HIGH TEMPERATURE COKE CHARACTERISTICS IN THE BLAST FURNACE – EVALUATION OF COKE PROPERTIES IN THE RACEWAY AREA

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Abstract

Core-drilling into the coke bed of raceway and hearth has been performed in the LKAB Experimental Blast Furnace (EBF®) during short stoppages aiming to characterize raceway conditions corresponding to different operational conditions. All coke operation, injection of pulverized coal and injection of a mixture of coal and blast furnace flue dust (BFD) were evaluated and compared. The samples have been studied regarding particle size and distribution, coke have been evaluated with chemical composition and thermal history, i.e. coke graphitization degree. In addition, the results have been compared to drilled raceway core samples from SSAB industrial blast furnace in Luleå.

Coke in drill-cores consists of bosh, raceway and deadman coke. In comparison with charged coke this coke has changed characteristics depending on the exposed conditions which vary along the radius of each drilled core. Coke in raceway area has increased ash content due to gasification of C and the ash composition is altered due to both reduction and gasification of ash minerals as e.g. SiO₂ and alkalis in raceway and oxidation/condensation of gaseous compounds and uptake of compounds from the melt. Coke exposed to highest temperatures in the raceway area have increased the most in graphitization degree, and subsequent bird’s nest and deadman cokes graphitization degrees decreases. K₂O-content in coke correlates to the graphitization degree as well as the SiO₂/Al₂O₃ quotient which decreases at higher temperatures.

Presence of slag and coke aggregates indicates the formation of bird’s nests at the end of the raceway. The end of raceway and position of a significant bird's nest in the industrial samples are indicated by the increasing content of K₂O and increasing ratio of SiO₂/Al₂O₃ in coke. In the industrial BF the pronounced formation of a bird’s nest redirect the gas from moving towards the BF center. As a result the coke in deadman cannot be heated and the temperature indicated by the graphitization degree decreases.

Injection of BFD influences the raceway conditions as the combustion peak is moved further into the raceway when BFD and PC mix are injected. Analyze of fines shows remaining unreacted BFD, which contains iron oxide with oxidation degree between FeO and metallic Fe. Increased FeO-content in raceway will decrease the melting point of tuyere slag and therefore improve the permeability at raceway end and the fact that the core when drilled could be pushed further into the EBF than for the other cores indicates higher permeability after injection of PC and BFD mixture.
**Introduction**

SSAB EMEA in Luleå produces the major part of their coke at their coke plant. The coke is characterized by high strength after reaction (CSR) and low reactivity (CRI). The ash content of 10-11 % contains high ratio of SiO$_2$ and relatively low contents of Fe$_2$O$_3$, CaO and MgO. The coke produced at SSAB is also used for most of the tests in the LKAB Experimental Blast Furnace (EBF®). In earlier studies samples from the shaft collected with probes, during excavation and charged and collected as basket samples have been investigated [1],[2]. These studies show that the SSAB coke persist the internal conditions in the thermal reserve zone well and the coke reactivity with CO$_2$ is low. However, gaseous compounds in the EBF atmosphere are picked up and reach the highest values just before the cohesive zone.

A stepwise increase in the graphitization degree of coke correlated to the temperature increase has been stated in the literature and confirmed in earlier studies. As the coke making temperature is around 1100°C an increased graphitization degree can be expected at higher temperatures. Vertical probe measurements in the EBF have shown temperatures of approximately 1050°C in the thermal reserve zone [3]. Therefore, the use of graphitization degree for samples from the lower part of the BF is valuable as a temperature indicator comparing changes of other properties in the coke. The flame temperatures in the combustion zone, i.e. raceway, are in general 2000-2300°C when operating with pulverized coal injection (PCI). At these temperatures and with the existing gas compositions reduction and gasification reactions occur. Except for reduction and gasification of alkalis picked up in the shaft, SiO$_2$ in the ash can be expected to be reduced and gasified in the high temperature region and these reactions may be critical for the raceway coke behavior. Moreover, CaO and MgO have similar behavior [4]. Such effects can be studied and compared in raceway samples and contribute in the evaluation of coke properties and operational conditions.

