

Production of Low Phosphorus and Nitrogen Steels Using HBI in the EAF

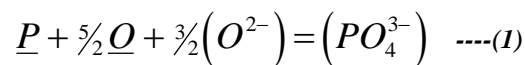
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1. INTRODUCTION

Commercially produced Hot Briquetted Iron (HBI) usually contains more phosphorus than scrap. Operational data, however, show that low phosphorus melts are still obtained using high phosphorus HBI as a feed in steelmaking. This effect can be explained by the nature of the phosphorus in the HBI and the practices in the use of the HBI.

The phosphorus reaction can be written as:



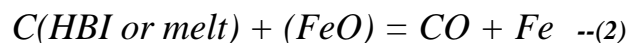
where \underline{P} and \underline{O} are dissolved in the metal and (O^{2-}) and (PO_4^{3-}) are in the slag. The O^{2-} represents a free oxygen ion the concentration of which increases with slag basicity. Phosphorus removal is favoured by high oxygen contents, high basicities and low temperatures.

For EAF operation, the production of low phosphorus steel from a high phosphorus HBI charge has been demonstrated by trials conducted at BHP's Sydney Steel Mill and routine practice at CASIMA in Venezuela. The use of a flush slag practice results in the removal of a phosphorus rich slag early in the heat when temperatures are low and before the phosphorus can be reduced and transferred to the metal phase.

The phosphorus levels calculated for an EAF using a thermodynamic model and a mass balance shows that if full slag and metal contact occurred the steel phosphorus content could be as high as 0.045%. Using commercially available HBI this is not the case. In actual practice using a phosphorus of 0.095% in the HBI it is normal to achieve an average of 0.014% phosphorus in the melt.

The Nitrogen levels of an EAF operation using DRI are also lower than with scrap. The dilution of the scrap by the low residual HBI is a known factor. However additions of HBI and DRI at BHP Steel plants and other operations⁶ have reported added benefits. DRI and carbon react to form CO gas in the melt but modeling these mechanisms do not give predictions of nitrogen levels that match results. The production of lower nitrogen steels using DRI needs to be better understood.

The reactions of Carbon with the HBI could be written as;



The resulting Nitrogen and Phosphorus levels from the use of HBI can be examined by looking at each of the HBI constituents. Depending on the level of these constituents the ease and costs in producing high quality steel can be known. The predictable nature of these constituents from a particular source of HBI leads to predictable final quality steel. Nitrogen and Phosphorus levels can be very low when using HBI in an optimum manner.

2. HBI SPECIFICATIONS

Two HBI sources were used for trials and analysis. The specification of these HBI are shown in Table 1.

Table1. Specification of HBI used in test work

	FeT Wt%	Met %	P Wt%	CaO Wt%	SiO2 Wt%	C Wt%	MnO Wt%
HBI#1	92.7	92.5	0.065	0.04	1.60	1.31	0.14
HBI#2	92.0	94.5	0.095	0.50	1.79	1.87	0.15

HBI#1 was produced using Mt Newman fines from Australia in the FIOR process whilst HBI#2 was produced using Venezuelan Pellets in the VENPRECAR plant using the MIDREX process. HBI#2 is made from higher phosphorus ores.



Figure1. HBI #1 Briquettes used in trials

3.EFFECTS OF CARBON

The precise amount of Carbon present in the HBI can determine the final Nitrogen content. There are three proposed benefits using the carbon in HBI for low Nitrogen steels;

1)The carbon reacting with the FeO to produce CO gas in the melt.

Bubbling CO gas removes Nitrogen if sufficient carbon remains in the melt ⁹. Preliminary injection trials at BHP Research laboratories¹⁰ confirm the increased removal of Nitrogen by injecting Iron Carbide with 4.7% Carbon compared to injecting HBI fines with 1.3% Carbon(see figure 4). The increased Carbon causing increased generation of gas and lower nitrogen;

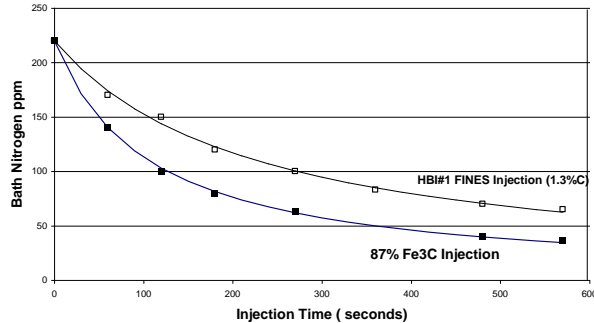


Figure2. Induction Furnace Injection Trials with Crushed HBI#1¹⁰

2)The HBI melts in the slag shielding the melt from the Nitrogen in the furnace.

