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THE ANALYSIS OF SELECTED PARAMETERS OF BLAST FURNACE OPERATION

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The paper presents results of the analysis of selected parameters of blast furnace operation and the influence of various factors on them. The study was carried out in cooperation with a Blast-Furnace Department of a Polish steelworks and was based on the results coming from this Department. The analysis covers the period of one calendar year.

Keywords: blast furnace, pig iron, effectiveness, productions, linear regression method

INTRODUCTION

The basic economic goal of blast furnace process is the production of pig iron at the lowest possible cost [1]. It should be emphasized that during production process a large amount of pig iron is produced, so huge streams of materials are involved in the process. Therefore, even small changes in the operation of blast furnace can affect the cost [2, 3]. In order to capture these changes, both complicated and simple technical and economic indicators should be assessed on current basis [4 - 6]. Values of these technical and economic indicators may depend on many factors, inter alia: charge richness and physical properties of charge, physical properties and chemical composition of blast furnace coke and alternative fuels, quantity and quality of blast, technological parameters of device and utilization of calendar time (including number of stops) [7, 8].

The paper presents the results of a study on the influence of various factors on the selected parameters in the blast furnace.

METHODOLOGY

The analysis presented in the paper is divided into the following components:

Quantitative analysis of selected blast furnace parameters using basic statistical characteristic.

The assessment of variability of selected parameters of blast furnace.

The influence of selected factors on parameters of blast furnace operation using linear regression method.

The tested blast furnace is a device with 12 - meter hearth and 3 200 m^3 of usable capacity. Table 1 presents basic parameters of tested device.

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Table 1 **Basic parameters of the tested blast furnace [9, 10]**

Usable capacity	3 200 m^3
Diameter of hearth	12 000 mm
Diameter of top of blast furnace	9 000 mm
Amount of tuyeres	32 pcs.
Diameters of tuyeres	130 mm
Amount of heating stoves	4
Amount of tap holes	4
Length of tap holes	2 400 mm
Inclination angle of tap holes	9 – 10°
Content of agglomerate in charge	Over 80 %
Temperature of blast	1150 – 1200 °C
High pressure of gas in the top	215 kPa
Enriching the blast in oxygen	up to 27,5 %
Amount of slag	270 – 350 kg/1 Mg of pig iron
Installation for the injection of pulverized coal	

The assessment of blast furnace operation was made based on selected parameters: unit daily production, intensity of combustion of coke for running time, pig iron yield, slag yield and utilization of calendar time.

RESULTS OF THE ANALYSIS

Basic statistical characteristics of parameters were calculated. The results of the analysis are presented in Table 2. It can be said that the average daily production received from 1m^3 of volume of blast furnace is app. 1,6 Mg/(m^3 24h), while average intensity of combustion of coke for running time - 782 kg/24h/m^3. Yield of pig iron reached the value of 60 %, while yield of slag – the level of nearly 345 kg/1 Mg of pig iron. It must be added that utilization of calendar time index was app. 93 %. All parameters were characterized by slight variability, the highest was noticed for intensity of coke combustion (over 8 %) and unit daily production of pig iron (6 %), but these values are satisfactory. Values of the rest of parameters did not exceed 4 %.

UNIT DAILY PRODUCTION OF PIG IRON

Unit daily production of pig iron is defined as total daily production per $1m^3$ of the volume of blast furnace [4, 7]. In modern blast furnaces this parameter is above 2,0, the higher the value of this parameter, the better work of blast furnace. It can be calculated according to the following formula [4, 11, 12]:

$$E = \frac{P_d}{V_u}$$

where:
E – unit daily production of pig iron / Mg/(m^3×24h),
P_d – daily production of pig iron / Mg/24 h,
V_u – useful volume of blast furnace / m^3.

The assessment of variability of this parameter was made. Values of this parameter in separate months were compared to the average value (Figure 1), this variability was caused by many factors, among them execution of production plan is the most important.

