Use of DRI in EAF's

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Part III: Slag Practices and Oxygen/Carbon Injection when Melting Direct Reduced Iron

Introduction

When melting DRI or HBI in an EAF, a well designed slag combined with proper oxygen and carbon injection practices leads to higher yields, lower energy consumption, reduced refractory wear and consistent tap to tap times. Dissolved hydrogen and nitrogen contents in liquid steel are lowered due to the boil caused by using DRI when combined with a good foaming slag.

Depending on the percentage of DRI used in the charge, the slag and oxygen/carbon injection practices must be substantially different as compared to a furnace melting 100% scrap. DRI is very unlike scrap from the standpoint of metallic content. Scrap is inherently composed of iron. While many non-metallic materials may be mixed into a pile of scrap, the intrinsic pieces of steel scrap usually have around a 98 to 99% metallic iron content.

DRI or HBI has a 79 to 89% metallic iron content. The remainder of the DRI or HBI is made up of FeO, carbon, phosphorous, sulfur and gangue. A slag must be designed to neutralize the acid material contained in the gangue to protect the basic lined EAF; to remove the phosphorous from the melt; and to promote foaming. Knowledge of the DRI FeO and carbon content is essential when designing the oxygen and carbon injection practices. DRI can be classified as either carburizing or decarburizing.

Slag Additions when Melting DRI

An operator needs to estimate the chemical composition of all raw materials put into the EAF during the melt: scrap, DRI or HBI, quick lime, dolomitic lime, injectable coke or graphite, oxygen and charge carbon. The desired tap carbon, temperature and phosphorous levels should also be known. As a rule of thumb, EAF slag FeO levels are approximated by the formula: % FeO = 10% + 1/%C.

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All tonnage electric arc furnaces melting DRI or HBI have a basic lining. This is due to the need to remove phosphorous and sulfur from the melt. With this in mind an operator needs to make a basic slag in the EAF.

Depending on the nature of the operation, the basicity ratio, CaO/SiO_2, may range from 0.9 to 2.5. Factors such as yield, energy and refractory consumption, slag foaming and slag weight are affected by the basicity. Slag composition during a melt varies with time due to the continuous charging of quick lime and dolomitic lime simultaneously with DRI or HBI and increasing FeO content from oxygen injection.

As a general rule, slag needs to be fluid to work in the EAF. A highly viscous slag containing solid lumps of lime does not react with the liquid steel melt nor does it foam. Except in certain instances, the use of calcium fluoride, CaF_2, (Spar) as a slag liquifier should be avoided in the EAF due to the excessive wear it causes to the EAF refractory lining.

In designing a slag composition an operator must first determine all the contributors of silicon or silica. Sources can include the DRI or HBI, ash in the coal charges or coke breeze injectants, steel scrap, iron castings, quick lime and dolomitic lime additions. In the case of silicon contained in iron castings or steel scrap, the operator needs to convert the Si to SiO_2 by the following formula: wt. Si x 60/28 = wt. SiO_2.

Next the weights of all silica additions are summed. When initially adding DRI or HBI an operator should begin with a desired basicity around 1.8 (CaO/SiO_2). The total CaO addition is determined as follows: Σ wt. SiO_2 x desired basicity = wt. CaO. A series of trials should be conducted which include slag chemistry analysis. Based on the data, fine tuning of a good computer driven charge model will help to manage slag chemistries after the initial trials.

If MgO is not added to the slag, it will be leached from the furnace refractory lining and dissolved into the slag. After determining the basisity, one should design into the slag a 6 to 12 % MgO addition.[1] Direct heating of the slag by the electric arc in the EAF enables the slag to “shape up” quickly. The MgO can be obtained from dolomitic lime or MgO fines blown into the slag.

By knowing the quick lime and dolomitic lime compositions an operator can then calculate the flux addition weights.* Depending on the charge weight of DRI or HBI, SiO_2 gangue content, aim tap phosphorous levels and slag FeO percentage, the total lime addition to the EAF may range from 25 to 70 kg/tap ton.

Slag of sufficient volume to cover the arc during foaming needs to be available in the EAF. Foaming slag has a specific gravity 1/3 that of normal slag. This leads to a threefold increase in slag height so that minor decreases in the slag weight will not lead to an exposed arc during foaming operations.

