Classification of DRI/HBI based on the performance in the EAF A help for steelmaker's procurement of metallics

Rutger Gyllenram
KTH Royal Institute of Technology

Classification of DRI/HBI based on the performance in the EAF. A help for steelmaker's procurement of metallics.

R. Gyllenram, Kobolde & Partners AB 1, Sweden; P. Sikström, R. Hahne, M. Tottie, LKAB, Sweden 2;

R. Gyllenram, Kobolde & Partners AB, Ringvägen 100, 118 60 STOCKHOLM, +46 708 665770, rutger.gyllenram@kobolde.com.

Summary

Using DRI/HBI in electric steelmaking involves handling a complexity regarding slag formers. The gangue that is a natural part of the material differs between DRI/HBI coming from different ore products. However, the full analysis of the DRI/HBI is not always declared or even asked for. Whereas scrap is specified into a number of different classes HBI/DRI is often handled as one single commodity. As a consequence the steelmakers might face problems with the slag if they do not observe the changing conditions. Having a nomenclature for different types of DRI/HBI pointing out these differences might be the first step to greater awareness of this problem. This paper uses eight calculation cases to illustrate the importance of slag considerations when evaluating DRI/HBI. Finally a way to classify them is given as a basis for further discussions.

Key Words

DRI, HBI, Scrap, Metallics, Value-in-use, classification, slag, MgO-saturation

Introduction

While scrap is divided into many different, well defined, classes, DRI/HBI is often treated as a single material. Since the analysis of DRI/HBI is dependent on the mineralogy of the ores used and additions made when making pellets, the analysis of DRI/HBI may vary drastically resulting in different performance in the EAF and varying slag amounts and properties.

In the same way as the steelmaker relies on a scrap classification for decisions in raw material procurement and management, an adequate nomenclature for DRI/HBI is needed. Based on thermodynamic calculations for direct reduction in a shaft furnace and steelmaking in the EAF and using a model for MgO saturated slag, different scenarios using DRI/HBI are studied. Finally, based on the scenarios, different ways to classify DRI/HBI are suggested as a basis for further discussions.

Need for an adequate nomenclature

Metallization and carbon content that are currently used to classify DRI/HBI are clearly important properties giving important information about the energy requirements for the charge. However, using these as the sole specification of the material offers very little information on the metallurgical complexity of making an optimal charge mix.

Using different materials also changes the slag practice and leads to some non-trivial metallurgic considerations. This is valid both when buying a new type of DRI/HBI for a mini-mill and when changing the pellet mix in an integrated plant with reduction and smelting. Helping the plant management to take this into account is perhaps the most important role for a more precise nomenclature.

Defining factors

The first and possibly the most important factor for the amount of slag generated is the content of gangue oxides in the DRI/HBI, the most significant being silica (%SiO2). Other oxides like Al_2O_3, TiO_2 and V_2O_5 also need to be neutralized by lime additions and thus affects the amount of slag and its properties. Where the DRI/HBI is intended to be used in a blast furnace or as a minor addition to an EAF scrap charge, the amount of gangue oxides might have limited importance. But as soon as the amount of DRI/HBI charged into the EAF increases, say over 10 -15 %, the resulting slag volume and properties become an issue.

The second factor is the MgO amount since MgO dissolves in the slag up to the saturation level. The distribution of MgO between solid and liquid phase follows an equilibrium according to equation 1.

$$MgO(solid) \leftrightarrow MgO(liquid)_{sat} \quad (1)$$

In an undersaturated slag MgO from the magnesite refractory is dissolved into the slag. A steelmaker therefore adds dolomite stone or burned dolomite to create an oversaturated slag in order to reduce the refractory wear. An even distribution of the slag formers in the furnace is of great importance in order to avoid areas with aggressive slag and the MgO in the pellet melts more easily than dolomite. A DRI/HBI with an elevated amount of MgO contains at least part of the MgO necessary to form a slag with good properties as the DRI/HBI is melting. Finally, any content of CaO present in the HBI/DRI contributes to early slag formation and reduces the total amount of ordinary lime required.

