Use of metallics in electric arc furnace steelmaking

Conference Paper · November 2016

1 author:

Rutger Gyllenram
KTH Royal Institute of Technology

Use of metallics in electric arc furnace steelmaking

Presentation at the American Metal Markets conference on DRI and Mini mills in Chicago 2016-11-16--18

Rutger GYLLENRAM

Kobolde & Partners AB, Ringvägen 100, 118 60 STOCKHOLM Sweden, rutger.gyllenram@kobolde.com

Abstract: In this study, steelmaking in an Electric Arc Furnace, EAF, using two types of recycled scrap with different levels of tramp-Cu and different prices, is compared to steelmaking where part of the burden is changed to a virgin iron source. By using the tool RAWMATMIX® for optimizing EAF charges, a Value in Use, ViU, is calculated for Pig Iron, three different types of DRI with different temperature and MgO content and a commercial HBI with high Silicon. The result shows that the ViU per ton material differs from +3 % to -20 % for different sources. Using virgin material also affects the environmental profile of the product and especially the Global Warming Potential, with different CO_2 burdens depending on source. The paper shows the importance of making ViU calculations when establishing a raw material price.

Key words: Electric arc furnace, Scrap, DRI, HBI, Pig Iron, Tramp element, Global Warming Potential, Value in use

1. Background

Steel is a 100% recyclable material. Obsolete products together with new scrap coming from production, are collected, sorted and formatted to fit into different classes according to some classification system. Each class states the allowed geometry, density, thickness, levels of alloying elements or pickable metal parts, coatings, steriles, sources for the material etc. One example of a system for specifying the different classes is the Scrap Specifications Circular [1].

Tramp elements are unwanted alloys that occur in scrap. They may have many different origins, but usually some main sources can be identified. Copper is used in bearings and electrical wire and is often found in scrap. In scrap that comes from recycled steel the copper content in the steel matrix is often higher than in scrap that comes from blast furnace steel. Most steels are sensitive to the cupper content. Thus, in many plants it is the only element considered in charge optimization. Other examples of elements that occurs as tramp elements are Nickel and Chromium coming from ferritic alloyed steel scrap; and tin and lead which often come from different kinds of coatings and bearings [2].

For a steelmaker it is important to know the analysis and uncertainty of the scrap in order to avoid getting to much of a tramp element into the steel. A steel charge normally consists of about ten different scrap types, which are blended to give the right analysis and smelting properties at the lowest possible cost. When the demands on low levels of tramp elements are high, scrap sources with a known analysis must be used. This can be new scrap from known sources or virgin material from ore like Blast Furnace Iron or Direct Reduced Iron.

By using Life Cycle Analysis, LCA, the environmental load from primary production of steel from ore and secondary production of steel from scrap can be scrutinized. Although it is right to argue that there can be no scrap based steelmaking unless there has been a primary steelmaking first, it is important to understand how different sources changes the load. The way to report the impacts are given in a number of standards and for the Global Warming Potential an ISO technical specification also exist [3]. Using virgin material together with recycled material adds a twist to this question, which is discussed later in the paper.

2. Method

In this study, we have chosen to set a market price to scrap of a premium and second quality and then estimate the Value in Use, ViU, for the virgin iron sources. No 1 heavy melting steel is a heavy old scrap, in this case with a Cu limit of 0.25% and X is a similar scrap with a Cu limit of 0.4%. Prices are averages representative for a period with intermediate levels, basically from 2014[4]. The calculation base is 100 tons of steel with a Cu-limit of 0.22%. In the reference charge we use 100 % scrap and in the virgin charges we use 60 ton scrap and the rest virgin material.

