THE EFFECT OF SELECTED PROPERTIES OF COKE ON THE QUALITY OF COKE AND INDICATORS OF BLAST FURNACE PROCESS

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Received: 10.12.2013
Accepted: 18.04.2014

Abstract
The topic of the paper is a part of research related to the problem of the effect of production factors on the quality of pig iron and indicators of blast furnace process. It includes part of the issues related to the analysis of quality of coke. Researches were made in collaboration with Blast Furnace Department of Polish steelwork and were based on the results coming from this Department. The analysis covers the period of eight months. The basic quality parameter of coke, among parameters presenter in this paper, ash content is the parameter which has significant importance for the blast furnace process (parameters of the process and quality of pig iron). Pearson's correlation coefficients between the ash content in coke and various indicators were determined. For indicators of the process, for which value of Pearson’s correlation coefficient with the ash content of coke was sufficiently high, functional dependence was determined as regression function. It should be noted, however, that the research should be continued, because it did not include all quality parameters of fuels. Only comprehensive analysis can generate appropriate results.

Keywords: iron, coke, blast furnace

1 Introduction
Production of products with suitable quality and at the lowest possible cost level is the main goal of any production process. Pig iron is one of basic materials used in steelmaking processes, the quality of pig iron effects the economics and quality of steel. Quality of pig iron is determined by standards that provide acceptable content of elements for various grades. In addition, it is important to maintain the optimum value of technical and economic indicators of the process. It allows to optimise the production process and costs. Production of pig iron with appropriate chemical composition and temperature allows to cut the steelmaking process cost and to achieve the appropriate quality of the steel.

The quality fo the pig iron is effected by a variety of factors, which can be divided in three basic groups: quality of ferrous burden materials, quality of coke and alternative fuels, the parameters of blast furnace process.

These factors have also effect on technical and economic indicators of the production process. Indicators illustrate various aspects of the process. They are used for the description and the analysis of the process, enable the assessment of its run and allow the optimisation.
The analysis should include those factors, which are important from the point of view of the quality of pig iron. The topic of the paper is a part of research related to the problem of the effect of production factors on the quality of pig iron and indicators of blast furnace process. The paper includes part of the issues related to the analysis of quality of fuels. Researches were made in collaboration with Blast Furnace Department of Polish steelwork and were based on the results coming from this Department. The analysis covers the period of eight months. Ferrous materials are the basic raw materials used in the blast furnace process. The second group of materials used in this process are fuels.

Blast furnace (stabilized) coke is the basic fuel in the blast furnace process. It performs three tasks: in technological term as fuel, in chemical terms as a reducing agent and carbonising pig iron (carbon is main component of coke \[^1\] and in mechanical term as a grate resistant in high temperature \[^2\]. It is also the main factor responsible for the cost of the blast furnace process, so it the minimum of its use should be achieved \[^3, 4\]. It carries, however, high requirements of the quality of coke used in the process \[^5 – 13\]. The effect on the properties of coke has, among others, the ash content, which have an effect on \[^1 – 13\]: quality of the pig iron and slag formation, cohesion of pieces of the coke and thus its mechanical strength, the amount of flux, what can increase the consumption of the coke.

In addition to the blast furnace coke, other fuels are used in the process: fine assortments of the coke (e.g. coke breeze), which significantly reduces the cost of fuels \[^2, 14-17\], small amounts of coke oven gas and natural gas. Blast furnace gas is used for heating blast. These fuels are used to reduce total cost of the blast furnace production \[^2, 18\].

In the tested blast furnace, blend of cokes with various grain and physical and chemical properties is used. Chosen characteristics of cokes used in this process are presented in Table 1.

### Table 1

<table>
<thead>
<tr>
<th>Properties</th>
<th>Required values for each assortment of coke</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Blast furnace</td>
</tr>
<tr>
<td>Grain size, mm</td>
<td>25-80</td>
</tr>
<tr>
<td>The ash content in the dry state, A(_{d}), % - max.</td>
<td>10.5</td>
</tr>
<tr>
<td>S content in the dry state, S(_{d}), % - max.</td>
<td>0.8</td>
</tr>
<tr>
<td>The moisture content, W(_{t}), %</td>
<td>5.0</td>
</tr>
<tr>
<td>The content of volatile matters in the dry state, V(_{daf}), % - max.</td>
<td>1.1</td>
</tr>
<tr>
<td>Calorific value, kJ/kg</td>
<td>ok. 29 500</td>
</tr>
</tbody>
</table>

2 The analysis of selected quality parameters of the coke

The analysis of selected quality parameters of the coke used in the blast furnace process was made. Parameters related to the chemical composition of the coke were selected: the moisture content, the content of volatile matter, ash content (other parameters are also tested). The average content of these components in various assortments of cokes in the study period was presented in Table 2.

Based on the analysis (Table 2), it can be said that in nearly all cases the content of ingredients in each assortments of the coke ranged in the standards (Table 1). In two cases the limits were
exceeded: the moisture content in nut coke (12.4%, while limit was on the level of 12%) and content of volatile matter (2.41, while limit is at the level of 2%) and ash (16.25% with maximum value 13%) in coke breeze.