Calculation examples

To find relevant classification levels calculations have been made assuming an MgO saturated slag [3] using the optimization tool RAWMATMIX® [2].The classification factors discussed are:

- "Minimum Slag Amount" or MSA
- "DRI/HBI MgO Fraction" or DMF

The MSA is the minimum amount of slag you get in a 100% DRI/HBI operation with an MgO saturated slag assuming 20%FeO and 42%CaO.
The DMF is the fraction of MgO, in the slag specified above, coming from the DRI/HBI.

Capital and other costs are shown in Table 1 and a number of production parameters used in the calculations are shown in Table 2.

Cost factor	**Amount**	**Unit**
Availability	95	%
Fixed costs per year	20	MEUR
Capital investment	340	MEUR
Interest rate	15	%
Depreciation time	10	Year
Capital cost per year	73,8	MEUR
Additional cost per ton steel	4	EUR
Slag handling fee per ton slag	20	EUR
Dust handling fee per ton dust	40	EUR

Table 1 Capital and other costs [1]

Parameter	**Amount**	**Unit**
Furnace burners	5000	kWh/charge
Oxygen for slag foaming	3000	Nm^3/charge
Electrode consumption	4.38	kg/MWh
Process water	10	m^3/min
Tapping temperature	1600	˚C
Tap weight	100	ton
Average power on	50	MW
Average power idling	5	MW
Average idle time	5	min
Average power off time	4	min
Power on heat loss	5	MW
Idle/Power off heat loss	1	MW
Post combustion	6	% in furnace
Dust from lime in EAF	1	%
Dust from metallics in EAF	1	%

Table 2 Production parameters [1]

The data used for DRI/HBI materials is shown in Table 3. The DRI/HBI data is based on calculations using seven different DRI-pellets that are either commercially available on the market or used in plants close to the mine. The eighth material is based on a mix of DRI 1, 3 and 5. The price of DRI is calculated from a published price for Blast Furnace Pellets of 144.65 c/u [7] plus freight and handling costs and does not include any DR-pellet premium.

DRI/HBI Material	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Fe met (%)	84.46	84.78	84.63	82.13	84.49	82.58	81.13	84.52
C (%)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
SiO_2 (%)	1.69	1.63	1.73	2.43	0.95	4.55	4.53	1.48
Al_2O_3 (%)	0.74	0.34	0.66	0.51	0.23	0.24	0.95	0.56
FeO (%)	9.45	9.48	9.47	9.19	9.45	9.24	9.08	9.46
MnO (%)	0.21	0.03	0.09	0.03	0.10	0.00	0.33	0.14
CaO (%)	1.05	0.95	1.03	2.59	1.21	0.93	0.79	1.09
MgO (%)	0.13	0.61	0.12	0.42	0.88	0.23	0.78	0.35
P_2O_5 (%)	0.08	0.03	0.13	0.07	0.08	0.03	0.12	0.09
V_2O_5 (%)	0.07	0.01	0.01	0.35	0.27	0.00	0.06	0.11
TiO_2 (%)	0.07	0.05	0.05	0.13	0.19	0.04	0.16	0.10
Other (%)	0.05	0.09	0.08	0.14	0.16	0.16	0.08	0.09
Fe_{tot} (%)	91.81	92.15	91.99	89.27	91.84	89.76	88.18	91.87
Met (%)	92	92	92	92	92	92	92	92
T (˚C)	25	25	25	25	25	25	25	25
Price (USD/ton)	381.38	382.19	381.78	377.28	381.53	377.72	375.53	381.55
Upstream CO_2 (kg CO_2eq) *	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Table 3 Raw material properties CO_2 values are based on shaft furnace production using Natural Gas.

Data for slag formers and other additions is shown in Table 4.