Next, the influence of the level of execution of pig iron production on the unit daily production of pig iron in the studied period was calculated, results are presented in Figure 2 (auxiliary calculations: standard error - Se = 0,064, standard variability indicator - Ve = 4 %, error of slope of regression line - d(a) = 3,44, Wald's test value - F = 4,63, Wald's test critical value - F_α = 3,28). It is possible to conclude that the increase in the level of production plan execution index by 1 % resulted in increasing the unit daily production of pig iron by approx. 0,007 Mg/(m^3×24h).

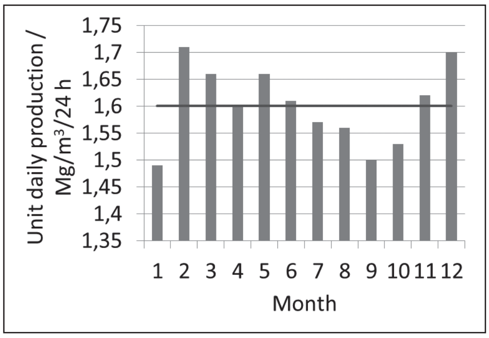

Figure 1 Value of unit daily production of pig iron

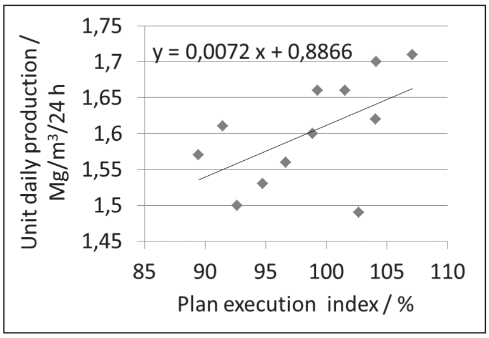

Figure 2 Unit daily production of pig iron vs. production plan execution

INTENSITY OF COMBUSTION OF COKE FOR RUNNING TIME

Intensity of combustion of coke for running time determines how much kg of coke, combustioned during the day, per 1 m^3 of useful volume of blast furnace it is calculated according to the formula [4, 12]:

$$J = \frac{C_d}{V_u}$$

where:
J – intensity of combustion of coke for running time in blast furnace / kg/(m^3·24h),
C_d – the amount of coke combustioned in the blast furnace during 24 hours / kg/24·h.

The results of analysis of variability are presented in Figure 3. It can be said that in month 2 value of this parameter exceeded 911, in months 3, 4 and 6 - 800 kg/(m^3·24h). The lowest value of this parameter was noticed in month 9 - 655 kg/(m^3·24h). This parameter was characterized by the highest variability. This situation was caused by many factors, among them, as it was for daily production of pig iron execution of production plan is the most important.

Analysis was carried out to determine that the increase in the plan execution index by 1 % resulted in increasing the intensity of combustion of coke for running time by approx. 7,91 kg/(m^3/24h) – Figure 4. In this case auxiliary calculations show a good fit of the regression function to the empirical data (standard errors below the level of 7 % of the studied phenomenon).

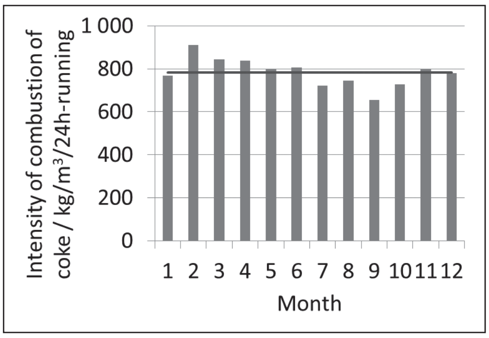

Figure 3 Value of intensity of combustion of coke for running time

Table 2 **Basic statistical characteristics of selected parameters of blast furnace**

Characteristics	Unit daily production of pig iron / Mg/24h/m³	Intensity of combustion of coke for running time / kg/24h/m³	Pig iron yield / %	Slag yield / Kg/1 Mg of pig iron	Utilization of calendar time index / %
Average	1,6	782,9	60,11	344,7	93,18
Standard deviation	0,07	63,93	0,56	13,33	2,98
Variation	6 %	8,2 %	0,9 %	3,9 %	3,2 %
Maximum value	1,71	911,9	60,96	363,47	97,88
Minimum value	1,49	655,3	59,28	321,95	88,45