In this study the properties of coke collected at the raceway level via core-drilling is compared and analyzed relative a quite wide variation in operational conditions before core-drilling and includes all coke operation, operation with PCI and operation with injecting a mixture of pulverized coal (PC) and blast furnace flue dust (BFD). Additionally, the results are compared with core-drillings carried out in the industrial BF of SSAB in Luleå using the same coke and injected PC. The effect from hot metal and slag flow is compared for the EBF cases and for the different positions in the full scale BF which the position of a tuyere relative the taphole may have impact on the flow of melt.

**Experimental blast furnace, EBF®**

The LKAB EBF® has a working volume of 8.2 m$^3$, a diameter at tuyere level of 1.2 m and is equipped with a system for injection of reduction agents. The working height from tuyere level to stock line is 6 m and there are 3 tuyeres separated by 120°. The blast is normally pre-heated to 1200°C and can be enriched with O$_2$. Gas, oil or PC can be injected with O$_2$ addition to the lance. The oxy-coal system with the swirl-type lance results in high combustion efficiency. A bell-less top is used for material charging to the EBF and the furnace is operated with an excess top pressure. The operation of the EBF is similar to a commercial blast furnace, although with a shorter response time. Therefore, it is a valuable tool for detecting differences in properties of ferrous burden materials as well as different injection agents and new process concepts. The samples evaluated in this study have been collected from the EBF raceway during short stoppages and part of the results are also reported elsewhere [5]-[6]. Other studies include solid sampling from the hearth [5].
SSAB EMEA BF No.3

In April 2004 core-drilling into 3 of the 32 tuyeres was carried out at SSAB EMEA BF No. 3 in Luleå. BF No. 3 is operated on almost 100 % olivine pellets but some dust briquettes and additives in terms of BOF slag, limestone and minor amounts of ferromanganese slag are also charged. BF No.3 has a working volume of 2 540 m³ and a hearth diameter of 11.4 m. The material is charged via belt conveyer and distributed with a bell-less top. The blast volume is ~ 250 kNm³/h including oxygen enrichment and moisture added to the blast. The blast temperature is ranging between 1100 to 1150°C. BF No. 3 can operate with an excessive top pressure of 150 kPa and the average hot metal production is ~ 6 400 tonnes/day. BF No.3 has 2 tapholes, where one is in use during approximately three weeks before the change of taphole and replaceable runners. At the time for core-drilling the PC rate were ~ 135 kg/tHM and the average consumption of reducing agents in total ~ 459 kg/tHM. The oxygen content in the blast was in average ~ 24 %, the productivity 2.45 tons/m³24h and the flame temperature reached ~ 2170°C. A low volatile PC was injected via single coaxial lances with air in the coaxial part. The purpose of the core-drilling was to characterize the raceway and deadman by studying of the core samples and process data of the period prior to the core-drilling [7].

Raceway core drillings

Experimental setup and macroscopic evaluation

The coke used in the BF No. 3 and in LKAB EBF® in this study is produced by SSAB EMEA in Luleå. The properties of coke correspond to high quality coke regarding CSR (70.0-72.9 %) and CRI (19.2- 20.6 %) as well as the mechanical strength with Micum values of M40 79.5-80.2 % and M10 7.7-8.0 %.

4 core-drillings into the raceway of the EBF were performed at 3 different campaigns. Prior stoppages, the EBF was operating under different injection conditions and process parameters settings as presented in Table 1, which also shows data prior core-drilling at BF No. 3. The core-drillings at BF No. 3 were carried out using a drilling machine from Ruukki [8] with their specially trained personnel. At the EBF, a short stoppage can be made quite quickly with maintaining of blast and injection while at BF No. 3 the blast and PCI are stepwise decreased and often there is no injection at all just before the stoppage.

