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THE ASSESSMENT OF EFFICIENCY OF WORK OF BLAST FURNACE

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The paper presents results of the analysis of selected indicators used to assess the efficiency of blast furnace operation: running time operation, plan fulfilment, unit daily production of pig iron and the influence of these parameters on monthly pig iron production and intensity of coke combustion. 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, production management, linear regression method

INTRODUCTION

The blast furnace process has been in use for centuries and is still the most important iron making process worldwide. Driven by economical as well as ecological reasons, blast furnace iron making significantly advanced in the past decades. A number of changes and technological modifications have been made contribute to the competitive efficiency of modern blast furnaces - such as, among others: higher blast temperatures, elevated top gas pressure levels, enhanced burden distribution and sinter quality as well as the injection of hydrocarbons [1].

The effectiveness of ironmaking process in blast furnace can be characterized in different ways based on smelting rate, output productivity or fuel consumption [2]. It is also possible to assess the effectiveness using other indicators operating on a different, more general level (such as running time utilization or plan fulfilment). In process of production of pig iron even small changes in the operation of blast furnace can affect the cost [3, 4]. Therefore, a broad approach to analysing blast furnace operation is necessary, taking into account different perspectives and allowing – in the final analysis – to minimize process costs [5].

The paper presents the results of a study on the influence of various factors on the selected indicators used to assess the efficiency of blast furnace operation time. A number of other parameters for the operation of the blast furnace are presented in the publication [6].

THE ANALYSIS OF SELECTED EFFICIENCY PARAMETERS

The concept of efficiency in the literature is very broad and difficult to clearly define. The problem of efficiency is related, among others, to the principle of rational management of enterprise resources. In case of technical efficiency, it is maximizing production volume (or parameters of process) using certain volume of inputs. Many authors identify the efficiency with the production yield and productivity and determine as a measure related to production outputs to resources used for their formation [7]. The use of appropriate efficiency measures is a valuable skill for assessing the results of the production process in enterprise [8]. The paper presents the analysis of selected efficiency parameters for the blast furnace work.

For the analysis, data related to the work of one of two blast furnaces operating simultaneously in the steelworks were used. Presented results, on a monthly basis, cover the time of one calendar year.

Based on the collected data, presented the blast furnace operation time and production volume, three basic indicators used to assess the efficiency were calculated:

- Running time utilization – indicator used to assess participation of working time in the whole running time utilization:

$$\text{Running time utilization} = \frac{\text{Working time}}{\text{Running time}} \quad (1)$$

  Where:
  Running time = calendar time-planned downtime (current repairs),
  Working time = running time – unplanned downtime.
- Plan fulfilment – indicates what part of the production plan has been completed:

$$\text{Plan fulfilment} = \frac{\text{Production completed}}{\text{Production plans}} \quad (2)$$

- Unit daily production of pig iron = total daily production per $1m^3$ of the volume of blast furnace:

$$\text{Unit daily production} = \frac{\text{Daily production}}{\text{Useful volume of blast furnace}} \quad (3)$$

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Statistical analysis of these parameters were conducted. Next, the assessment of variability of parameters was made. Results of the analysis are presented in Table 1 and Figures 1 – 3.

• did not exceed 4 %.

Table 1 **Basic statistical characteristics of selected parameters of blast furnace**

Characteristics	Running time utilization / %	Plan fulfilment / %	Unit daily production of pig iron / Mg/24h/m^3
Average	95,05	95,6	1,6
Standard deviation	2,308	3,57	0,07
Variation	2,43%	3,74%	6 %
Maximum value	97,75	102,18	1,71
Minimum value	89,47	89,18	1,49

According to the results presented in Table 1 it can be said that:

- Averages values of running time utilization and plan fulfilment indexes was very high and exceed 95 %. Average unit daily production was 1,6 Mg/24h/m^3 and it was much lower than similar devices in the world.
- All parameters went slight fluctuations, coefficient of variation exceeded 6 % for unit daily production of pig iron, for next two parameters did not exceed 4 %.

Analysing the results presented in Figure 1, it can be stated that index values were high, only in one month value was lower than 90 %. It oscillated between 89,5-97,5 %. Running time is theoretical time which the device can work. However, unplanned downtime often occurs due to current failures. This effects on the level of use of running time. A large number of breaks were also caused by problems with reception of pig iron. It was related to the reduced demand for pig iron by steel plant that is the main recipient of this product. Technological breaks were also a problem.