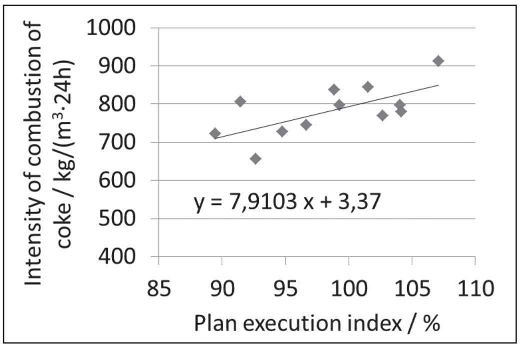

Figure 4 Intensity of combustion of coke for running time vs plan execution index

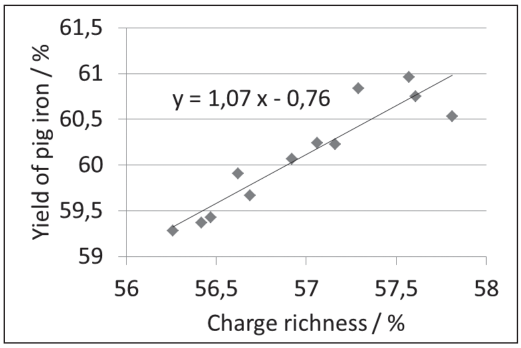

Figure 6 Yield of pig iron vs. charge richness

PIG IRON YIELD

Pig iron yield is a kind of parameter that determines the percentage of pig iron production that can be received from 1 Mg of ferruginous burden. It can be calculated according to the following formula [4, 12]:

$$Y_p = \frac{P}{B}$$

where:
Y_p – pig iron yield / %,
P – the level of pig iron production / Mg.
B – the amount of ferruginous burden used in production process / Mg.

The assessment of variability of this parameter was made (Figure 5), it shows that the level of this parameter was slightly under the average value, while from the month 5 increased and was higher, except month 8 and 12. This parameter was characterized by the lowest variability. It must be underlined that the level of this parameter depends mainly on the richness of ferruginous burden used in the production process.

The influence of the level of ferruginous charge richness on the yield of pig iron was calculated (Figure 6). It is possible to conclude that the increase in charge richness by 1 % resulted in increasing the yield of pig iron by approx. 1,07 %. Auxiliary calculations (e.g. Ve = 0.4 %) show a good fit of the regression function to the empirical data.

SLAG YIELD

Slag yield determines the amount of slag production that is produced during the manufacturing of 1 Mg of pig iron. It can be calculated according to the following formula [4, 12]:

$$Y_s = \frac{S}{P}$$

where:
Ys – slag yield / %,
S – the level of slag production / Mg.

The assessment of variability of this parameter was made (Figure 7). It can be said that on the beginning of the studied period the level of this parameter was under slight variability. The lowest values were noticed in the middle of studied period: in month 5 and 6 (325 kg/1 Mg of pig iron), while the highest in months 3 and 8 (363 kg/1 Mg of pig iron).

The influence of the level of ferruginous charge richness on the yield of slag in the studied period was calculated (Figure 8). The increase in ferruginous charge richness by 1 % resulted in decreasing the yield of slag by approx. 23,72 kg/1 Mg of pig iron. In this case auxiliary calculations show a good fit of the regression function to the empirical data (standard errors below the level of 7 % of the studied phenomenon).

UTILIZATION OF CALENDAR TIME

Utilization of calendar time index characterizes the level of use calendar time to produce pig iron [4, 12]:

$$U = \frac{T_w}{T_c}$$

where:
U - Utilization of calendar time index / %
T_c - Calendar time = theoretical time when the device can work (continuous mode);

