Effect of coal and coke ash on blast furnace slag formation – Comparison between PCI, charcoal, fossil-based coke and bio-coke

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Abstract: Blast furnace is the most used process for production of pig iron in the world. It is charged mainly with metallurgical coke and ferrous materials such as pellets and/or sinter. When descending inside the blast furnace, iron bearing materials start to reduce and with other burden material start to melt, which leads into formation of so-called primary slags from which the final slag is formed as materials descend inside the furnace. Every primary slag originates from one charge material and has unique effect on the total composition of the blast furnace slag. This work focuses on the primary slags of coke and pulverized coal injection (PCI). The global trend is to decrease the use of fossil-based carbon by replacing it with bio-based carbon. The primary slags of the coke and PCI originate from coke ash and pulverized coal ash. The purpose of this work is to evaluate how blast furnace slag composition is changed when fossil-based coke is replaced with bio-coke and PCI is replaced with charcoal. The effect differs case-by-case as presented in this work, but it was found out that replacing fossil-based coke with bio-coke and PCI with charcoal the solidus and liquidus temperatures as well as CaO/SiO_2 - and MgO/Al_2O_3 -ratios are increased. This comparison is based on mass balance calculations.

I. FOSSIL-BASED COKE, BIO-BASED COKE, PCI AND CHARCOAL

Several different compositions of biomasses and biochar have been reported in the literature [1-4]. Bio-coke can be made using these different bio-based materials depending on the target use. This work compares the composition of the formed blast furnace slag when fossil-based coke is replaced with bio-based coke and PCI is replaced with charcoal. In order to perform this comparison, one composition for each coke (metallurgical coke and bio-coke with 3 wt% Swedish wood charcoal addition [5]), PCI [6] and charcoal (produced from pine chips [2]) were chosen from literature and the ash compositions were scaled to 100% focusing on four main components which can be seen in Table I.

Table I. Ash amount and composition for fossil-based coke, bio-based coke, PCI and charcoal.

Analysis	Fossil-based coke	Bio-based coke	PCI	Charcoal
ash, wt%	12.22	11.53	7.93	1.5
Ash composition				
Al_2O_3	32.75	32.65	30.00	5.77
SiO_2	65.60	64.96	61.00	16.90
CaO	1.15	1.74	6.00	61.97
MgO	0.49	0.65	3.00	15.35

2. COMPARISON BETWEEN SLAGS PCI, CHARCOAL, FOSSIL-BASED AND BIO-BASED COKES PRODUCE

Primary slag of coke forms 13% [6] of the slag in blast furnace. Typical slag composition [5-7] can be seen in Table II. The CaO and MgO are the basic constituents of the slag whilst SiO_2 and Al_2O_3 are the acid constituents [8]. The difference between typical slag composition and slag compositions originating from using bio-based coke, charcoal as PCI and both bio-based coke and charcoal are also presented in Table II.

The different effects these replacements have on the final slag properties are presented in Table III. The solidus and liquidus temperatures were calculated using a commercial thermochemical software FactSage version 7.2 and its FactPS and FToxid databases and can be seen in Table III. Most important slag properties are the liquidus temperature, viscosity and the desulphurising capacity [8]. Slag should be in liquid form (temperature being in the range of 1350°C-1450°C). Increase seen in solidus and

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liquidus temperatures could present a problem when planning to replace coke and PCI.

MgO/Al_2O_3 -ratio has also an effect on the melting temperature; the minimum in melting temperature (~1320°C) can be found with MgO/Al_2O_3 -ratio around 0.78 and melting temperature increases after this point. Viscosity also has a minimum with MgO/Al_2O_3 -ratio around 0.81. [6, 9]

Table II. Slag composition for fossil-based coke and differences when fossil-based coke is replaced with bio-based coke, PCI is replaced with charcoal and both fossil-based-coke and PCI are replaced with bio-based coke and charcoal.

Slag composition	Fossil-based coke and PCI	Fossil-based coke replaced with bio-based coke	PCI replaced with charcoal	Fossil-based coke replaced with bio-based coke and PCI replaced with charcoal
Al_2O_3	10.22	10.02	8.35	8.72
SiO_2	40.76	40.47	38.61	38.91
CaO	39.47	39.87	42.75	42.23
MgO	9.54	9.64	10.28	10.12

Table III. Different effects of the replacements have on final slag features.

	Fossil-based coke and PCI	Fossil-based coke replaced with bio-based coke	PCI replaced with charcoal	Fossil-based coke replaced with bio-based coke and PCI replaced with charcoal
Solidus temperature	1231°C	1233°C	1339°C	1315°C
Liquidus temperature	1379°C	1381°C	1425°C	1409°C
CaO/SiO_2 -ratio	0.97	0.99	1.11	1.09
MgO/Al_2O_3 -ratio	0.93	0.96	1.23	1.16

3. SUMMARY

Increase in slag basicity (CaO/SiO_2) increases the sulphur distribution ratio (%(S)/%[S]) [8, 10]. In blast furnace process the required slag basicity is a compromise between desulphurising capacity, binding power of alkalis and liquidus temperature. When replacing fossil-based coke with bio-based coke and/or PCI with charcoal the changes in slag composition should be evaluated according to the process requirements.

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