The steel is produced in a modern EAF with burners using Liquid Petrol Gas, LPG. We strive for a slag that contains 20% FeO, 38% CaO as well as a 10% MgO oversaturation to reduce refractory wear. The same amount of time for charging the different raw materials to the furnace is assumed. The virgin materials are: pig iron, PI, which is a commodity that is traded globally, two types of DRI from a natural gas based shaft furnace and finally a commercial HBI which again is a globally traded commodity. The pig iron has the analysis of a normal blast furnace iron which is low in Si. The first DRI is a low-Si and high MgO containing DRI typical for the Gulf area and the USA. The second DRI has a slightly lower MgO content. Finally, the HBI is a standard commercial grade with a higher Si content. It is worth noting that the chemical composition of DRI and HBI is totally dependent on the composition of the ore. The software RAWMATMIX® calculates the raw material mix that meets the product requirements at lowest possible cost. It uses the MgO saturation model presented by Selin [5] to calculate lowest possible amount of slag former addition to meet the slag requirements. Dust is calculated as a percentage of metals melted and a percentage of the fine fraction of the raw materials. This comparison is simplified in the way that it is assumed that no difference between carbon in the raw material and inject carbon exists. The yield for injected carbon is however often lower than for carbon in the metallics.

When estimating the ViU for a material x the difference between the production cost for a reference case, C_{ref}, and the production cost for a case using material x, C'_x, is divided by the amount of material x, w_x. C'_x does not include the cost for x and the result will be the price for x that would result in the same production cost as the reference case everything else alike. It could be expressed as in equation 1.

$$ViU_x = \frac{C_{ref} - C'_x}{w_x} \qquad \text{Equation 1}$$

The ViU may be higher or lower than the market price. Thus if it is higher you should buy and if it is lower you should avoid buying. It is evident that the ViU is strongly dependent on the reference case which should be representative for the normal practice you use for the steel product for which you consider to use the alternative material. Furthermore, the calculations are simplified and do not reflect real burdens in all aspects. However, the method gives an opportunity to investigate the intrinsics of different materials and how they are priced.

3. Calculation data

A number of production parameters used in the calculations are shown in Table 1.

Table 1 Production parameters*

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	45	MW
Average power off /idle time	5 / 4	min
Power on/idle heat loss	5 /4	MW
Idle/Power off heat loss	1	MW
Post combustion	6	% in furnace
Dust from lime in EAF	1	%
Dust generated in arc	1	%

* Parameter data are examples collected from industrial furnaces

The data used for raw materials are shown in Table 2. Important figures to note are the Cu-content and the Fe_{tot} value. Other raw material data are shown in Table 3 and other cost data in Table 4.

Table 2 Raw material properties

	NO 1	X	PI	DRI1	DRI2	HBI
Fe	95	94.3	94	84.57	84.57	82.74
C	0.4	0.4	4.2	2	2	2
Si	0.3	0.3	0.5			
Mn	0.8	0.8	0.2			
Cu	0,2	0.4	0			
FeO	2	2	1	9.46	9.46	9.24
CaO				1.1	1.1	0.93
MgO				0.35	0.35	0.23
SiO_2	0.5	1		1.48	1.48	4.55
Al_2O_3	0.5	0.5		0.56	0.56	0.24
Other	0.5	0.3	0.1	0.48	0.48	0.07
Fe_{ot}	96,56	95,86	94,78	91,95	91,95	89,95
Met				92%	92%	92%
Temp C	25	25	25	Hot 500 Cold 25	25	25
Price (USD) [4]	264	240	-	-	-	-
Upstream CO_2 (kg CO_2eq) [6]	0	0	1.35	0.7	0.7	0.7

Table 3 Other raw material and energy data

Raw material	Price * (USD)	Upstream CO_2 ** (kg CO_2eq)	Comments
Burnt Lime (kg)	0.12	1.24 [7]	100% CaO
Burnt Dolomite (kg)	0.15	1.63 [7]	30% MgO 70% CaO
Magnesite bricks (kg)	1	4.01 [7]	100% MgO
Inject coal (kg)	1	0,012	53 kWh/ton [8]
Electrodes (kg)	4	1,58	24,5 GJ/ton [9]
LPG (GJ)	20	8 [10]	55 Nm3 O2/GJ
Electricity (kWh)	0.15	1.0	Average fossil el.
Oxygen (Nm^3)	0,1	0.661	Average fossil el.
Process water (m^3)	0,1	0.344	
CO2 emission used for process and estimation of upstream emission			
Natural Gas (GJ)	64.6 kg CO_2/GJ		
LPG (GJ)	65.7 kg CO_2/GJ		
Inject Carbon	3.7 kg CO_2/kg		
Electrodes	3.7 kg CO_2/kg		