Raw material	Price* (EUR/kg)	CO_2 ** (kg CO_2.eq)	Ref upstream CO_2
Burnt Lime	0,12	1,96	100% CaO 8 MJ/kg
Burnt Dolomite	0,15	2,7	30% MgO, 70% CaO 11 MJ/kg
Magnesite bricks	1	10,5	43 MJ/kg
Inject Carbon	1	0,25	1 MJ/kg
Electrodes	4	6,6	27 MJ/kg
LPG incl Oxygen	20	25	55 Nm3 O2/GJ
Electricity	0.15	0,819	Coal based
Oxygen	0,1	0,393	ASU 0.48 MWh/kNm3 electr
Process water	0,1	-	Included in plant el.
CO_2 data for process emission and upstream calculation			
Natural Gas	245 kg CO_2/GJ		
LPG	291 kg CO_2/GJ		
Inject Carbon	3.7 kg CO_2/kg		
Electrodes	3.7 kg CO_2/kg		
*Prices are average prices from 2014 [1].			
**Upstream CO_2 are examples or estimations for typical production facilities. Large variations may occur. Energy source is Natural Gas unless otherwise stated [1][4][5].			

Table 4 Other raw material and energy data.

Comparison of gangue oxide content

In figure 1 below eight types of HBI materials are plotted based on their SiO_2 content. Five are calculated based on commercially available DRI, two are HBI products from countries that produce these using domestic natural gas resources and the eighth is a commonly used mix of three of the others.

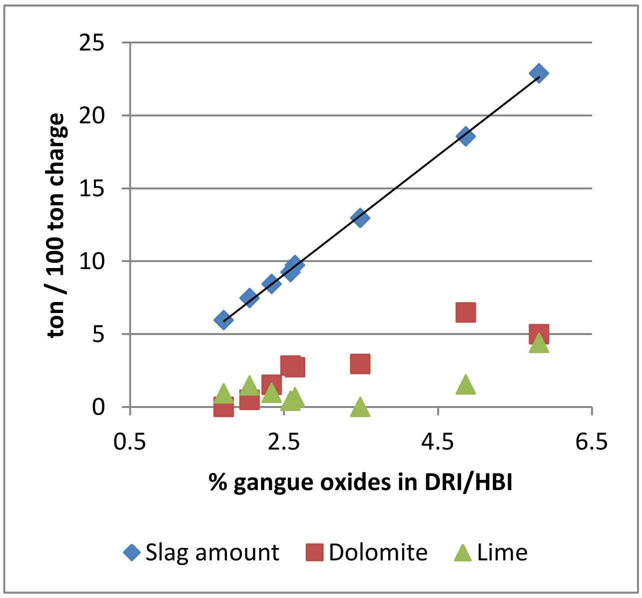

Figure 1 Slag volume and addition of dolomite and lime for HBI with differing gangue oxide content

The figure demonstrates the connection between high gangue oxide content and the amount of slag. The solid line shows a linear regression of the slag amount data and indicates that there is a linear relationship between the two measurements. The figure also shows the amounts of lime and dolomite that need to be added to achieve the required MgO saturated slag composition. These additions vary greatly between the different cases which is due mainly to variation in the MgO content of the materials. This will be discussed in more detail in the next section.

As can be seen from figure 1 the difference in slag amount vary from around 6% to 23% of the amount of metal produced. This vast span demonstrates clearly the value of knowing the slag characteristics of your DRI/HBI. For the purpose of the nomenclature suggested by this paper a slag amount of less than 10% of the amount of metal produced could be considered “low” while a slag amount above 15% could be seen as high. For the examples above an estimate from the relationship shown in figure 1 would be that “Low MSA” would correspond to a DRI/HBI with a gangue oxide content less than 2.6% while “High MSA” would correspond to an oxide content above 3.7%.

Comparison of MgO content

MgO content in the slag helps reduce refractory wear but the more evenly distributed the MgO is in the furnace the more effective this protection will be. If the source of the MgO is the DRI/HBI material itself the MgO will be naturally spread out throughout the melt compared to if the MgO gets added through additions of dolomite. MgO takes relatively long to dissolve which makes the distribution even more important. A measurement of the portion of the MgO required for equilibrium that comes from the DRI/HBI material is therefore of interest.

Figure 2 shows the total slag amount in tons per 100 ton charge for the eight example charges. It can be noted that there is a connection also between high MgO content in the DRI/HBI and low slag amounts. However, the effect of differing SiO_2 contents in the various example charges makes this connection less obvious.