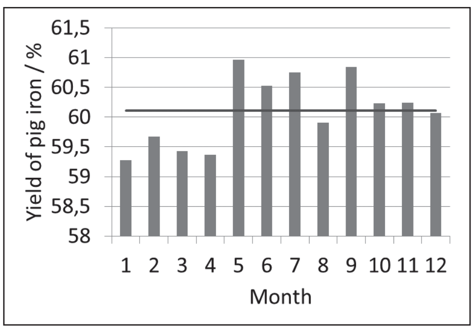

Figure 5 Value of yield of pig iron

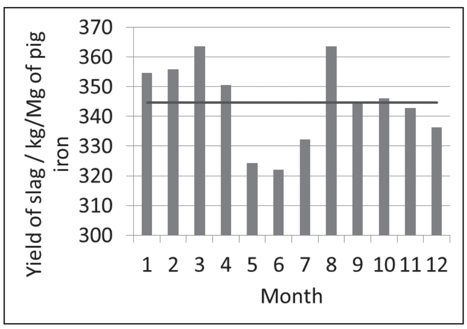

Figure 7 Value of yield of slag

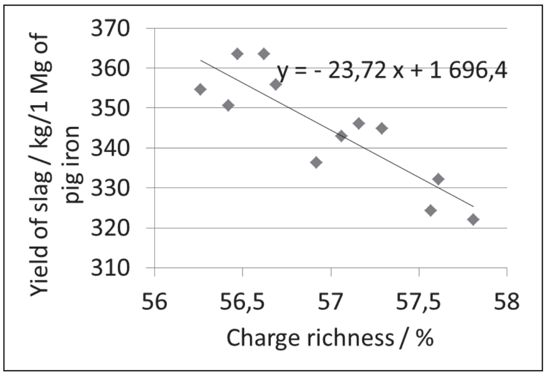

Figure 8 Yield of slag vs. charge richness

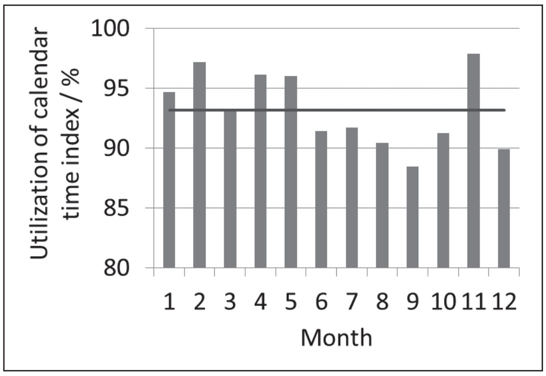

Figure 9 Value of utilization of calendar time index

T_w - Working time = calendar time - time of planned breaks - time of unplanned breaks.

The assessment of variability of this parameter was made (Figure 9). It can be said that on average 93 % of calendar time was used to produce pig iron. This parameter was characterized by slight variability (app. 3 %). The highest values were observed in month 11 (98 %) and 2 (97 %), while the lowest in month 9 (88,5 %). No trend can be observed in this parameter. The level of this parameter can be caused by many factors, among them total number of stops of device (planned and unplanned) is the most important.

The increase of total number of stops by 1 resulted in decreasing the utilization of calendar time index by approx. 0.98 % (Figure 10). Auxiliary calculations (standard error on the level of 2,6 % of the studied phenomenon, significance of the model explanatory variable) show a good fit of the regression function to the empirical data.

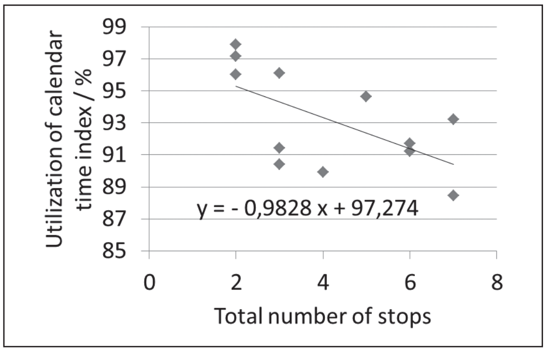

Figure 10 Utilization of calendar time index vs. total number of stops

CONCLUSION

The assessment of work effectiveness of each device, including blast furnace, is related to the assessment of its work parameters. Values of these parameters depend on many factors. The paper presents only selected dependencies. The analysis showed that the production plan execution influenced significantly on changes of parameters such us unit volume production and the intensity of the coke for running time, while charge richness – on changes of yield of pig iron and yield of slag. In case of utilization of calendar time index, total number of stops had the greatest influence. It should be remembered that the analysis includes only selected parameters and dependencies. In order to assess the effectiveness of this device fully, all parameters should be evaluated at the same time and the cost account should also be included.

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