tls per each 1% carbon in the DRI, in particular if carbon is in the form of Fe₃C.

Why use DRI

There are two reasons for an EAF to add DRI as part or all of its iron units: residual element control and lack of premium grade scrap.

Scrap availability is limited in certain regions of the world. The pressure on the scrap market from minimills forces scrap users to turn to lower grade sources, such as obsolete scrap. The problem with obsolete scrap is its quality. Growth in electric arc steelmaking has led to an unavoidable faster turnabout of scrap and consequently, to increased contamination by other elements [Grobler, 3]. Residuals such as Cr, Ni, Mo, Cu and Sn, range from 0.15% to 0.75% depending on the type of scrap. Residuals have adverse effects on mechanical properties of the resulting steel. Thus, using scrap-only charged EAFs for the production of quality steels as well as low carbon steels is generally avoided. Another problem for scrap-only based EAFs is nitrogen. The N content of EAF steels is higher than BOF steels. Consequently, steel grades produced in an EAF generally have

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The advantages of charging DRI are numerous:
- Pellets of near constant dimension;
- Known composition;
- Absence of tramp elements;
- Purity or the absence of non-metallic substances improves productivity and lowers energy consumption;
- Easy use in the EAF: DRI pellets can be dumped into an EAF along with scrap, using buckets or continuous feeding;
- Availability: unlike low residual scrap supply, DRI is usually available in the market;
- Associated carbon: DRI has the added benefit, when compared to scrap, that it contains an associated energy value in the form of combined carbon.
- Easy generation of foaming slag;
- Direct charging: the use of hot DRI directly transported and charged to a furnace can reduce energy consumption by 16% to 20% by making use of the energy value of the DRI at temperatures greater than 600°C [Scarnati, 4];
- Easy handling and storage: Able to feed without opening the furnace roof using a continuous feeding system. Also, the more stable steel bath surface reduces the risk of electrode breakages [Takla, 5];
- Blending abilities of DRI with scrap allow cheaper scrap grades;
- More environmentally friendly: Avoids problems of hazardous contaminants in EAF dust eg lead or cadmium, as well as reducing the formation of dioxins and furans.

In particular, the HYL route complies with the strictest environmental regulations worldwide without the need of specific process requirements and/or additional equipment for treating heavy hydrocarbons in natural gas, sulphur in iron ore and/or de-NOx systems. The NOx level is below environmental limits due to the overall energy integration of the HYL process, made possible even without a large amount of air preheating for energy recovery [Duarte, 6].

DRI use in a conventional EAF
Typically, if DRI charged in the EAF is less than 25% of the total, it is charged using a scrap bucket. This can lead to the formation of DRI ‘icebergs’, so called ‘ferrobergs’, if the DRI is not spread out in discrete layers within the scrap bucket. The issue of ferrobergs increases as the proportion of bucket fed DRI increases.

The alternative and more effective way to add DRI is by means of a conveyor belt that will drop the DRI into a chute mounted...
on the EAF roof (Fig 2). This method provides good control of the melting process when large proportions of DRI are used. Pioneers of these belt feeders are Tenaris Siderca and ArcelorMittal Acindar which, in the 1980s and 90s, were able to achieve excellent results in terms of steel quality and specific key performance indicators (KPI) [Poblete, 7].

Continuous feeding of DRI is into a flat bath. The subsequent foaming of the slag is necessary for the insulation of the arc and the protection of the furnace refractories. Foamy slag also reduces the arc and the protection of the furnace refractories. Foamy slag also reduces the arc. The slag density which allows the DRI to penetrate through it into the liquid bath.

The process of continuous DRI feeding to the EAF is the idea for the development of the Consteel scrap charger in the 1980s by its inventor John A Vallomy. As Melshop Manager of the Siderca steel plant in Argentina, Vallomy was acquainted with continuous charging of DRI to the EAF and thought that since continuous feeding was working for DRI, there was no reason why it would not also work for scrap [Memoli, 9].

The issue at that time was to find a dependable conveyor to charge pre-heated scrap into the EAF. Today, after twenty-five years of experience, the Consteel is a consolidated technology with over 45 operating plants. Table 1 is a summary of the benefits of charging DRI in an EAF where scrap is continuously fed via Consteel or by conventional bucket charges.

**Scrap bucket charging vs Consteel**

In both scenarios, part of the charge is DRI fed continuously through the furnace roof.

