Dr.-Ing. A. Ehrenberg, 15/01/2021

Pig iron production and slag generation in blast furnaces

1 Process description

A blast furnace is a shaft furnace working acc. to the counter flow principle. Fig. 1 shows a schematic picture. The input, i.e. the mixture from burden (iron ores, sinter, pellets, correction materials) and coke/coal depends on the individual steel plant situation. However, the tasks to be fulfilled by the liquid blast furnace slag are always the same [3, 4, 5]:

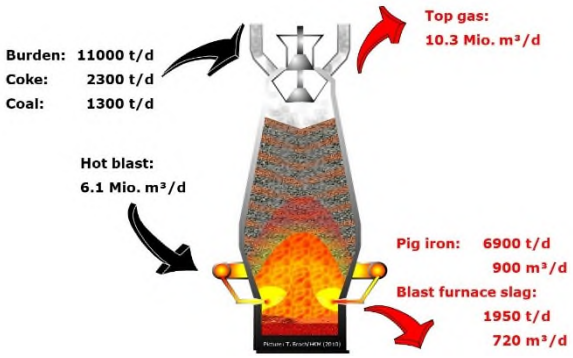

Fig. 1: Typical mass flow for an average blast furnace [1]

- to reduce the melting point (eutectic) in order to save energy and to reduce costs (Fig. 3)
- to incorporate non-metallic mineral phases (gangue) and coke ash
- to incorporate Sulphur from the reduction agents coke and coal
- to incorporate alkalis (danger of crust formation in the blast furnace)
- to create a low viscosity in order to fulfil the refinement tasks, to foster the liquid Fe separation and to be manageable
- to protect the pig iron against re-oxidation by hot blast
- to inform on the operating status of the blast furnace.

Thus, slag is a metallurgical tool.

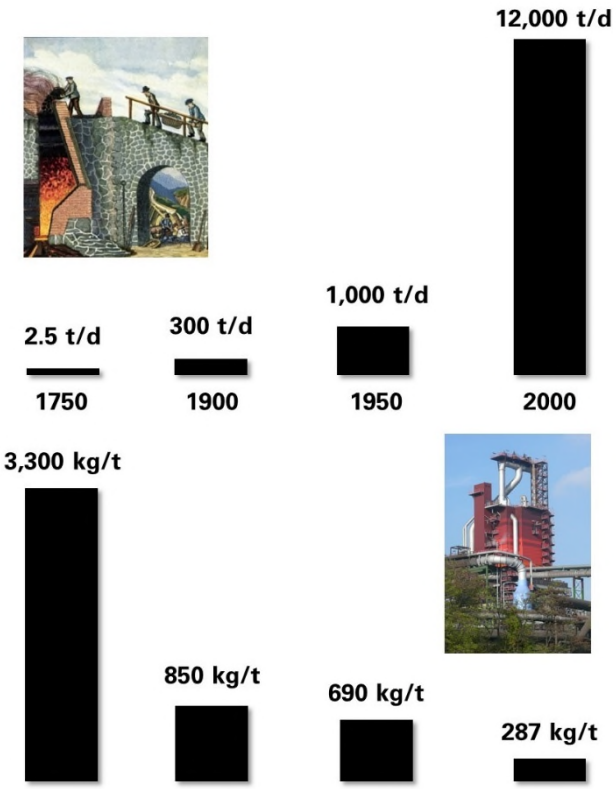

Fig. 2: Increase in productivity and decrease of the average slag/metal ratio in course of time [2]

[1] Picture from T. Broch, Hüttenwerke Krupp Mannesmann GmbH, 2010
[2] Ehrenberg, A.: Iron and steel slags - from wastes to by-products of high technical, economical and ecological advantages. in: Pöllmann, H. (Ed.): Industrial Waste. Characterization, Modification and Applications of Residues. Verlag de Gruyter, Berlin, 2021, ISBN 9783110674866
[3] Geiseler, J.: Composition and structure of slags. in: Slag atlas. 2. ed., Düsseldorf, 1995
[4] Ullmanns Enzyklopädie der Technischen Chemie. 4. ed., 1972-1984
[5] Cavaliere, P.: Clean ironmaking and steelmaking processes. Cham, 2019

The metallurgist Pawlow wrote [6]: *"The blast furnace operators have always aimed to adjust the chemical composition of the slag to the demands of the individual ores to be smelted."*

Fig. 3 shows the very narrow range in the ternary phase diagram describing the typical composition of blast furnace slags and the eutectic to be adjusted.

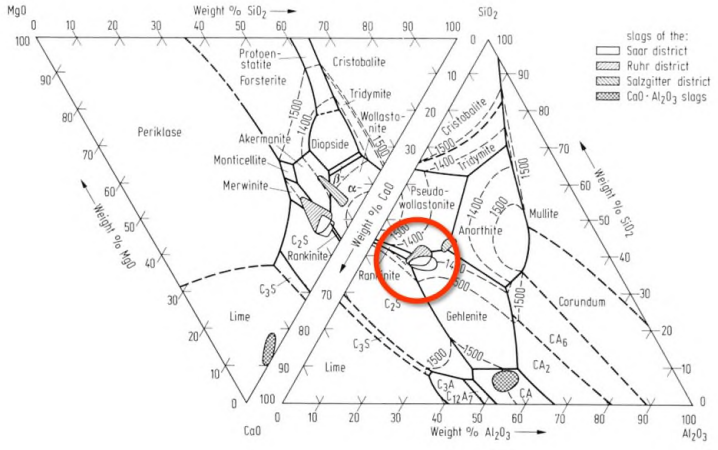

Fig. 3: Phase diagram being relevant for blast furnace slags [7]