Table 1. Average process parameters at around 4 and 8 hours before stoppage and tuyere core-drilling in the EBF and in SSAB BF No.3, respectively

<table>
<thead>
<tr>
<th>Process parameters</th>
<th>EBF</th>
<th>SSAB</th>
</tr>
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<tbody>
<tr>
<td>Injection conditions</td>
<td>Core 1</td>
<td>Core 2</td>
</tr>
<tr>
<td>Injection</td>
<td> </td>
<td>All coke</td>
</tr>
<tr>
<td>PCR</td>
<td>-</td>
<td>154</td>
</tr>
<tr>
<td>Blast temperature</td>
<td>1190</td>
<td>1217</td>
</tr>
<tr>
<td>Blast velocity</td>
<td>134</td>
<td>139</td>
</tr>
<tr>
<td>O₂ enrichment*</td>
<td>-</td>
<td>4.0*</td>
</tr>
<tr>
<td>Moisture to blast</td>
<td>24</td>
<td>18</td>
</tr>
<tr>
<td>RAFT (flame temp.)</td>
<td>~2260</td>
<td>~2220</td>
</tr>
</tbody>
</table>

*including oxygen to lances
**PC & BF flue dust mixture of 27 % of BF flue dust and 73 % of PC, 110 kg PC & 40 kg BFD/tHM
†flame temperature estimated with consideration of iron oxide in injected mix
After the stoppage of the EBF, the tuyere No. 2 was taken out and a steel tube with an inner diameter of 185 mm was pushed into the tuyere. The tube was plugged and cooled with N₂ gas. After opening of the tube, the core was photographed and divided into 10 cm sub-samples as can be seen in Figure 1. The cores were emptied and each sub-sample was screened. Fractions >5 mm were sorted into coke, slag and metal (magnetic) material. Chemical analyzes were made on coke and fine material <0.5 mm. X-Ray Diffraction (XRD) analyzes of coke have been made in order to determine the graphitization degree. The graphitization degree is represented by the Lc value and is calculated using Scherrer’s equation [1] on XRD measurements at the (002) carbon peak position. Lc is defined by the medium height of the graphite crystal and a higher value represents a higher degree of ordering in the carbon structure and increases at higher temperatures. Coke in sub-samples from core 3 and 4 have been scanned at wider angle interval and evaluated.

![Figure 1. Raceway cores taken out of tuyere No. 2 at the EBF](image)

Macroscopic evaluation shows that core 1 contains coke pieces covered with drops of melt and partly coated with slag; leading to coke glued together forming aggregates. In core 2, corresponding to PCI of 154 g/Nm³, the coke pieces are “cleaner” with metal and slag drops on coke mainly found in rounded raceway coke and almost no aggregates found. Coke in core 3, after PCI of 165 g/Nm³, contains higher amount of metal drops generating some coke agglomerates and there are also a higher ratio of greyish, rounded coke blasted by the gas. When opening core 4, taken after a period with mixed PC and BFD injection prior drilling, the first impression was that the core contained a large amount of fines. However, when emptying the core, quite large coke pieces were found. Slag droplets can be observed at the coke surface and coke pieces are quite black with sharp edges. Some agglomerates are also found in core 4, mainly glued together with slag.

The positions of the drill-cores taken out from tuyeres 1, 8 and 12 at SSAB BF No. 3 are shown in Figure 2. The sample tube was 200 mm in diameter and had a length of 6 m, long enough for reaching the center of BF No. 3. More detailed description of the drilling and sample evaluation is reported elsewhere [7]. After drilling the cores were sealed and cooled with N₂ from the inside and with water on the outside. The cores were photographed and divided into 25 cm sub-samples after opening of the tubes. The drill-core from tuyere 1 is
shown in Figure 3. Each sub-sample were screened and fractions >10 mm were sorted in coke, slag and metal (magnetic). Coke in fractions >20 mm and fines <0.5 mm were used for chemical analyzes. XRD analyzes of coke from tuyere 1 have been made in order to determine the graphitization degree.

