IDENTIFICATION OF FACTORS CAUSING NITRIDATION OF CRUDE STEEL IN BOF BEFORE TAPPING

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Abstract
Determination of factors and measuring their impact on the amount of nitrogen in the metal is key attribute when optimizing technological and operational measures tending to minimize, respectively prevent of the final steel nitridization. Knowing the rate of influence of individual factors on the nitrogen content in the metal is crucial in dealing with prediction of the quantity for the production and processing stages of steel production in a closed production cycle. In this paper, factors determining nitrogen content in crude steel before tapping, using Cohen´s distribution table and graphical expression are presented. Influence of after-blows on nitrogen content is well known, but there are other factors which affect steel nitridization before tapping from oxygen converter.

Keywords: nitrogen, crude steel, basic oxygen furnace, factors of nitridization

1 Introduction

Nitrogen in steel causes brittleness of ferritic steels. Dissolution of nitrogen as well as other diatomic gases in the liquid steel can be described by equation (1):

$$\frac{1}{2}\{N_2\}=[N] \tag{1}$$

while its content may be defined by Sievert´s law (2):

$$\%[N]=k_N\,(P_{N_2})^{\frac{1}{2}} \tag{2}$$

The content of dissolved nitrogen depends on the root of the partial pressure [1]. This is given by the fact that diatomic gases are creating with metal an atomic solutions. When gas molecules are dissolved in the metal, they dissociate into atoms, so the number of atoms dissolved in the metal is twice than the number of initial molecules [2]. Sieverts law cannot be applied when the gas reacts chemically with the metal. Nitrogen solubility is also affected by the other elements in the steel [2, 3].

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In spite of listed above, in practice, the prediction of nitrogen content in steel is complicated in view of the fact that its content is influenced by significant amount of active factors [4, 5].
The nitrogen content in the final steel depends largely on the type of process [6]. In the basic oxygen furnace it depends mainly on pollution of blowing oxygen, while at high temperature in blowing area (over 2000°C)[7], the distribution reaches equilibrium of nitrogen between gas and metal is at 0.002 to 0.005 %. In the EAF, with the active effect of the electric arc, level of nitrogen content in the metal at 0.007 to 0.012%. For the identified nitrogen sources is considered nitrogen coming with pig iron, scrap, ferroalloys and coke [5]. Moreover, the presence of nitrogen in the oxygen used in a Q-BOP and BOP has also resulted in increased levels of nitrogen [8, 9]. There is also a greater probability of higher levels of nitrogen in liquid steel when after-blow is performed [10, 11, 12]. The main goal of this paper is to analyse the various factors affecting the nitrogen content of crude steel produced by LD process.

2 Experimental conditions and materials

Nitrogen content in crude steel was investigated in basic oxygen furnace before tap. The samples were taken from crude steel. Presence of dissolved nitrogen was analyzed in the samples.
The results of the nitrogen content in the metal were synchronized with the databases that contain information about the chemical composition of the metal, metal temperature, metal weights and other parameters, which were held on the stage of the manufacturing process, based on heat number and marking the point of taking samples.
In general, 66 samples of crude steel were taken there. Results of nitrogen contents in samples were synchronized with several databases according to heat number. These databases contained information about chemical contents, temperature and weight of steel and other responsive parameters.

2.1 The method for determining the factors

The statistical data processing was performed using the Statistica 7 made by Statsoft. All analysed factors were implied in the correlation matrix, by which quantitative dependence can be identified when changing one variable leads to changes in other variables. The function that expresses this dependency is called regression function. According to the regression function shape, we can define a positive and negative correlation. The increasing regression function means positive correlation dependence and decreasing regression function means the negative correlation dependence. The correlation coefficient for the statistical file is in a closed interval ⟨–1,1⟩. When linear correlation between ξ a η is tighter, the coefficient of correlation is approaching value near 1.
The correlation coefficient R measures the strength of the statistical dependence between two quantitative variables. The term correlation coefficient is most commonly found as Pearson correlation coefficient (3) [13].