Again there will also be a cost impact by having the MgO coming from the DRI/HBI which will be discussed in the next section.

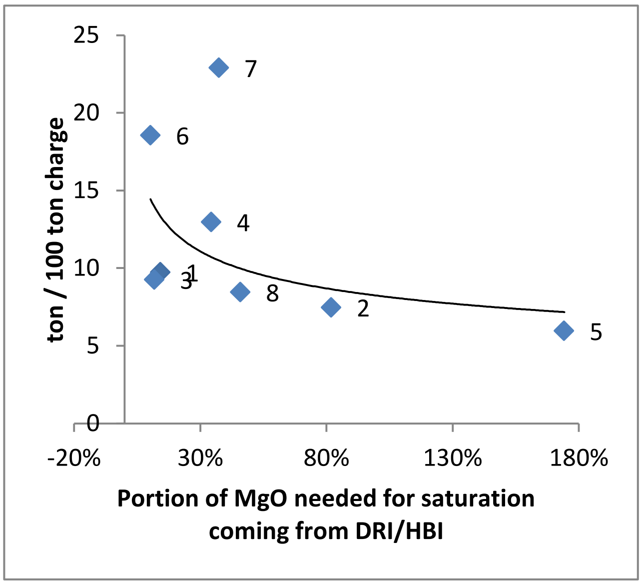

Figure 2 Slag amount as a function of the MgO content of the DRI/HBI material

Impact on charge cost

Changing raw material in fact also means changing your slag practice. We have seen above that there is great variation among available DRI/HBI materials in terms of their slag properties. It is also clear that the slag properties have a heavy impact on a whole number of production parameters including the total cost for production. Table 5 shows detailed production data and costs for the eight example charges studied in this paper.

It ca be noted that there is a strong correlation between the presence of gangue oxides and total cost for the charge. From the data it is difficult to draw definite conclusions on how the various oxides impact the result, partly because the presence of SiO2 dominates so much that it masks the impact from other substances.

		1	2	3	4	5	6	7	8
Costs (EUR)	DRI/HBI	33 041	32 885	32 993	33 781	32 843	33 942	34 564	32 967
	Electricity	7 881	7 540	7 815	8 355	7 408	9 166	9 805	7 694
	Carbon	1 890	1 927	1 905	1 763	1 970	1 651	1 534	1 916
	Oxygen	279	279	279	279	279	279	279	279
	Slag formers	380	195	372	344	87	900	990	267
	Plant costs	2 987	2 867	2 962	3 153	2 815	3 444	3 671	2 919
	Operating cost	**46 458**	**45 693**	**46 326**	**47 675**	**45 402**	**49 382**	**50 843**	**46 042**
	Capital	6 540	6 309	6 496	6 862	6 219	7 412	7 845	6 414
	Total production cost	**52 998**	**52 002**	**52 822**	**54 537**	**51 621**	**56 794**	**58 688**	**52 456**
Consumption	DRI/HBI (ton)	111.52	110.76	111.24	115.25	110.81	115.67	118.48	111.22
	Electricity (kWh)	52 540	50 264	52 100	55 700	49 383	61 106	65 364	51 297
	Carbon (kg)	1 100	1 168	1 122	932	1 222	750	577	1 143
	Oxygen (Nm^3)	2 787	2 787	2 787	2 787	2 787	2 787	2 787	2 787
	Lime (ton)	0.66	1.46	0.43	0.00	0.92	1.53	4.39	0.97
	Dolomite (ton)	2.72	0.50	2.84	2.94	0.00	6.49	4.98	1.51
Liquid slag	FeO (%)	20	20	20	20	20	20	20	20
	CaO (%)	38	38	38	38	38	38	38	38
	MgO (%)	9,78	11.00	10.44	10.38	15,31	11,70	10,42	9,91
	SiO_2 (%)	19,31	24.10	20.82	21,62	16,47	28,40	23,43	19,46
	Al_2O_3 (%)	8.50	5.02	7.97	4,54	4,00	1,49	4,92	7,43
	Other (%)	4,41	1,88	2,77	5,46	6,22	0,41	3,23	5,20
	Weight (ton)	9,730	7,474	9.257	12,969	6,371	18,552	22,889	8,447
Other	Undissolved MgO (KG)	0	0	0	0	415	0	0	0
	Dust weight (ton)	1,39	1,35	1.38	1,39	1,33	1,50	1,54	1,37
	Process carbon footprint	13 646	13 577	13 622	13 937	13 574	13 999	14 228	13 616
	Upstream carbon footprint	99 751	97 502	99 249	104 223	96 806	108 861	113 765	98 581