Work by Fruehan and Goldstein ⁹ suggest that this is the major impact of HBI gas evolution since the HBI becomes buoyant and floats in the slag;

Results obtained at Sydney steel mill support this idea. Increasing amounts of HBI addition had a diminishing effect in reducing nitrogen. The rate predicted by injecting the crushed HBI was not approached.

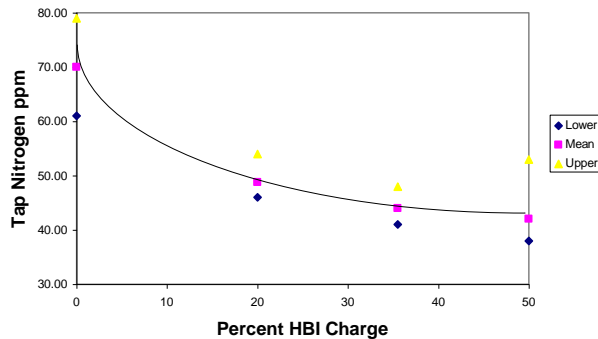


Figure3. Tap Nitrogen with % HBI#1 charged at Sydney EAF.

3)The Carbon reduces heat time reducing Nitrogen pickup.

A higher carbon content in the HBI reduces heat times. Whilst the addition of HBI increases heat times, higher carbon leads to lower penalties. The extra carbon is usually consumed by the extra FeO in the HBI. The exact balance can be calculated at a carbon to FeO ratio of 12 to 1. For 15% FeO in HBI the required Carbon content would be 1.25%.

Based this data the most efficient method of reducing Nitrogen is to inject the fines rather than add HBI to bath. The justification for the expense of higher carbons level than 1.25 wt% would not be apparent unless the HBI could be injected as fines.

4.. EFFECTS OF IRON OXIDE

The Iron Oxide content in the slag has an slight effect on the Phosphorus content in the bath. Because the activity of FeO in the slag has an effect on reaction 1). Increasing the FeO content at constant temperature and basicity, should decrease the Phosphorus content. The decrease in Phosphorus content was observed for high FeO slags at Sydney EAF.

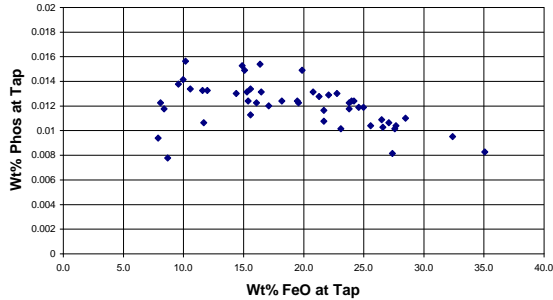


Figure4. The effect of Slag Iron Oxide on the Tap Phosphorus Level in Sydney EAF.

The Iron oxide present in the HBI is also known to have an impact on the yield and power requirement for melting HBI. If insufficient carbon is present in the melt than the FeO will report to the slag , lowering Phosphorus but reducing yield. To some extent using HBI in the EAF there is a trade off between low yields and low Phosphorus.

5. EFFECTS OF GANGUE

The main effect of the total Gangue in the HBI is to increase the slag volume. Comparing HBI#1 and another similar HBI the total slag at Sydney EAF was found to increase. With addition of 85% HBI the volume increase from 6 tonnes to 9.2 tonnes. This slag includes fluxes added to keep the basicity at a ratio of 2.2.

