New Approach to Nitrogen Control in EAF Steelmaking

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High grade steels, particularly in flat products are associated with low levels of dissolved nitrogen. For deep drawing steels it is desirable to keep nitrogen levels below 50 ppm, whereas a range of 120 to 150ppm is acceptable for high strength structural steels (1). In EAF steelmaking, molten metal is often exposed directly to the air during the melt down. Ionisation of nitrogen by the arc is also thought to accelerate the rate of nitrogen pick up by the steel. In addition, scrap and ferro-alloys can contain significant dissolved nitrogen. As a result, whilst steel produced from Oxygen steelmaking contains 30 to 40ppm, nitrogen levels in steel produce from EAF is typically in the range 70 to 100ppm.

As mini-mill operators have made the move from long products, traditionally associated with EAF production (2), to the more high value flat product range, the issue of nitrogen control has become important. A number of methods have been developed to lower nitrogen, including vacuum treatment, carbon oxidation to produce fine CO bubble to dissolve nitrogen, improving slag cover during melting and dilution with low nitrogen materials such as DRI and pig iron (2, 5). Goldstein et al. (3) studied the effect of adding DRI pellets on the removal of nitrogen from steel. They found that whilst the formation of CO bubble below the melt had the potential to lower the nitrogen level through “flushing” of nitrogen into fine CO bubbles, the buoyancy of DRI pellets reduced this effect, as the bubbles would pass through the slag layer.

Research into the use of iron carbide in EAF steelmaking during the 1990s found that injection of iron carbide nitrogen levels could be reduced from 80 to 30ppm, which was thought to be largely due the flushing effect of very fine CO bubbles travelling through the melt (5). Brooks and Huo (6) investigated the rate of CO generation from different iron carbide sources, as a first step to understanding the flushing effect of iron carbide injection. This line of thinking, that is, the idea that injecting an iron source with CO generating capability into an EAF had the potential to greatly lower nitrogen, lead to an AISI-DOE funded project at McMaster University by the authors of the paper (7, 8 & 9).

It was proposed that DRI fines be injected late in the melting sequence to remove nitrogen before lade treatment. DRI fines are generated from the DRI production processes or by attrition in transport and handling. The study on materials characterisation of the DRI fines, mathematical modelling of the nitrogen removal process and comparison to existing industrial data (7, 8 & 9).

It was found that the most important characteristic of the DRI fines was that the carbon and oxygen contents be balanced stoichiometrically to produce as much CO per tonne of DRI as possible. Ideally, the gangue content of the DRI fines should be minimised to reduce energy requirements for melting and slag volume. These relationships are summarised in Figure 1.
Thermodynamic relationships were developed to predict the level of nitrogen removal for a given level of CO generated from a quantity of DRI. These relationships were use to analyse plant train data from Ispat Hamburger and North Star operations, where a range of DRI fines, lump DRI and scrap feeds were trialled. Whilst, it was difficult to separate nitrogen flushing and dilution effects, the analysis suggested that approximately 25% of nitrogen can be removed from steel with approximately a 5% addition of DRI fines to an EAF.

Kinetic analysis of the process was based on the assumption that mass transport on the liquid side at the bubble is much slower than the gas side, that the kinetics could be controlled by adsorption of sulphur and oxygen at the interface and that mass transport of nitrogen from the bulk to the bubble region is no transport limiting. The model included the effect of bubble size and rising distance (i.e. how deep the fines are injected). Typical results are shown in Figure 2. These calculations show that the bubbles can only pick up a few percent of nitrogen during the rise, and that the curves become parallel after some rise time because the bubbles are approaching the equilibrium. The equilibrium content is also varying as the Ferro static head. Please note that very fine bubbles saturate very quickly, so producing the bubbles deeply in the bath is not required. This also means that because the kinetics is fast, a thermodynamic model can be largely use to assess the potential for removal of nitrogen for a given scenario. The practical engineering issues are more about how to ensure that the fine bubbles are evenly distributed in the bath to maximise nitrogen removal. An injection model was developed to allow selection of parameters such as lance diameter, solids feed rate, solid to gas loading and lance angle.
In conclusion, injecting DRI fines late in an EAF melting cycle has the potential to greatly lower the nitrogen level. Further industrial work is required to fully evaluate the concept but existing plant trial data and modelling analysis by the authors indicate that the idea is technically and economically viable.

References