Table 5 Charge data for the eight example charges

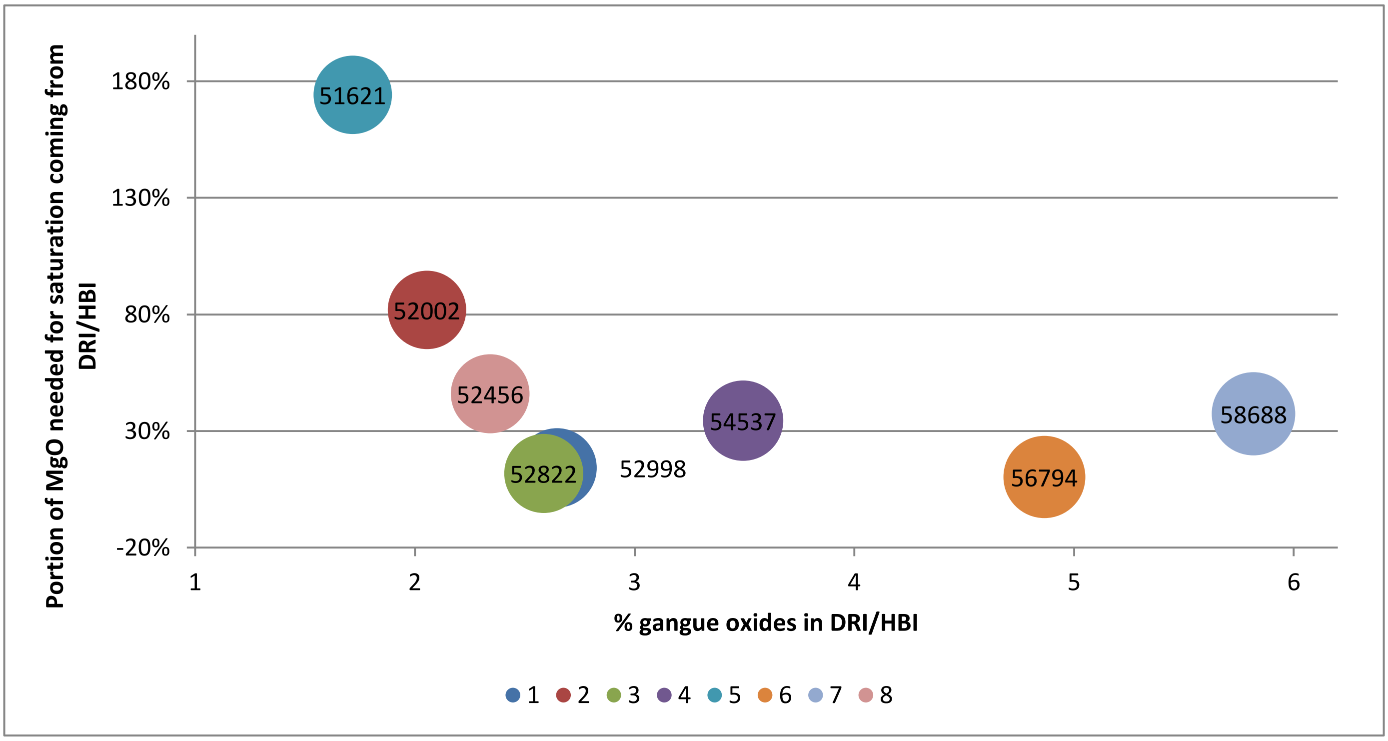

Figure 3 Charge cost in EUR/100 ton shown by the size of the circles

Carbon footprint

The calculations made with the above examples also yield a total carbon footprint for the steel product produced taking into account the total emissions for all raw materials as well as emissions generated by the smelting process itself.