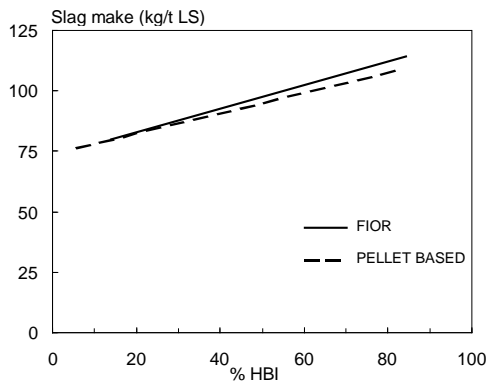


Figure5. Slag Make in Kg for additions of HBI#1 at Sydney EAF (similar to a pellet based HBI)

The slag volume increase effect Phosphorus content by mainly act as a flushing agent. If the slag was retained in the furnace then the (PO₄³⁻) in the slag would be expected to be picked up by the melt. However with a normal foaming slag and flushing practice at Sydney and Casima this pickup is avoided.

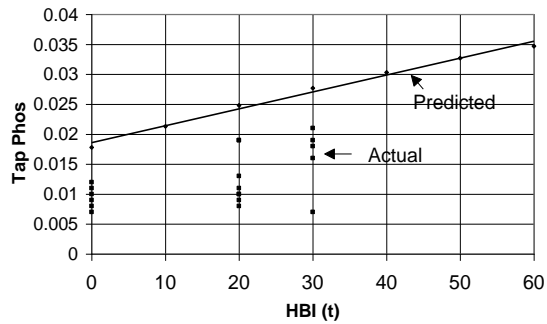


Figure 6. Results using HBI#2 at Sydney EAF compared to results predicted by a thermodynamic model.

In the case of Nitrogen the increase slag volume is also beneficial in protecting the melt from pickup. The slag generation starts early in the heat protecting the melt from any nitrogen in the furnace. This will slag also has other benefits in heat transfer.

6. EFFECTS OF SILICA AND ALUMINA

Data from Sydney suggest two effects of increasing the SiO₂ content of HBI;

- 1) Reducing the Phosphate Capacity of the Slag allowing some Phosphorus to go to the melt (as per Reaction (1)).

Increasing the SiO₂ content increased the Phosphorus in the melt even when extra lime was added. The effect of SiO₂ seemed to be stronger than that of the basicity, (shown in figures 7 And 8). This may have been due to not all the lime dissolving in the slags.

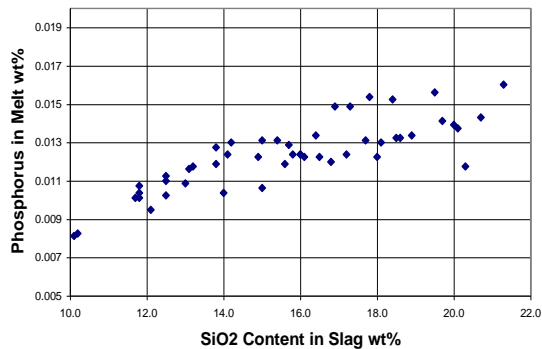


Figure 7. Phosphorus Content against slag SiO₂ at Sydney EAF using HBI #2 Trials

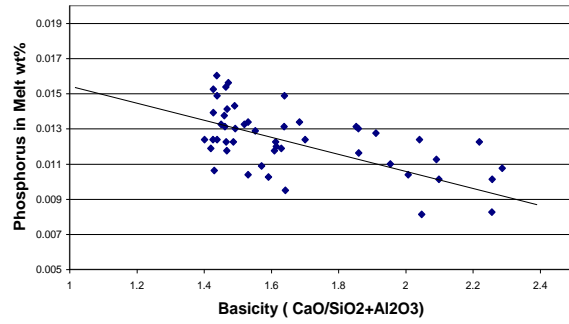


Figure8. Phosphorus Content against Slag Basicity at Sydney EAF HBI#2 Trials

2) The Basicity effects the slag foaming characteristics of the slag again shielding the melt from pickup of Nitrogen. An index is being developed to characterise foaming at Sydney EAF to try and establish a relation ship with Nitrogen pickup³.

7. EFFECTS OF FINES WITH DRI

For the EAF melt shop the fines content of the HBI has two effects;

- 1) Reduction in Yield: Material Lost in transport and feeding,
- 2) Reduction in Metallisation: Extra energy required for melting,

Field studies on the size fractions of dust have concluded that 80% of the fraction < 1mm is lost in handling and in the bag house.