* Prices are average prices from 2014-2016 [2].
** Due to shortage information, upstream CO_2 for burnt lime, dolomite, magnesite bricks, inject coal does not include CO2 emission from mining process and transportation between mining and production plant.

Table 4 Other costs

Cost factor	Amount	Unit
Slag handling fee per ton slag	20	USD
Dust handling fee per ton dust	40	USD

Calculation result

The optimized burden is shown in Table 5. The reference calculation, "Scrap", uses almost only the more expensive NO 1 as burden. The virgin materials that all lack Cu can use the less expensive X. The slag formers show that the HBI charge needs more dolomite than the others to balance the high Si content. In this evaluation, the charge time is left out.

Table 5 Charged materials, energy, slag volume and costs

Charge	Scrap	PI	HDRI	DRI1	DRI2	HBI
NO 1	99,337	21,280	24,278	24,278	24,349	27,105
X	5,890	44,918	43,419	43,419	43,384	42,006
Fe-alt	0	40,000	40,000	40,000	40,000	40,000
Lime	1,636	1,307	1,351	1,351	1,231	1,625
Dolo	2,012	2,067	2,294	2,294	2,579	3,851
Coal	2,131	559	2,126	2,126	2,118	1,971
Total energy kWh	56380	54125	55746	58533	59258	67264
Slag volume tons	7,985	7,231	8,941	8,941	9,149	12,348
Direct cost* USD/ton	348,97	223,22	236,35	241,65	242,44	256,92
ViU USD/ton**	264,00	314,38	281,55	268,30	266,32	230,12
+/-		50,38	17,55	4,30	2,32	-33,89
%		19,08	6,65	1,63	0,88	-12,84

*The price for metallics is set to 0
** The price for scrap or metallics giving the same direct cost.

Finally, it should be noted that when using virgin materials, the environmental profile of a material changes. According to the standards for LCA and environmental declarations [3], a recycled material comes free of upstream environmental burden for the period before it reached the "end of waste" status. A virgin material must carry its environmental burden, but can declare a credit that it can be recycled and replace steel from virgin materials. However, it is important to understand the carbon metrics in order to appreciate the environmental declarations and to communicate the environmental performance.

Table 9 Global Warming Potential expressed as kg CO_2 / ton.

	Scrap	PI	HDRI	DRI1	DRI2	HBI
CO_2 Process	114	112	138	138	137	133
CO_2 Upstream	301	964	608	640	646	715
CO2 Total	415	1076	746	777	783	848

* Upstream CO2 for Fe-materials left out

Upstream CO_2 is the main emission that is caused when producing the raw materials and energy products. Process CO_2 is the emissions from the process itself. Most of the upstream CO_2 from scrap comes from electricity and the virgin materials from the reduction process. In this example a coal- based electricity is used. However, the figure for scrap would change drastically if for example nuclear power was used instead.

4. Discussion

To draw conclusions from cost calculations is always tricky, since raw material prices are highly volatile. With the ViU calculation using scrap as a reference case you can avoid some of the uncertainties of comparing assumed actual costs. In these calculations, we take chemical properties and thermodynamics into account whereas other aspects must be left out and dealt with in a more case based reasoning way.

The approach used here is favourable to metallics since we have assumed the same furnace parameters for all burdens. A slower melting down, possibility to avoid a second basket together with injection capacity make a great difference. Furthermore, the price relation between good and bad scrap, electricity and coal set the scene.