Based on previous tests of raceway depth measurements by a steel rod and the results when emptying the cores, different zoning could be made as shown in Figure 4. Cores from tuyere 1 and 8 are measured to 2.75 m and the core from tuyere 12 to 2.25 m. The maximum depths recorded by the drilling machine were larger as the material in the cores were compressed by 0.22 m in tuyere 1, 0.12 m in tuyere 8 and 0.55 m in tuyere 12.

Coarser coke with sharper edges was found at the beginning of the cores, originated from the bosh area and have been down into the raceway cavity when the BF was stopped. Smaller, rounded raceway coke was found further in. At the end of the raceway, denser material with a higher content of fines forms the bird’s nest. Around this position a network of metallic iron surrounds the coke particles. The last part of the cores corresponds to deadman. Notably, in the core from tuyere 1, a large area of iron agglomerates was present after the bird’s nest, indicating a larger amount of melt is travelling in the area between the tapholes.

**Particle size of coke and material distribution**

Weighed amounts of coke >5 mm in the raceway cores taken out of the EBF are shown in Figure 6, together with total amount of material >5 mm and fines <0.5 mm. Larger gaps between coke and total material >5 mm indicates presence of magnetic material, slag and agglomerates. Comparing the cores with PCI prior drilling, core 2 have higher amounts of coke and lower amount of other material while core 3 has quite high ratio of magnetic material, aggregates and slag, indicating melt dripping through raceway area. The blast velocity seems to have greater impact on restricting the melt through raceway than PCI since the blast velocity is 10 m/s higher before drilling of core 2. In addition, the amounts of fines are low in core 2 suggesting that the higher gas velocity have blown them away. No indication of bird’s nest was found in core 2. The highest amount of fines in all cores is found at 30-40 cm position in
core 3. The coarser coke increases afterwards, indicating the back side of a bird’s nest, and the coke degradation decreases as the amount of 10-16 mm, but especially 5-10 mm coke, is lower. In core 2, the coke degradation is high and quite uniform along the length of the core. In core 1, after all coke operation, the coke degradation varies but is lower towards the center of the EBF indicating bird’s nest formation at position ~ 40 cm as the amount of fines increases afterwards. The weighed material in core 4, after injection of PC and BFD mixture, was in general lighter than the other cores although some magnetic material, slag and aggregates were found at positions 40-60 cm, especially in fraction 5-10 mm. The first 2 sub-samples of the core consisted mainly of coarse coke >16 mm. The coke degradation was lowest of all drilled cores as the amount coke larger than 16 mm was high and fractions 5-10 mm, but also 10-16 mm, were low. This indicates that the fines observed when opening the core may origin from injected BFD and/or PC fines. The highest coke degradation was found at position 30-40 cm and subsequent sub-sample had highest amount of metal, aggregates and fines, indicating a bird’s nest.

Figure 6. Weighed coke (in grams) in fractions >16, 10-16 and 5-10 mm and total amount of material >5 mm and <0.5 mm

Figure 5. Fractions >20 mm and <0.5 mm in drill-cores from SSAB BF No. 3
center have the lowest content of >20 mm particles. Small amount of fines are found in race-
way position and the amounts increases after the bird’s nest position and further towards
deadman. The lower amount of fines at tuyere 1 position may be a result of direct reduction of
FeO and other oxides consuming coke fines as more melt most likely travels between the tap-
holes at BF No. 3.