The reduction of metallisation for the fines is difficult to measure. Fresh HBI losses metallisation more rapidly than older HBI. The loss will depend on storage conditions. A conservative number is 15% loss for the 6.3 mm fraction after exposed storage for one month.

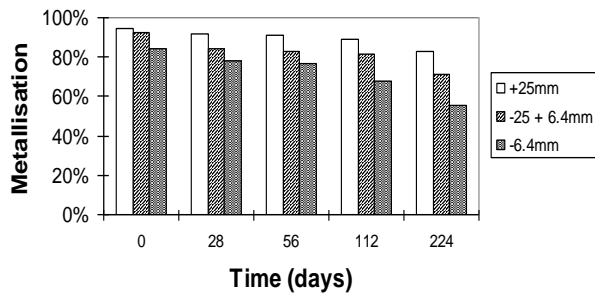


Figure9. The Metallisation Content HBI Fines with time

The amount of fines present will increase the amount of Iron Oxide in the bath as shown below after 3month storage,

%Fines<6.3mm	%Fines<25mm	FeO wt% (HBI#1)
0	0	14.25
1	0	14.56
1	1	14.67
2	1	14.96
3	1	15.26
4	1	15.56
5	2	15.95
10	2	17.47

Table1. Metallisation Content of HBI#1 with varying fines content (note typical <1.0% total)

The effect on Phosphorus and Nitrogen from the increase in FeO will be indirect. The main impact will be on yield losses and melting energy.

8. EFFECTS OF PHOSPHORUS

The Phosphorus content of the steel produced using the HBI is shown for two plants. All the results are considered to be normal phosphorus levels for high quality steels.

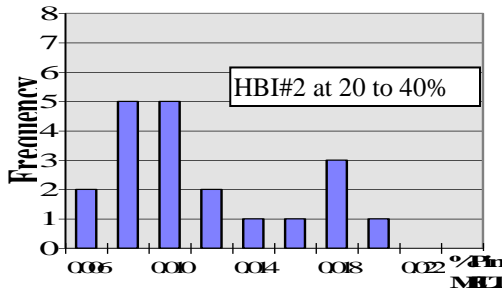


Figure 10. Melt Phosphorus at BHP's Sydney Steel Mill's 85 Tonne EAF during HBI trials using HBI#2.

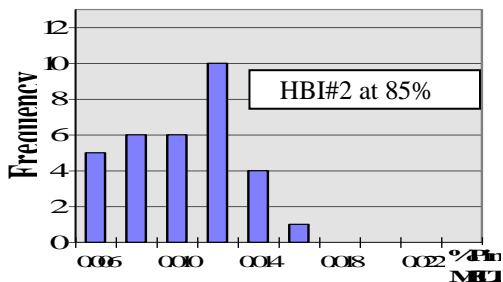


Figure 11. Melt phosphorus at SIVENSA's CASIMA 85 Tonne EAF during HBI trial using HBI#2.

The phosphorus results at BHP's Sydney Steel Mill are consistent with the average melt phosphorus of 0.012%. A few heats at Sydney had some reversion problems, but were related to incorrect practice from inexperience at using HBI#2

9. EFFECTS OF RESIDUALS

Low Nitrogen occurs in HBI because of the DRI Process uses a primary feed of Iron Ore containing low Nitrogen. Scrap contains varying amounts of Nitrogen in residual. The effect of trace element dilution can be easily measured for metallic elements but less easily for Nitrogen .

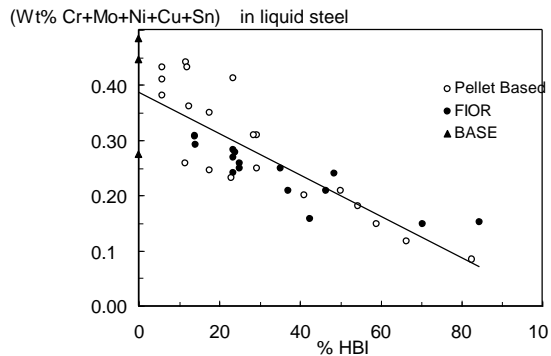


Figure12. Effect on Trace Metal Residuals using HBI #1

The measurement of dilution of Nitrogen is difficult because of the other effects of FeO , slag basicity and furnace slag practices. Pickup up nitrogen is also effected by Sulphur content and other furnace additives.