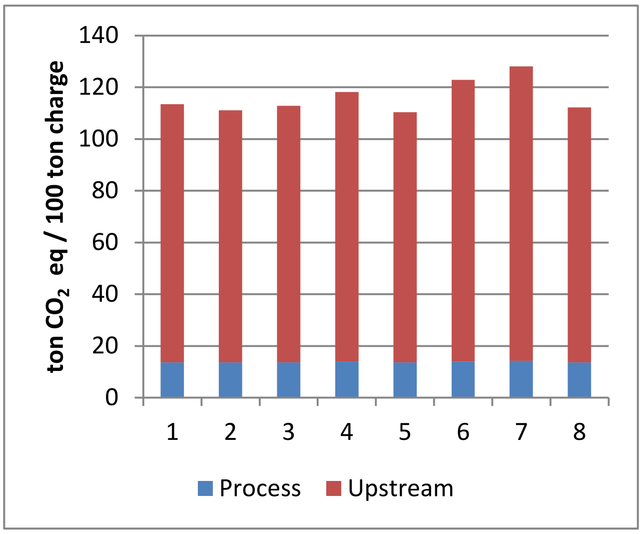

Figure 4 Carbon footprint for charges 1-8

Figure 4 shows the carbon footprint for production using the eight types of DRI/HBI materials. It can be noted that to a large extent carbon footprint follows cost with less costly charges also emitting less CO_2.

Suggestion for an adequate nomenclature

This paper shows the clear correlation between the presence of gangue oxides and slag characteristics and cost for EAF production using DRI/HBI materials. We have shown the impact of these oxides and the results support the idea to create a nomenclature that can be used to classify DRI/HBI according to their slag properties when melted.

Based on the results of the examples above we suggest a classification and nomenclature as described in Table 6.

Group	**Possible DRI/HBI trade terms**	**Definition**
Low MSA	Low MSA EAF grade	MSA < 10%
Medium MSA	Medium MSA	10% < MSA < 15%
High MSA	High MSA Blast Furnace grade High Si	MSA > 15%
Low DMF	Low DMF MgO-standard	DMF < 40%
Medium DMF	Medium DMF MgO-rich	40% <= DMF < 100%
High DMF	High DMF MgO-saturated	DMF > 100%

Table 6 Suggestions for classification names and levels for DRI/HBI taking slag properties into account.

In the example, materials that generate less than 10 tons of slag per 100 ton charge or <10% would be classified as “Low MSA” while those generating more than 15 tons (>15%) slag would be classified as “High MSA”.

In the same way materials that contain less than 40% of the MgO required to reach MgO saturation would be classified as “Low DMF” while those that contain more than enough for satuartion (>100%) MgO would be classified as “High DMF”.

Conclusion

Using DRI/HBI in steelmaking is not just using another type of scrap. The difference in mineralogy of the ore and additions made when pelletizing makes it important to take slag properties of the DRI/HBI when smelted into account. The most important result of a new nomenclature used in trading and reporting will be to help users to evaluate these slag properties and an increased urge to give and ask for the full analysis of a DRI/HBI product.

Abbreviations

DRI	Direct Reduced Iron
HBI	Hot Briquetted Iron
MSA	Minimum Slag Amount
DMF	DRI/HBI MgO Fraction

Acknowledgments

We would like to thank Dr Roger Selin and Mr Olle Westerberg for their support when preparing this paper.

References

[1] Private communication: representatives of the Swedish recycling industry, raw material suppliers and steel plant managers.
[2] RAWMATMIX® Technical documentation 2015
[3] Selin R., The role of phosphorus, vanadium and slag forming oxides in direct reduction based steelmaking TRITA-PT-87-04 ISSN 0284-3013, Stockholm 1987
[4] Gyllenram R et al., Taking in house and upstream CO2 emission into account in charge optimization for scrap based steel making, METEC InSteelCon, Düsseldorf 2011
[5] US Energy Information Administration, EIA, www.eia.gov
[6] Charge data gathered from a Swedish low alloy steel producer
[7] SBB Steel Markets Daily February 26, 2015