2 Slag/metal ratio

The slag/metal ratio depends on the individual plant situation. If only iron ores of lower quality (higher gangue) are available, then the slag/metal ratio is higher. However, sinter made from fine ores and steel plant residues or a high pellet input create less slag. If charcoal is used as a reduction agent instead of coke the Sulphur input into the blast furnace is lower enabling the slag to be lower in basicity, i.e. lower in limestone addition. However, coal instead of coke increases the Sulphur input which requires a higher basicity in order to release the pig iron from Sulphur. For dephosphorisation a higher basicity is advantageous, too. In contrary, to eliminate alkalis a more acid slag is preferable.

Also in the past, when blast furnaces did not achieve such high capacities and temperatures as today (about 1500 °C), the slag/metal ratio was (much) higher, as shown in Fig. 2.

Today, depending on the individual situation in the European steel plants a certain range of slag/metal ratios is given. Table 1 summarizes data from 2008 and 2014, respectively, being compiled for each country and based on data for the individual blast furnaces. The very low data for country No. 9 result from a specific raw material situation.

[6] Pawlow, M.A.: Metallurgie des Roheisens. 2. ed., Berlin, 1953
[7] Schlackenatlas / Slag atlas. 1. ed., Düsseldorf, 1981

Country	1	2	3	4	5	6	7	8	9	10	∅
2008	273	275	221	278	214	287	269	285	157	270	253
2014	281	283	213	275	203	299	264	298	164	268	255

Table 1: Slag/metal ratio in European blast furnaces 2008 vs. 2014 in kg/$t_{Hot\ metal}$ [8]

In general, there is no significant change in the values between 2008 and 2014. Thus, for a given plant situation the slag/metal ratio is more or less fixed. Due to cost reasons (raw materials, energy, productivity) no blast furnace operator is interested to produce more slag than necessary.

Already in 1908 Passow, a German slag scientist, wrote a statement being valid to date [9]:

"He [= the blast furnace operator] uses it [= the slag] normally just like it devolves on him, and because the raw materials being available near the blast furnace are very different, it is not a wonder that each blast furnace in general has a constant slag which is, however, different from those from the others [= blast furnaces] and that those having accidentally a very expedient raw material in the near produce a very convenient slag for cement production."

Seldom (due to increased costs) the slag chemistry is modified only to meet cement customer needs, e.g. by adding limestone or bauxite. In such cases the slag/metal ratio is increased only a little bit, too.

3 Statistics

Fig. 4 shows the average slag/metal ratio for all German blast furnaces since 1960 [10]. It is obvious that corresponding to the capacity and efficiency increase of the blast furnaces and the focusing on few iron ore producers worldwide the slag/metal ratio is nearly constant since many years.

The slight trend to a little bit higher values since 2000 is due to the enormous increase in ore demand worldwide and the limited availability of high quality iron ores.

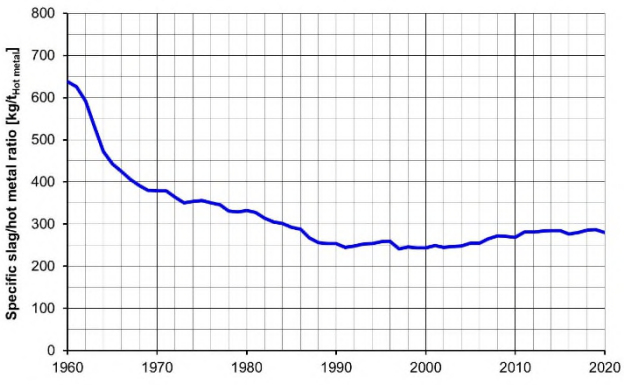

Fig. 4: Average slag/metal ratio for all German blast furnaces [10]

[8] Data: Steel Institute VDEh, Düsseldorf
[9] Passow, H.: Die Hochofenschlacke in der Zementindustrie. Würzburg, 1908
[10] Data: Fachverband Eisenhüttenschlacken, Duisburg

Fig. 5 shows as well the pig iron production as the blast furnace slag production in Germany since 1960 [8, 10]. After reaching the optimum low slag/metal ratio around 1990 the slag production follows the pig iron production parallel.

In 2020 the share of water granulated blast furnace slag was 90 % [10]. This material is latent hydraulic and it is used traditionally as a main constituent of cement.

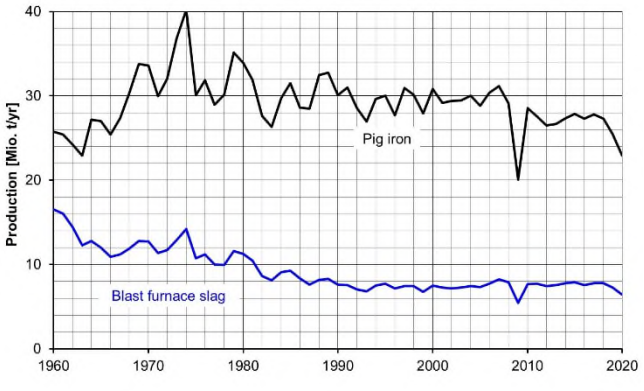

Fig. 5: Pig iron and blast furnace slag production in Germany [8, 10]