The analysis of the steel deoxidation process in a vacuum installation

IOP Conf. Series: Materials Science and Engineering **163** (2017) 012025 doi:10.1088/1757-899X/163/1/012025

The analysis of the steel deoxidation process in a vacuum installation

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Abstract. The oxygen is an element which has adversely affect to the steel quality because it causes embrittlement at high temperature, evidenced by the increased susceptibility on overheating and the appearance of cracks during deformation plastic, respectively by determining the appearance of the gas holes during castings solidification of products. As a result from a technological point of view, in industrial practice shall be adopted a series of measures that are intended to ensure a low oxygen content (recommended below 40ppm). The paper presents a few practical data taken from the industry in relation to the manner in which it is influenced the content of oxygen according with the vacuum parameters and the steel temperature. The resulting correlations, presented in both form graphical and analytical, are a real benefit to the industry, so can be determined a parameter depending on the other two.

1. Introduction

Deoxidation is the metallurgical process for removing oxygen from molten steel. The oxygen solubility in the molten steel decreases with decreasing of temperature, when the excess of oxygen are separated from solution in the form of oxide products - oxide phase, which will be found on the edge of the crystalline grains in the solidified steel [1], [2]. These compounds can form eutectic phases that can determine embrittlement of steel (cannot be plastically deformed). At medium oxygen contents, the steel presents lower mechanical characteristics (resilience), lower corrosion resistance and greater tendency to aging [1-4].

Steel deoxidation process is done through the following methods: precipitation (by using ferroalloys), diffusion (by using reducing or synthetic slag) - in the furnace [5] or in the secondary treatment aggregate [6], [7], and using a vacuum [8]. By using vacuum steel deoxidation, can be obtained grade steels with high purity.

Steel vacuum treatment aims to reduce the oxygen, hydrogen and nitrogen content in liquid steel, decreasing the content of nonmetallic inclusions as a result of accelerating of the settling process, respectively chemical and thermal homogenization of steel. All these metallurgical effects lead to improved physic-mechanical properties of the steel [9].

The vaccum deoxidation can be made on the folowing methods:

- Ferrous oxide dissociation through reaction:

$$[FeO] = [Fe] + \tfrac{1}{2}\{O_2\} \quad (1)$$

- Volatilization of oxides dissolved in the steel:

$$[MeO] \rightarrow \{MeO\} \quad (2)$$

- With carbon:

$$[C] + [O] = \{CO\} \tag{3}$$

The first two ways have not a practical importance for steelmaking, instead the third (known as self-deoxidation reaction with carbon) have a special importance because, through this, the oxygen dissolved in the steel bath it is transferred, in the gas phase. Carbon vacuum deoxidation is possible by the fact that the decreasing of the pressure increases the intensity of the carbon deoxidation (decreases the content of oxygen in equilibrium with the carbon) [1], [2]

The equilibrium constant of this chemical reaction is expressed as follows:

$$K_c = \frac{p_{CO}}{a_C \cdot a_O} = \frac{p_{CO}}{f_C \cdot f_O \cdot [\%C] \cdot [\%O]} \tag{4}$$

where: p_{CO} - partial pressure of carbon monoxide in the atmosphere;

a_C and a_O - activities of carbon and oxygen in liquid steel;

f_C and f_O – activities coefficients of carbon and oxygen in liquid steel;

[%C] and [%O] – content of carbon and oxygen in liquid steel [1], [2]

At the 1600°C steel temperature and 1 atm - partial pressure of carbon monoxide [10], the equation (4) became:

$$[\%C] \cdot [\%O] = 0.0025 \tag{5}$$

2. Experimental data's

To analyse how the deoxidation process in a vacuum installation is realized, were analysed a total of 17 charges of steel S 355 JO brand (according to EN 10025). It is noted that the charges were prepared in an electric arc furnace (EBT type), treated in the secondary treatment of LF. From there, the ladle with liquid steel was introduced into vacuum installation (VD) and finally, the steel was continuously cast – as is presented in Figure 1.

Figure 1. The main equipment's used in steel works

Were selected for analysis and further correlations the following parameters: the oxygen content, the duration of vacuum respective high vacuum treatment, steel temperature at the entering the VD facility and temperature drop during the treatment and, not least, the argon flow rate, used in the liquid steel stirring.