When melting, it is important to keep the slag in the EAF until foaming causes the slag to spill out of the furnace door. Early slag coming out of the EAF represents lost energy and yield. Tilting the EAF 3 to 5 degrees towards the tapping pit will minimize premature slag spillage.

Oxygen and Carbon Injection Practices

DRI as an iron bearing raw material is unique in that it carries its own supply of both carbon and oxygen. At a weight ratio of 3 units carbon to 4 units oxygen the material can be said to have a stoichiometrically balanced carbon content. At a C/O weight ratio greater than 0.75 the DRI is carburizing while at a ratio less than 0.75 the DRI is decarburizing.

As a quick rule of thumb, at 298 K (25°C or 77°F) 1 nm^3 oxygen gas will oxidize 1 kg of carbon.

Example 1.	Fe(total)%	Fe Metallic %	C%
	92.1	87.5	1.5

Based on this composition the DRI contains 1.31 % oxygen tied to the unreduced Fe. The weight ratio of carbon to oxygen is 1.15 so this material is carburizing. If the furnace is charged with 60 tonne of DRI, approximately 288 nm^3 oxygen gas will be needed to completely oxidize the 308 kg of excess carbon in the DRI.

Example 2.	Fe(total)%	Fe Metallic %	C%
	93.2	83.2	1.1

* Note: All tons are metric

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Based on this composition the DRI contains about 2.85 % oxygen tied to the unreduced Fe. The weight ratio of carbon to oxygen is 0.39 so this material is decarburizing. In this example, if the furnace is charged with 60 tons of DRI an additional 622 kg carbon will be needed in solution to reduce all of the FeO in the DRI to Fe.

As the DRI is melted, CO gas is formed. This causes a natural boiling action, which leads to the removal of dissolved nitrogen and hydrogen. If the slag on top of the melt is fluid it will foam.

In many cases, the oxygen supplied by the FeO far exceeds the requirements of the intrinsic carbon contained in the DRI. This will necessitate the addition of carbon to the bath. Some melt shops may initially charge from 500 to 1500 kg of coal or nut coke to the liquid heel at the start of the melt. This is a good practice provided that the heel is of sufficient volume to absorb the charge carbon.

If the DRI is decarburizing, then the injection of carbon directly into the liquid steel bath becomes imperative. During the course of the melt, coke breeze or graphite particles, 0.1 to 3.0 mm, are injected into the bath. Carbon must be added to reduce the FeO to Fe. This is an endothermic reaction.

Consumable lances are the preferred mechanism for injecting carbon and oxygen when melting heats containing 60 % or greater DRI. Depending on the EAF hearth geometry and initial charge weight, DRI continuous feeding may start when the liquid bath level is 700 mm or more below the door breast. While water cooled lances are very good for melting scrap, a consumable lance can extend far into the EAF and inject carbon and oxygen below the slag/metal interface.

If excess carbon is injected the operator can simultaneously blow oxygen into the bath to cause an exothermic reaction and form CO gas. This promotes early slag foaming and an energy saving of 2 to 4 kWh per nM^3 O_2 gas.

In an excellent report, IMEXA steel reports injecting carbon at 25 kg/min carbon per lance and using a total amount of 3000 nM^3 O2 gas based on a 220 ton tap weight. At the end of the melt the carbon injection rate per lance is increased to 30 kg/min.[2]

When foaming starts in the EAF a dramatic drop in sound occurs. Based on measurements made by the writer, the sound level may drop from 127 dB down to 104 dB. An operator should reduce the carbon injection rate when the sound decreases. Controlling the rate of carbon injection (foaming) based on sound intensity can be easily automated with the use of a dB meter.

References:

1. William T. Lankford,Jr., et. al., ed., The Making Shaping and Treating of Steel, 10th Edition, United States Steel Corp, 1985, Figure 16-4, pg 804.
2. R.D. Morales, et. al.,"The Slag Foaming Practice in EAF and Its Influence on the Steelmaking Shop Productivity," ISIJ International, Vol. 35 (1995) No. 9, pp.1054-1062.

Biographical Information

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