Chemical composition

The ash content in coke in raceway drill-cores from the EBF, here represented by the sum of
oxides in the XRF analyze is shown in Figure 7. All sub-samples have higher ash content than
the charged coke. The cores drilled after PCI, core 2 and 3, do not vary to a large extent to-
wards the center of the EBF, while large variations occur after all coke operation, core 1, and
injection of PC and BFD mix, core 4. Coke from core 1 has notably high ash content at posi-
tion 10-40 cm and core 4 coke has quite low content at position 20-40 cm. Figure 8 shows the
ash content in drilled core coke >20 mm samples from industrial size BF No. 3. The ash con-
tent is higher than charged coke and increases at bird’s nest position of tuyere 1 and 8 and
further into the deadman in all 3 cores. Especially high ash contents occur at position of iron
agglomerates in tuyere 1. The last sub-sample of tuyere 12 deviates in all analyzes.

In Figure 9, the K₂O-content and SiO₂/Al₂O₃ quotient in coke samples from EBF is compared
to values of charged coke. At high temperature in raceway combustion area silica and alkali
compounds in coke ash are reduced and SiO gas as well as alkali metals will evaporate. All
drill-core samples have lower SiO₂/Al₂O₃ than charged coke, indicating SiO₂ reduction and
gasification. The quotient as well as the alkali content is generally higher in the first sub-
samples and decreasing further in, but the positions varies with different injection setups.

The SiO₂/Al₂O₃ quotient in coke from drilled cores from BF No. 3, see Figure 10, increases at
birds nest and deadman position and are slightly higher or around the value of charged coke.
However, in bosh and raceway coke the value is lower, indicating gasification of silica com-
ounds. In addition, almost all K₂O have been reduced and evaporated in the raceway, while
the content is still high at birds nest and deadman position, especially in tuyere 1.

C and Fe dominate in fines <0.5 mm and the total amounts are shown in Figure 11 for both
EBF drill-cores and SSAB BF No. 3. The basicity B2 is also shown in the same figures. The
C-content in sub-samples from the EBF vary between 11-60 % and Fe between 19-54 %. Un-
like the EBF cores, C- and Fe-contents in fines from drill-cores from BF No. 3 are high in
bosh and raceway areas and decreases in deadman. Tuyere 8 shows the trend most distinctly
indicating good reduction of FeO by coke fines. Drill-cores from industrial size BF No. 3
shows lower basicity in the raceway area and B2 increases at bird’s nest and deadman position. Basicity in fines from EBF cores differs depending on conditions in raceway prior core-drilling. Unlike the industrial size BF, B2 in fines seems to decrease in positions where signs of bird’s nest have been noticed.

Figure 9. The K₂O-content and SiO₂/Al₂O₃ quotient in coke from EBF drill-cores and in charged coke

Figure 10. K₂O-content and SiO₂/Al₂O₃ quotient in >20 mm coke samples from BF No. 3

Figure 11. Sum of C- and Fe-content and B2 in drill-core fines <0.5 mm from the EBF (left) and from SSAB BF No. 3 (right)
XRD

The graphitization degrees, represented by the \( L_c \) values, in coke samples from the EBF are shown in Figure 12. Generally, the \( L_c \) value of bosh coke in the first sub-sample, have lower \( L_c \) than subsequent raceway coke. \( L_c \) in the last sub-sample in the cores from EBF decreases slightly. Core 3, with injection of 165 g/Nm\(^3\), has the highest level of \( L_c \) indicating the highest temperatures in raceway followed by core 2, with PCI of 154 g/Nm\(^3\). In core 4, with injection of PC and BFD mixture, \( L_c \) is initially low in raceway and increases to a quite high level at position 40-50 cm. The ash content is also lower, suggesting that coke is less affected by gasification reactions. Indications of remaining BFD at position 0-30 cm were found in fines <0.5 mm [6] and may influence combustion characteristics in raceway. It seems like the combustion takes place further into the raceway, at position 40-60 cm, than with PCI.

L\(_c\) of coke in bosh, raceway and bird’s nest area, and one sub-sample of deadman coke (position 2.25-2.5 m), in the core drilled from tuyere 1 at BF No. 3 are shown in Figure 13. The highest \( L_c \) occurs in the beginning of raceway and decreases towards the end. The deadman sub-sample has lower graphitization corresponding to lower temperature. This trend coincides with other raceway core drillings made [9]-[10].