$$R_{xy} = \frac{\sum x_i y_i - n\bar{x}\bar{y}}{(n-1)s_x s_y} \tag{3}$$

Where: n number of measured parameters
X, Y parameters, which can be written as x_i and y_i, where i = 1, 2, 3, ..., n
$\bar{x}$, $\bar{y}$ average values of parameters X and Y
s_x, s_y standard divergence of parameters X and Y

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Based on equation (1), the order of factors can be determined, that have the highest impact on the amount of nitrogen in every phase of the steel production in closed cycle. Interpretations of the correlation coefficient R depends on the context and nature of the processed data. Value of 0.8 for the verification of a physical law using precision measuring instruments is very low but in the social sciences is it very high [13]. Jacob Cohen created a simple tool for the interpretation of correlation coefficients for a research work [14] (**Table 1**).

Table 1 Interpretation of correlation coefficients

Correlation coefficient	Description
0 – 0.1	trivial, very small, close
0.1 – 0.3	a little, low
0.3 – 0.5	moderate
0.5 – 0.7	big, high
0.7 – 0.9	very big, very high
0.9 – 1	perfect, clear

The value of R^2 (4) is called the coefficient of determination and expresses the ratio of common variability between two variables. Achieved value of R^2 significantly depends on the nature of the processed data. The interpretation of obtained values of coefficient of determination depends mainly on the nature of the analyzed data.

$$R_{xy}^2 = 1 - \frac{s_{y|x}^2}{s_y^2} \quad \text{or} \quad R_{xy}^2 = 1 - \frac{s_{x|y}^2}{s_x^2} \tag{4}$$

Where: $s_{x|y}^2$, $s_{y|x}^2$ quadratic error of linear regression
s_x^2 , s_y^2 spread of the value *x* or *y*.

3 Results and discussion

Based on the correlation matrix generated using Statistica 7 ranking factors were compiled which impact on the final nitrogen content in the given production stage. By combining the results of the correlation analysis and empirical experiences can it be possible to choose the most powerful agents, in which the following complex statistical operations represented variables. A positive correlation coefficient reflects an increase in the nitrogen content increasing examined parameter.

In **Table 2,** the sequence of the most important factors affecting the nitrogen content in the crude steel after oxygen converter process is presented. The results of the regression analysis were obtained from the correlation matrix using the Statistica 7.

Based on Cohen's distribution correlation coefficients could be interpreted as small to medium. However, it is necessary to appeal to the non-stationary nature of the data of the integrated system and the fact that it is an operational data, where the great success was achieved by the moderate correlation coefficients.

On the **Fig. 1** to **Fig. 5,** effects of some parameters from **Table 2** on the resulting nitrogen content in the steel after steel making process in oxygen converter in a closed production cycle are graphically expressed.

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Table 2 The sequence of the factors affecting the nitrogen content in the crude steel after oxygen converter process before tapping

Order of effects	Factor	Correlation coefficient R	Determination coefficient R^2
1.	After-blow [s]	0.4291	0.1842
2.	Manganese content in steel [%]	– 0.3017	0.0910
3.	Phosphorus content in steel [%]	– 0.2339	0.0547
4.	Carbon content in steel [%]	– 0.2055	0.0422
5.	Briquettes [kg]	– 0.1594	0.0254
6.	Tapping temperature [°C]	0.1457	0.0212
7.	Time of oxygen blowing [s]	– 0.1314	0.0173

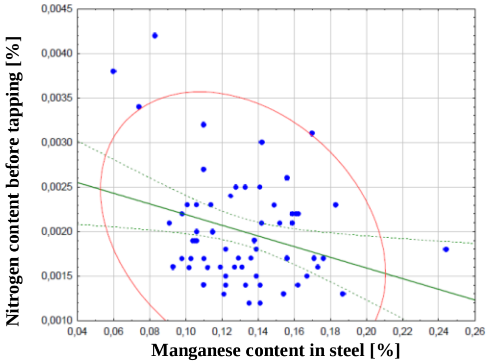

Fig.1 The influence of manganese content in steel on nitrogen content before tapping