The case provides typical results for a modern micro-mill EAF producing 300kt of liquid steel operating for 300 days a year charging either 100% scrap or 40% scrap + 60% cold DRI. The Consteel conveyor will be used for the scrap charge, and DRI will be fed directly into the furnace through the roof, together with the required slag-forming and carburizing additives. Table 2 presents the EAF parameters.

For comparisons purposes, the average active power and the supersonic oxygen injector configuration are the same for both cases. Nevertheless, the bucket furnace simulation has been performed considering the addition of three oxy-fuel burners.

**Table 3** presents the metallic charges used for the calculations.

The EAF has:

- 1650 Nm/h supersonic O₂ flow; plus
- Coal powder injection flow rate up to 60kg/min; and
- Two DPP bottom porous plugs for Ar/N₂ purging:
  - Ar/N₂ injection flow rate up to 300NL/ min each line.

**Table 3** summaries the benefits of charging DRI continuously fed through the roof, together with the required slag-forming and carburizing additives.

**Consteel scrap with roof fed DRI**

The process of continuous DRI feeding to the EAF was the idea for the development of the Consteel scrap charger in the 1980s by its inventor John A Vallomy.
Simultaneous feeding of DRI and scrap from the beginning of the heat enhances the arc cover by slag due to good slag foaming resulting from high CO evolution when charging DRI. This provides increased arc stability and arc efficiency throughout the entire heat: lower power-on time and lower electric energy consumption.

DRI chemical composition results in CO-rich fumes, resulting in enhanced scrap preheating when using the Consteel process. Fig. 4 compares key operating parameters for the two methods of charging.

Recent operating results

At a Consteel EAF facility in South Korea, DRI and HBI have been fed through the furnace roof. HBI has also been fed on the Consteel conveyor. After several trials the plant determined that the most efficient way to charge DRI is through the roof while HBI should be charged via the conveyor.

DRI is fed through the roof, starting about 3 minutes after the beginning of power-on and continues until about 5 minutes before the end of scrap charging. The operation is maintained as a parallel feeding practice to increase the total feeding rate and balancing the furnace thermal distribution. Although DRI cannot be charged via Consteel, to avoid re-oxidation, HBI can be fed on the Consteel conveyor, to be heated by the furnace off-gasses.

The best results are obtained when the bath temperature is maintained at about 1550°C (2820°F) or higher. That leads to rapid melting of the DRI pellets and avoids the formation of ferrobergs. A very stable foamy slag is formed and typically active power is 10% higher than that possible when melting of scrap alone. It is very beneficial to inject oxygen near the point where the DRI impinges on the bath in order to speed up DRI melting and to promote its circulation. Increasing the active power during feeding DRI leads to typical power consumptions that are similar to those obtained with a 100% scrap operation with similar or shorter power-on times.

For this Consteel EAF, with a tapping size of 160t, the chemistry of the DRI can vary as it is purchased on the merchant market. Typical operating results with 45t of DRI in the charge (~25% of total charge) are:

- **Power-on time**: 38 to 42 minutes
- **Power consumption**: 330 to 380kWh/
charge tonne
- Oxygen consumption 28 to 31Nm$^3$/charge tonne
- Carbon injection 12 to 15kg/charge tonne.

Figs 6 & 7 summarise data of over 1500 heats of Consteel with DRI charged through the roof. The Consteel conveyor speed must be slowed as the amount of DRI charged through the roof is increased as otherwise the residence time of scrap in the Consteel tunnel is too short for efficient transfer of heat from the EAF off-gasses to the scrap.

**Charge flexibility**

Charging scrap by bucket is a discrete operation. Minimising the number of buckets is always beneficial as heat is lost from the furnace each time the roof is opened. When it comes to charging more than 25% of the charge as DRI a bucket charged furnace suffers constraints. Consider a conventional two-bucket charge EAF where the first bucket is 60% of the total charge and DRI is charged through the roof. To avoid having to make a second bucket charge, 40% of the total charge must be DRI through the roof. If the quantity of DRI available is insufficient for this, the balance of scrap must be charged by a second bucket. As a consequence, there is a loss of energy due to opening the roof as well as time lost in charging the second bucket. This reduces the benefits achieved by charging DRI through the roof.

In contrast, the Consteel EAF furnace is performing continuous scrap charging and can accommodate any proportion of scrap in the charge and balance it with DRI through the roof. Therefore Consteel is the preferred process to the extent of having the flexibility to decide which is the most convenient scrap/DRI mix, for residuals and quality considerations or for a simple economic equation.

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