Coke in drill-cores from the EBF has been analyzed in XRD and compounds found are shown in Figure 14. Sub-samples at the position of 0-10, 10-20 and 50-60 cm from core 3, after PCI, and core 4, after PC and BFD injection, have been studied.

![Figure 12. \( L_c \) values (Å) in coke from EBF raceway core-drilling](image1)

![Figure 13. \( L_c \) values (Å) in coke from SSAB BF No. 3, drill-core from tuyere 1](image2)

![Figure 14. XRD pattern for coke from core 3 (left) after PCI, and in core 4 (right) after injection with PC and BFD mixture. Original charged coke is indicated to the right](image3)
At position 0-10 cm and 10-20 cm in core 4, coke looks more like original coke than in core 3. Mullite, 3Al₂O₃·2SiO₂, is the major silicon-aluminum compound in original coke, and can also be noticed in the first sub-sample at position 0-10 cm. As comparison, original coke before charging is also shown Figure 14. The coke peak is positioned at 20 ~ 26° and has an additional peak of graphite at all positions in core 3 but only further into core 4 at position 50-60 cm. In addition, gehlenite, Ca₂Al₂SiO₇, is found in all sub-samples after PCI but only at the position of 50-60 cm in the core after injection of PC and BFD mixture. However, akermanite, Ca₂MgSi₂O₇, can also be present as the peaks are overlapping in many cases. Fe is also found further into the EBF center in both cores. Some iron silicon and SiC may be present in core 3. In addition, SiC is noted in core 4 sub-sample 10-20 cm. Peaks pointing at presence of MgAl₂O₄ spinel are noticed in core 3 and in the 50-60 cm sub-sample in core 4, suggesting these samples have been subjected to higher temperatures. Gornostayev et. al. [11] found spinel crystals of MgAl₂O₄ in tuyere coke which believed to be a product of altered minerals during the decent in the BF reacting with reduced Mg (g) and H₂O (g).

**Concluding discussion**

Coke in drill-cores consists of bosh coke from above the raceway, raceway coke and deadman coke. In comparison with charged coke this coke has changed characteristics depending on the exposed conditions which vary along the radius of each drilled core. The changes include changed particle shape due to turbulence, high temperature and oxidation conditions and therefore the raceway coke is smaller and more rounded than bosh and deadman coke. The degree of coke degradation depends on raceway conditions such as blast velocity. Coke in raceway area have increased ash content due to gasification of carbon which is more pronounced in core 1, after all coke operation, due to absence of other injected carbon containing material. Slag/metal droplets occur on coke surface and, in the case of deadman coke in industrial size BF, oxidation/condensation of compounds from BF gas in low temperature regions. In addition, the ash composition is altered due to both reduction and gasification of ash minerals as e.g. SiO₂ and alkalis in raceway and oxidation/condensation of gaseous compounds and uptake of compounds from the melt. Coke exposed to highest temperatures in the raceway area have increased the most in graphitization degree, and subsequent bird’s nest and deadman cokes graphitization degrees decreases. K₂O-content in coke correlates to the graphitization degree, i.e. the temperature, as well as the SiO₂/Al₂O₃ quotient which decreases at higher temperatures. Coke particles have different macroscopic appearance dependent on raceway conditions, as slag coating during all coke and PC and BF flue dust injection, metal coating for high PCI etc.