Analysing the values of plan fulfilment index (Figure 2) it can be seen that plan was done at the high level, usually bigger than 90 % (only in month 9 it decreased to value ap. 89 %). Difference between production

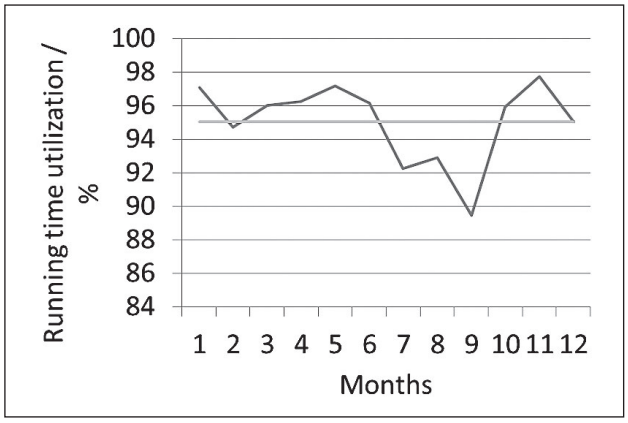

Figure 1 Value of running time utilization of blast furnace in the study period

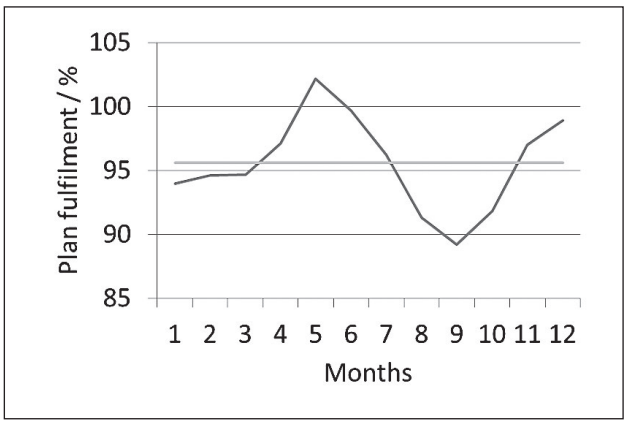

Figure 2 Value of plan fulfilment of blast furnace in the study period

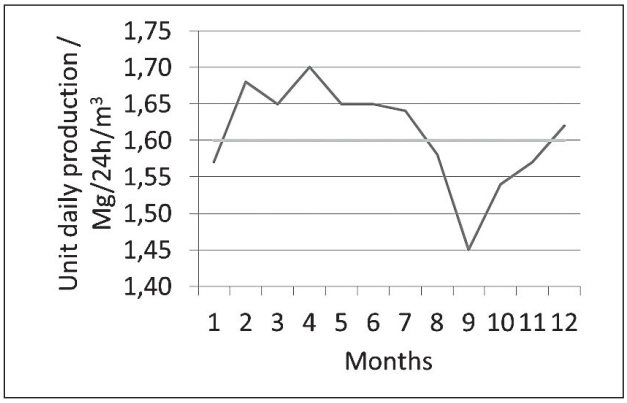

Figure 3 Value of unit daily production of pig iron in the study period

planned and completed was on the average of 4 %. The analysis showed that usually company had problem with execution of plan of production. Only in month 5 production was higher than plan.

The elements causing problems with execution of production plans include: the problem of the demand for pig iron from the steel plant, breaks in the operation of the device, the quality of ferrous materials, quality and types of fuels and device operation parameters.

Based on results presented in Figure 3, it can be concluded that values of unit daily production of pig iron was on the average level of 1,6 and was varied and ranged within 1,45-1,70 Mg/24h/1m^3. The difference may seem to be small. It should be remembered that the tested object was app. 3 200m^3 of volume, what indicates difference in daily production of whole device on the level of several hundred Mg. The reasons of this diversity can be caused by many factors, which include: problems with fulfilment of production plan, level of parameters of process or quality of used materials (ferrous materials and fuels).