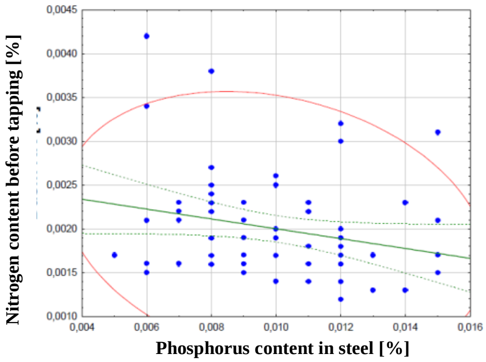

Fig.2 The influence of phosphorus content in steel on nitrogen content before tapping

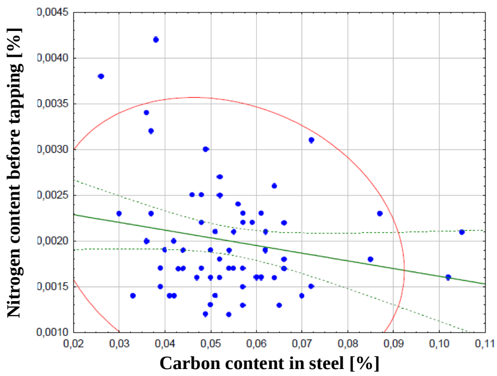

Fig.3 The influence of carbon content in steel on nitrogen content before tapping

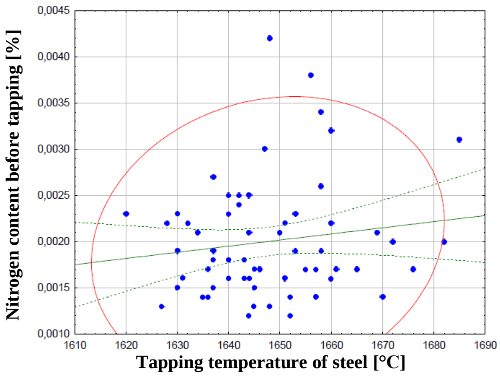

Fig.4 The influence of tapping temperature of steel on nitrogen content before tapping

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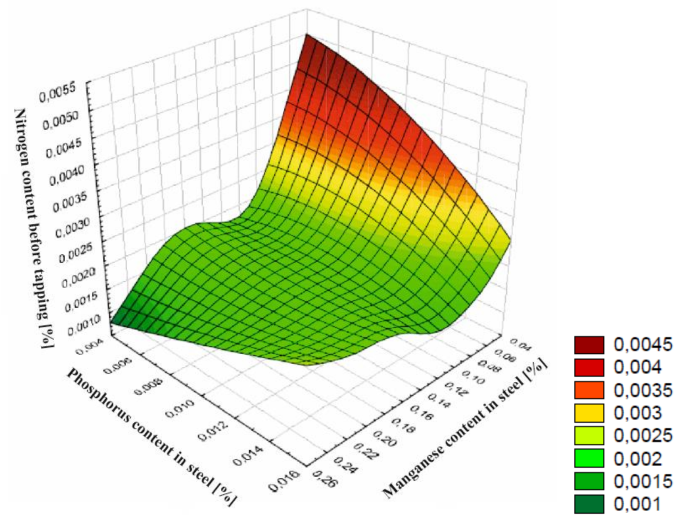

Fig.5 The influence of phosphorus and manganese content in steel before tapping on nitrogen content in crude steel

With the increasing number of after-blow, the nitrogen content in the steel increases as shown in **Fig. 6** as an example of another series of experiments. After-blow is performed if the chemical composition is not sufficient for the required steel grade.

An investigation was conducted on a set of 699 statistical data of heats for the period from 01.2010 to 03.2011. Average nitrogen content was calculated according to the number of after-blows (Fig.6).