Presence of slag and coke aggregates indicates the formation of bird’s nests at the end of the raceway. The K₂O-content, as the content is nearly zero in raceway, is a good indicator of temperature and the transition from raceway to bird’s nest and deadman can clearly be seen in the cores from the industrial sized BF and less significant in the EBF. The end of raceway and position of a significant bird's nest in the industrial samples are indicated by the increasing content of K₂O and increasing ratio of SiO₂/Al₂O₃ in coke. In the industrial BF the pronounced formation of a bird’s nest redirect the gas from moving towards the BF center. As a result the coke in deadman cannot be heated and the temperature indicated by the graphitization degree decreases. Ash released during combustion cannot reach the basic slag formers charged from the top and a uniform distribution with comparably low basicity of fines <0.5 mm in the raceway and higher B2 from the bird’s nest towards the center of the BF is found.
Different injection conditions may explain part of the differences found between pilot and full-scale. The injection conditions at the EBF include oxy-coal injection with a swirl-tip lance. The change to oxy-coal system made it possible to increase the PC injection rate up to 170 kg/tHM with stable conditions, probably due to improved combustion efficiency of PC. In the EBF, gas flows with relatively long penetration depths which resulted in a rather uniform temperature distribution, stated by the graphitization degree, of cores after operation with PCI. The highest temperature indicated by the graphitization degree of core 3 hints that the combustion is efficient also at the higher injection rate. In addition, higher PCI results in a higher amount of volatiles released by the coal particles and therefore a higher release of heat when ignited [12]. At BF No. 3 a straight coaxial lance with air in the coaxial part is used. In this lance it is possible that air travelling in parallel to the coal plume hinder the hot blast with higher oxygen content from reaching the coal particles efficiently. Another difference is the raceway area relative the total cross section area and the raceway length relative the radius, which is higher in the EBF compared to in the industrial BF where the center region is filled with a large volume of deadman coke [1],[3].

In BF No. 3 the flow of melt through raceway area is most likely related to the position relative the tapholes. The largest amounts of slag and iron agglomerates were found in tuyere 1 drill-core positioned between the tapholes. Tuyere 12, positioned at the opposite direction has not as distinctive signs of bird’s nest and also had the largest compression. Slag found on coke pieces in EBF core 1, after all coke operation, can hinder both gasification and temperature rise, as the graphitization was lower than expected based on the calculated theoretical flame temperature. Reported studies with PCI and coke showed that slag with high viscosity may cover the coke surface while slag with lower viscosity falls down from the surface [13]. Molten coke ash has high melting point and high viscosity and thermodynamic calculation indicates that ash from the PC used decreases the melting point of the ash released [5] when the actual PC is injected.

Injection of BFD influences the raceway conditions [6] as reduction of iron oxides in BFD are assumed to lower the flame temperature and reduce melting temperature and viscosity of tuyere slag. The graphitization degree, K\textsubscript{2}O-content and SiO\textsubscript{2}/Al\textsubscript{2}O\textsubscript{3} quotient in coke in the first part of raceway in core 4 indicate lower temperatures. In addition, the ratio of coke particles >16 mm are less affected, based on material distribution, ash content, chemical composition and the coke shape with quite sharp edges. XRD measurements on coke at this position show similarity of charged coke with presence of mullite and quartz in the first sub-sample. Presence of gehlenite in is found in coke subjected to higher temperatures, based on the graphitization degree of core 3 and sub-sample 50-60 cm in core 4. It cannot be stated if present gehlenite origin from slag droplets on the coke surface or from the ash itself. However, at position 40-60 cm the temperature has raised significantly, indicating that the combustion peak position is moved further into the raceway when BFD and PC mix are injected. As BFD contains practically no volatiles, the amount of volatiles in injected PC is diluted and the fast ignition initially in raceway might have been delayed. Analyze of fines <0.5 mm [6] shows remaining unreacted BFD in the first 3 sub-samples as the Zn-content was higher. Moreover, estimation of the oxidation degree of iron oxide showed a reduction degree between FeO and Fe\textsubscript{net} in core 4. The amount of fines <0.5 mm were less than in core 3 but higher than in the other cores. Fines noted when opening the core indicate some unconsumed BFD. Increased FeO-content in raceway will decrease the melting point of tuyere slag and therefore improve the permeability at raceway end [14] and the fact that the drill-core could be pushed further into the EBF than for the other cores indicates higher permeability after injection of PC and BFD mixture.
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