THE INFLUENCE OF SELECTED PARAMETERS ON MONTHLY PRODUCTION OF PIG IRON

Efficiency parameters analysed in the paper have great influence on two main factors that measure the results of blast furnace work. One of main factors is

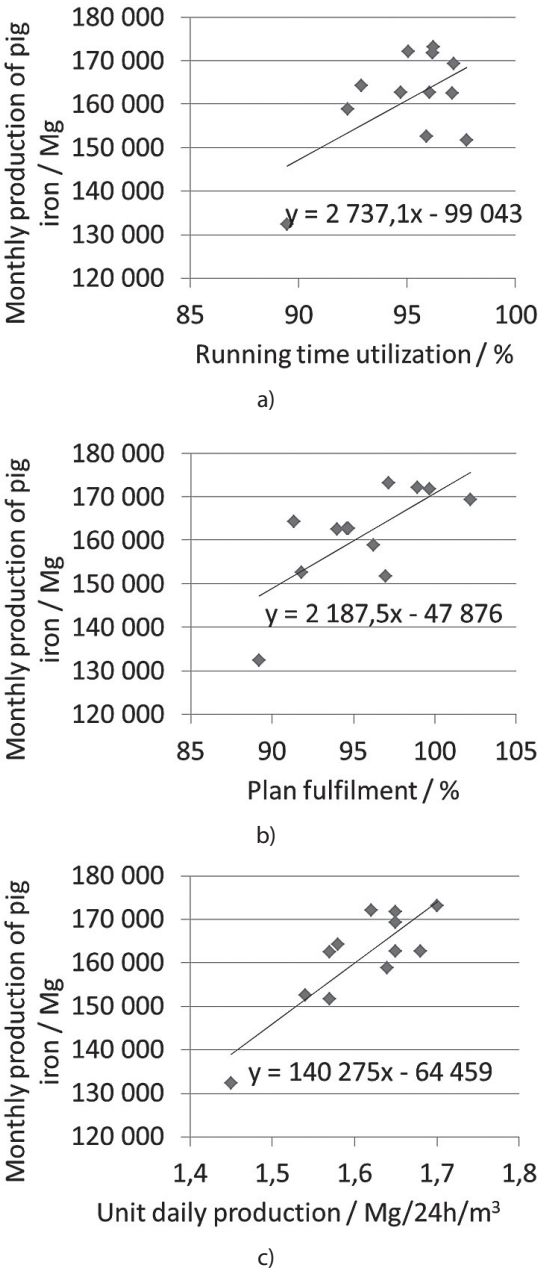

Figure 4 Linear dependence of monthly production of pig iron on: a) running time utilization, b) plan fulfilment, c) unit daily production

monthly production of pig iron. The effects of efficiency of parameters on monthly production of pig iron is presented in Figure 4 and Table 2.

Table 2 **Auxiliary calculations for the regression functions of monthly production of pig iron**

Parameter	Running time utilization	Plan fulfilment	Unit daily production
S	9 895,11	8 504,315	6 387,9
V	6,14%	5,27%	3,96%
F	4,89	10,16	25,73
Ist - F	0,0514	0,00969	0,000483

where: S – standard error, V - coefficient of residual variation, F - the value of the Wald test for the significance of the independent variable, Ist-F - probability value of F.

Results of the analysis presented in Figure 4 and Table 2 allow to conclude that auxiliary calculations for all functions show a good fit of the regression functions to the empirical data. Values of standard errors were very low (under 7 %) and the model explanatory variable are significant.

All regression functions show positive dependences. Increasing running utilization time by 1 % resulted in monthly production of pig iron by app. 2 737 Mg while increasing plan fulfilment by 1 % resulted in increasing monthly production of pig iron by app. 2 187 Mg. When it comes to unit daily production of pig iron, the increasing value of this parameter by 1 Mg/24h/m^3 resulted in increasing monthly production by 140 275 Mg.

THE INFLUENCE OF SELECTED PARAMETERS ON INTENSITY OF COMBUSTION OF COKE

The effects of efficiency of parameters on intensity of combustion of coke were calculated. The results of analysis are presented in Figure 5 and Table 3.

Based on Results of the analysis presented in Figure 4 and Table 2 it can be said that auxiliary calculations for all functions show a good fit of the regression functions to the empirical data. Values of standard errors were very low (under 8 %) and the model explanatory variable are significant.