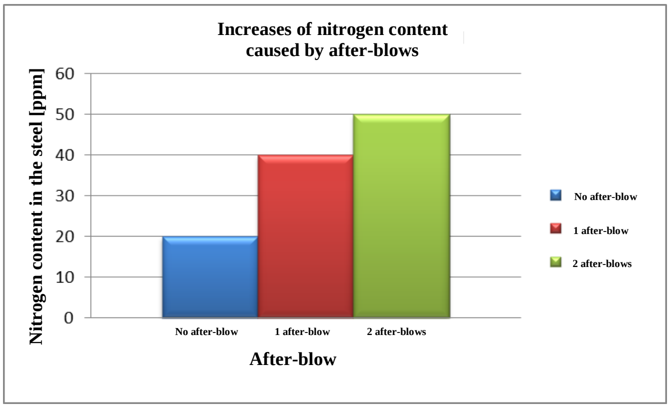

Fig.6 Influence of after-blow on nitrogen content in the steel

The nitrogen content in heats without after-blow is approximately 20 ppm. When one after-blow is performed, the nitrogen content is 40 ppm. Two after-blows cause increasing nitrogen content in steel to approximately 50 ppm.

The green prediction interval ellipse shows the area where are 95 % of all points. Two red dashed lines are showing the confidence interval for the regression line and confidence interval around the regression line are shown for the regression line.

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On the **Fig. 7**, there is a histogram of nitrogen activity and on the **Fig. 8**, there is a histogram of nitrogen content in steel before tapping from converter. Activity of nitrogen is determined on the basis of known chemical composition and activity coefficients according to [15, 16, 17].

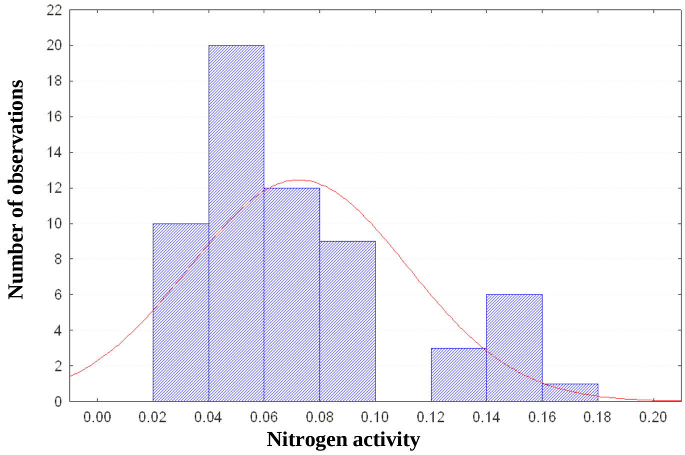

Fig.7 Histogram of nitrogen activity in steel before tapping from converter

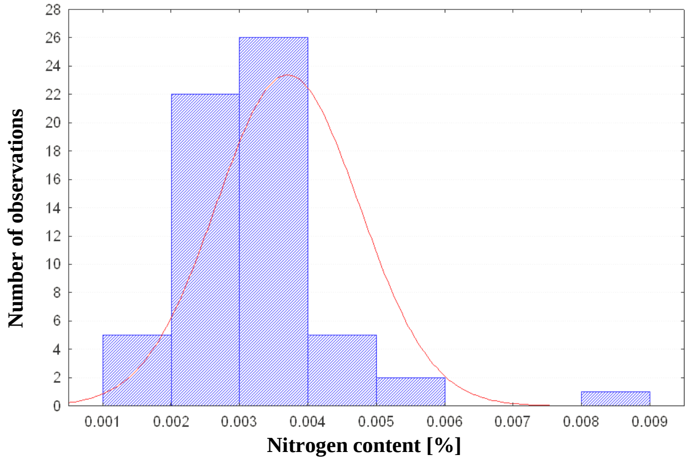

Fig.8 Histogram of nitrogen content in the observed heats

Conclusions

Identification of factors affecting the nitrogen content in crude steel before tapping from oxygen converter helps to determine the source of nitrogen. Knowledge of the level of influence of individual factors helps to create and correct existing production processes with reduction the nitrogen content in steel.

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