Table 2 The average content of moisture, volatile matter and ash in various assortments of coke in the study period

<table>
<thead>
<tr>
<th>Assortments of coke</th>
<th>The moisture content, %</th>
<th>The content of volatile matter, %</th>
<th>Ash content, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blast furnace coke</td>
<td>4.10</td>
<td>0.68</td>
<td>9.49</td>
</tr>
<tr>
<td>Nut coke</td>
<td>12.4</td>
<td>0.76</td>
<td>9.41</td>
</tr>
<tr>
<td>Pea coke</td>
<td>11.1</td>
<td>1.06</td>
<td>10.03</td>
</tr>
<tr>
<td>Coke breeze</td>
<td>16.25</td>
<td>2.41</td>
<td>11.05</td>
</tr>
</tbody>
</table>

3 The effect of selected quality parameter of the coke on the quality of pig iron and technical and economic indicators

The basic quality parameter of coke, among parameters presenter in this paper, ash content is the parameter which has significant importance for the blast furnace process. Therefore, it is necessary to determine the effect of ash content in the coke on the quality of pig iron and technical and economic indicators of the blast furnace process. For this purpose, Pearson's correlation coefficients between parameters were determined. The results of this analysis were presented in Table 3.

Table 3 The values of Pearson’s correlation coefficients between the ash content in the coke and the quality parameters of pig iron and selected technical and economic indicators of the blast furnace process in the study period

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ash content in coke</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe content in pig iron</td>
<td>-0.68</td>
</tr>
<tr>
<td>Si content in pig iron</td>
<td>0.11</td>
</tr>
<tr>
<td>Mn content in pig iron</td>
<td>0.80</td>
</tr>
<tr>
<td>S content in pig iron</td>
<td>0.10</td>
</tr>
<tr>
<td>P content in pig iron</td>
<td>0.78</td>
</tr>
<tr>
<td>KIPO</td>
<td>0.47</td>
</tr>
<tr>
<td>The yield of slag</td>
<td>0.12</td>
</tr>
<tr>
<td>Consumption of materials</td>
<td>0.22</td>
</tr>
<tr>
<td>Consumption of fuels</td>
<td>0.63</td>
</tr>
<tr>
<td>The yield of pig iron</td>
<td>-0.67</td>
</tr>
<tr>
<td>Inconsistent production</td>
<td>0.71</td>
</tr>
</tbody>
</table>

For quality parameters of pig iron and indicators of the process, for which value of Pearson’s correlation coefficient with ash content of the coke was sufficiently high, functional dependence was determined as regression functions. Results of regression analysis are presented in Fig. 1 – 6 and Table 4 – 9.

Results of the analysis of the effect of ash content of the coke on the Fr content in pig iron (Fig. 1, Table 4) shows that this dependence can be describe by following formula:

\[ \hat{y} = -0.2495x + 96.86 \]

(1.)

where:  
\( x \) – ash content in coke, %,
\( y \) – Fe content in pig iron, %.
Calculations presented in Table 4 (standard error not exceeding 1% of examined parameter, the coefficient of determination at the level of 0.46, significance of the variable of the ash content of the coke) indicate good fitting of regression function with the experimental values. Based on created regression model it can be said that the 1% - increase the ash content in the coke resulted the 0.25% - decrease of Fe content in pig iron.

Fig. 1 Regression function describing the effect of the ash content of coke on the Fe content in pig iron in the study period

Table 4 Calculations for regression function describing the effect of the ash content of the coke on the Fe content in pig iron in the study period

<table>
<thead>
<tr>
<th>R²</th>
<th>S_e</th>
<th>V_e</th>
<th>F</th>
<th>F_{ist}</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.46</td>
<td>0.105</td>
<td>0.11%</td>
<td>5,31</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Fig. 2 Regression function describing the effect of the ash content of the coke on the Mn content in pig iron in the study period

Table 5 Calculations for regression function describing the effect of ash content of coke on the Mn content in pig iron in the study period

<table>
<thead>
<tr>
<th>R²</th>
<th>S_e</th>
<th>V_e</th>
<th>F</th>
<th>F_{ist}</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.64</td>
<td>0.036</td>
<td>0.036</td>
<td>10,86</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Results of the analysis the effect of the ash content of the coke on the Mn content in pig iron (Fig. 2, Table 5) shows that this dependence can be describe by following formula:
\[ \hat{y} = 0.1228x - 0.8945 \] (2.)

where:  
\( x \) – ash content in coke, %,
\( y \) – Mn content in pig iron, %.

Calculations presented in Table 4 (standard error exceeding little more than 10% of examined parameter, the coefficient of determination at the level of 0.64, significance of the variable of the ash content of the coke) indicate good fitting of regression function with the experimental values. Based on created regression model it can be said that the 1% - increase the ash content in the coke resulted the 0.12% - increase of Mn content in pig iron.