Different types of virgin materials might require some adjustments to the burdening and the process equipment, like charging through the roof of the furnace. Issues that are often discussed are the amount of metallics that can be charged in the furnace and 20-40 % is mentioned when it is charged together with scrap in the first bucket, less for HBI than for DRI and even less for PI. A big advantage is the higher density of metallics that makes the charging more efficient. [12]. The higher carbon content improves the CO_2 generation within the melt, which result in lower nitrogen levels [13] and decreases the need for carbon injection but may make HBI and Pig Iron harder to melt [12].

Using virgin material in order to abate the level of tramp elements will probably be a more common practice in the future due to more scrapped products coming from steel produced from scrap, and increased demands on the steel products produced.

PI has historically been traded at 40-100 USD over a premium scrap (A3). Compared to the calculated premium of 50 USD it seems that the market appreciates the known analysis of PI compared to scrap.

HDRI is mainly used in integrated DR-plants and the price is dependent on the price of natural gas. They seldom use large amounts of scrap, but that may be changed in the future. The value of the saved energy is obvious.

For CDRI it is worth noticing the value of an MgO content in the metal in order to decrease the amount of dolomite is here around 2 USD/ton. The benefits of having an MgO saturated primary slag at meltdown is well known but does not generate a cost benefit in these calculations.

HBI is often used in smaller amounts to assess a low tramp element charge in many plants and traded at price levels far higher than the 230 USD estimated here. In this case the silicon content and the resulting slag amount decreases the ViU drastically.

One might wonder if the data cannot be interpreted that there is a strong potential for a better scrap processing and sorting. Furthermore, that indicates better ways to measure the levels of tramp elements in old scrap. In a market survey by the International Iron Metallics Association, IIMA, PI is traded at a price 10% over the price of premium scrap whereas HBI is traded 10%-20% under the premium scrap [14] taking all aspects into account. The raw material users and traders might find it valuable to look at the ViU for the materials in order to establish a market price reflecting the value the different materials bring to the steelmakers.

In the end, it is not about whether to use scrap, PI or DRI, it is about the right price for different types of scrap, PI and DRI and to find an optimal mix.

References

1. ISRI, Institute of Scrap Recycling Industries, Inc, Scrap Specifications Circular, 1/21/2016
2. Private communication: representatives of the Swedish recycling industry, raw material suppliers and steel plant managers.
3. ISO/TS 14067: 2013 Greenhouse gases -- Carbon footprint of products -- Requirements and guidelines for quantification and communication[S].
4. Wirtschaftsvereinigung 2014 Jan-Dec average
5. Selin R., The role of Phosphorus, Vanadium and slag forming oxides in direct reduction based steelmaking[D].Stockholm, Sweden: Kungliga Tekniska Högskolan, 1987
6. 2006 IPCC Guidelines for National Greenhouse Gas Inventorie-Chapter 4 Metal Industry Emissions. 2006.
7. Kobolde&Partners AB, A white paper of estimating carbon footprint of slag former and refractories in RAWMATMIX®, 2015
8. Ernst Worrell etc., Energy Efficiency Improvement and Cost Saving Opportunities for Cement Making, p23, 2008
9. Best Available Techniques(BAT) Reference Document for the Non-Ferrous Metal Industries-Chapter 10. Processes to produce carbon and graphite electrodes, cathodes and shapes, 2014
10. 2014 Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors Final.
11. https://www.eia.gov/
12. Abel M, The use of scrap substitutes like Cold & Hot DRI / HBI and Pig Iron in Electric Steelmaking, IIMA – ORE-BASED METALLICS – SHORT COURSE, Moscow – 30th September, 2016
13. Shalimov A.G. ,Nemenov A. M., Production of electric steel with reduced Nitrogen content[J]. Metallurgist, 2010, 54(3):210-225
14. Barrington C, OECD Steel Committee Raw Materials Workshop- Scrap Supplements Market. Paris: Iron Metallics Association, 2011

This presentation is based on:

Gyllenram R., Wei W, Jönsson P. Raw material assessment for electric arc furnace steelmaking, ICS, International Congress on Science and Technology of Steelmaking, Beijing May 12-14 2015.

Comments are welcome.