10. EFFECTS OF FEED ORE TYPE

Examination of HBI#1 and HBI#2 has shown that the phosphorus is associated with the oxygen rather than the Iron. Mapping of elements using a scanning electron microscope was used to determine the distribution of the elements in HBI. Oxygen maps and the Phosphorus maps matched well. The Iron maps indicated that the phosphorus was not associated with the iron (see figures 14 to 16).

Typical results for HBI#1 and HBI#2 did not show any difference between the HBI in term of phosphorus distribution. This is of further interest since the feed ores used were Australian Mt Newman Fines for HBI#1 and a higher Phosphorous Venezuelan fine ore for HBI#2. Further work is required to determine the distribution using other feed fine ores and pellet ores.

The only real effect of Ore type on Nitrogen removal would again be the reducibility of the ore giving the HBI a metallisation . The ore type might also determine the amount of Fe₃C in the ore which would have a greater value on lowering Nitrogen than FeO.

Figure13. Scanning Electron Microscope Map of Oxygen in HBI#1.

Figure14. Scanning Electron Microscope Map of Iron in HBI #1

Figure15. Scanning Electron Microscope Map of Phosphorus in HBI#1.

11. DISCUSSION

The phosphorus added to the furnace in the HBI does not reach equilibrium with the steel melt. If the phosphorus is in the form of oxides - not associated with the iron - then this favours the phosphorus remaining in the slag. Work at BHP's laboratories examining HBI shows phosphorus is largely present in the iron free areas of the matrix i.e. it is present in the oxide form.

This work is supported by chemical analysis performed by Midrex² which suggests that only 5% of the phosphorus is associated with iron.

Operational practices in the use of HBI can favour the phosphorus to remain in the oxide form.

In the EAF slag flushing continually removes the oxide preventing reversion into the bath. The conditions for a foaming slag favour removal of the phosphorus as demonstrated in Figure5.

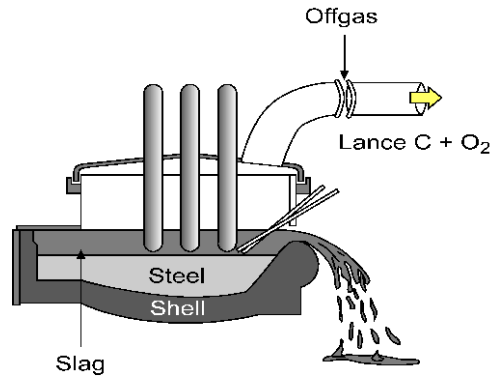


Figure 16. Schematic of an EAF during normal flushing practice resulting in low phosphorus.

6. CONCLUSIONS

The results at Sydney and Casima EAF plants give an increased understanding of the effects of using HBI on the Phosphorus and Nitrogen using DRI. An understanding of the chemistry in the furnace can give favorable conditions for lower Phosphorus and Nitrogen. Several important points can be established,

- 1) Low phosphorus steel can be easily produced using HBI#1 (0.065%P) and HBI#2 (0.095%P). The phosphorus content of the HBI is not directly transferred to the bath,
- 2) Under some conditions a slight lowering of yield may be desirable (by increasing the FeO) in order to achieve a lower Phosphorus,
- 3) Low Nitrogen and low Phosphorus contents result from the same practices of adding HBI,
- 4) Nitrogen reduction due to the addition of HBI is not only caused by the evolution of CO gas but other interactions occur.
- 5) The Phosphorus in the HBI is in the mineral form and thus the feed ore Phosphorus has little impact on the final melt Phosphorus.
- 6) Injecting fines into the EAF bath would be likely to remove Nitrogen to a greater extent than that measured at Sydney EAF.

Further work on the effects of injecting HBI fines and the nature of Phosphorus in the feed ores are planned. The constituents of HBI should be considered when developing HBI practices in order to achieve the highest quality steel.

7.ACKNOWLEDGEMENTS

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