Results of the analysis of the effect of the ash content of the coke on the P content in pig iron in the study period (Fig. 3, Table 6) shows that this dependence can be describe by following formula:

\[ \hat{y} = 0.0287x - 0.1817 \] (3.)

where:  
\( x \) – ash content in coke, %,
\( y \) – P content in pig iron, %.

Calculations presented in Table 6 (standard error not exceeding 10% of examined parameter, the coefficient of determination at the level of 0.786, significance of the variable of the ash content of the coke) indicate good fitting of regression function with the experimental values. Based on created regression model it can be said that the 1% - increase the ash content in the coke resulted the 0.02% - increase of P content in pig iron.

Results of the analysis of the effect of the ash content of the coke on fuel consumption (Fig. 4, Table 7) shows that this dependence can be describe by following formula:

\[ \hat{y} = 11.657x + 384.52 \] (4.)

where:  
\( x \) – ash content in coke, %,
\( y \) – fuel consumption, kg/1 Mg pig iron.
Calculations presented in Table 7 (standard error little exceeding 1% of examined parameter, the coefficient of determination at the level of 0.636, significance of the variable of the ash content of the coke) indicate good fitting of regression function with the experimental values. Based on created regression model it can be said that the 1% increase the ash content in the coke resulted the 11.66kg/1 Mg pig iron increase of fuel consumption.

![Fig. 4](image.png)

**Fig. 4** Regression function describing the effect of the ash content of the coke on fuel consumption in the study period

<table>
<thead>
<tr>
<th>R²</th>
<th>S_e</th>
<th>V_e</th>
<th>F</th>
<th>F_{ist}</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.63</td>
<td>5.67</td>
<td>1.5%</td>
<td>3.98</td>
<td>0.09</td>
</tr>
</tbody>
</table>

![Table 7](image.png)

**Table 7** Calculations for regression function describing the effect of the ash content of the coke on fuel consumption in the study period

Results of the analysis of the effect of the ash content of the coke on the yield of pig iron (Fig. 5, Table 8) shows that this dependence can be described by following formula:

![Fig. 5](image.png)

**Fig. 5** Regression function describing the effect of the ash content of the coke on the yield of pig iron in the study period

<table>
<thead>
<tr>
<th>R²</th>
<th>S_e</th>
<th>V_e</th>
<th>F</th>
<th>F_{ist}</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.67</td>
<td>0.75</td>
<td>1.25%</td>
<td>5.00</td>
<td>0.06</td>
</tr>
</tbody>
</table>

**Table 8** Calculations for regression function describing the effect of ash content of coke on the yield of pig iron in the study period

![Table 8](image.png)
\[ \hat{y} = -1.7373x + 76.871 \]  

(5.)

where:  
x – ash content in coke, %,  
y – the yield of pig iron, %.

Calculations presented in Table 8 (standard error little exceeding 1% of examined parameter, the coefficient of determination at the level of 0.67, significance of the variable of the ash content of the coke) indicate good fitting of regression function with the experimental values. Based on created regression model it can be said that the 1% - increase the ash content in the coke resulted the 1.73% - decrease of the yield of pig iron.

![Graph showing regression function](image)

**Fig. 6** Regression function describing the effect of the ash content of the coke on the inconsistent production in the study period

**Table 9** Calculations for regression function describing the effect of the ash content of the coke on the inconsistent production in the study period

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( R^2 )</td>
<td>( S_e )</td>
<td>( V_e )</td>
<td>( F )</td>
<td>( F_{ist} )</td>
<td></td>
</tr>
<tr>
<td>0.71</td>
<td>3.23</td>
<td>26.84%</td>
<td>56.15</td>
<td>0.04</td>
<td></td>
</tr>
</tbody>
</table>

Results of the analysis of the effect of the ash content of the coke on the inconsistent production in the study period (**Fig. 6, Table 9**) shows that this dependence can be describe by following formula:

\[ \hat{y} = 8.2758x - 67.146 \]  

(6.)

where:  
x – ash content in coke, %,  
y – inconsistent production, %.

Calculations presented in Table 9 (standard error exceeding nearly 27% of examined parameter, the coefficient of determination at the level of 0.71, significance of the variable of the ash content of the coke) indicate that level of inconsistent production depends on the ash content, but also significantly on other parameters. Based on created regression model it can be said that the 1% - increase the ash content in the coke resulted the 8.27% - increase of inconsistent production. It should be noted, however, that in this case standard error (\( S_e \)) was high. Choice of different regression model should be taken into consideration.
4 Conclusions

Many different factors have an effect on the quality of pig iron and technical and economic indicators [20]. These factors can be divided into three main groups: quality of ferrous burden materials, quality of coke and alternative fuels and the parameters of blast furnace process. In this paper selected quality parameters of the coke were taken into consideration. Ash content in coke was chose as the main factor in this analysis. Mathematical description of selected dependences to assess the effect of ash content in coke on the selected parameters was made. It should be noted, however, that the research should be continued, because it did not include all quality parameters of fuels. Only comprehensive analysis can generate appropriate results.

References