Also in this case, all regression functions show positive dependences. Increasing running utilization time by 1 % resulted in intensity of combustion of coke by app. 13,5 Mg/24h/m^3 while increasing plan fulfilment by 1 % resulted in increasing intensity of combustion of coke by app. 6,6 Mg/24h/m^3. When it comes to unit daily production of pig iron, the increasing value of this parameter by 1 Mg/24h/m^3 resulted in intensity of combustion of coke by 511,43 Mg/24h/m^3.

Table 3 **Auxiliary calculations for the regression functions of intensity of combustion of coke**

Parameter	Running time utilization	Plan fulfilment	Unit daily production
S	29,84	37,29	25,79
V	4,28%	5,35%	3,71%
F	13,13	4,92	20,97
Ist - F	0,0046	0,052	0,001

CONCLUSION

The analysis of selected parameters of operation of blast furnace allowed to assess the efficiency of its work. Three selected indicators were analysed: running time utilization, plan fulfilment and unit daily production of pig iron. This allowed to state that high values (over 95 %) were obtained for running time utilization and plan fulfilment. The value of unit daily production was at the average level, it was app. 1,6 Mg/24h/m3 and was slightly lower than optimal value for similar devices. In all cases only slight variation was noticed.

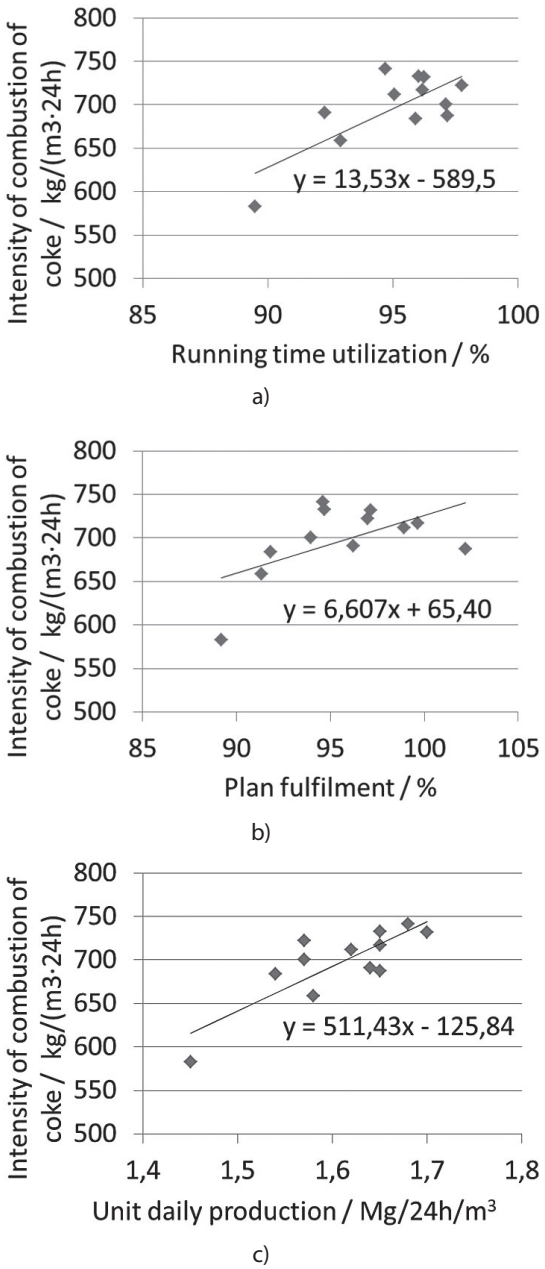

Figure 5 Linear dependence of intensity of combustion of coke on: a) running time utilization, b) plan fulfilment, c) unit daily production

The main factors affecting the values of this indicators were:

- unplanned downtime (often occurs due to current failures),
- reduced demand for pig iron by steel plant,
- technological breaks,
- the quality of ferrous materials,
- quality and types of fuels,
- level of parameters of process.

The assessment of dependence of monthly pig iron production and intensity of coke combustion allowed to confirm that values of these parameters are significantly important for the efficiency of blast furnace operation. The increase of the value of these parameters caused the increase in the monthly production volume and intensity of coke combustion.

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