3. Results analysis

After data's processing, have been obtained correlations expressed by polynomial functions of 3 and 4 degrees, respectively exponential and logarithmic; but given the closer value for correlation coefficients and simplest form of correlations represented by polynomial functions of second degree, only these were presented. The correlation equations that define the upper and lower variation domain for each correlation are presented. The correlations presented are representative in terms of the values of correlation coefficients, and in the technological sense, all is presented in graphical and analytical form [11].

Regarding the duration of steel vacuum treatment (Figure 2) and high vacuum treatment (Figure 3), is established that with the increasing of these times, it ensures a decrease in oxygen content [1], [2], [12].

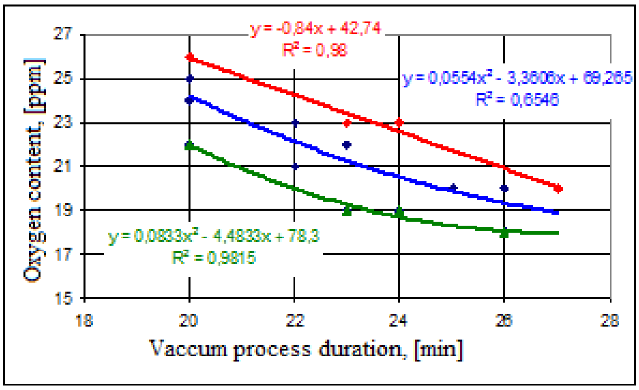


Figure 2. Correlation between oxygen content and the vacuum process duration

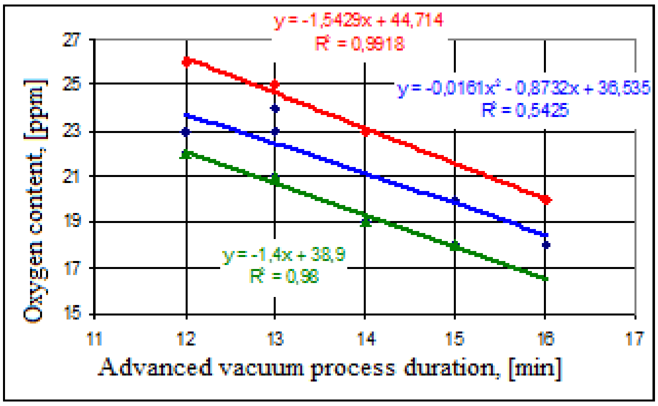


Figure 3. Correlation between oxygen content and the advanced vacuum process duration

A vacuum time treatment varies between 20 to 27 minutes, and the oxygen content of 26-18 ppm. Duration of high vacuum treatment was within 12-16 minutes. Desirable as the duration for the two phases of vacuum cycle should be as close as possible to the maximum duration, but it should be kept in mind that the vacuum system is without any heat input, which limits the duration of treatment (the temperature should not fall below a certain value). Mentioned that by using the superior quality refractory materials for ladle (resistant to steel and slag corrosion activity and advanced thermal insulation capacity) allows increase the vacuum duration from 15 min to 26 min.

The temperature of the steel at the entrance in the plant facility, is situated at the upper limit of the technical variation domain, steel is more fluid, so it provides good conditions for mixing by argon bubbling of the metal bath and the possibility of a larger decreasing of temperature during the vacuum treatment, respectively an increasing of the time of this operation. As a result of these presented data, is confirmed that with increasing values for steel temperature at entrance in the vacuum facility, the steel oxygen content is decreasing (Figure 4) and also with higher values of temperatures drop, the steel oxygen content is decreasing (Figure 5).

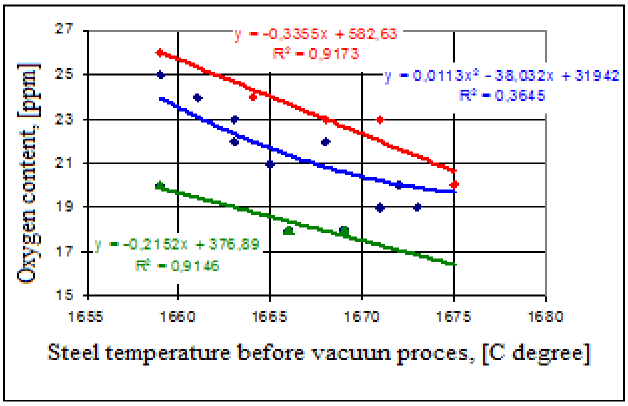


Figure 4. Correlation between oxygen content and the steel temperature before vacuum process

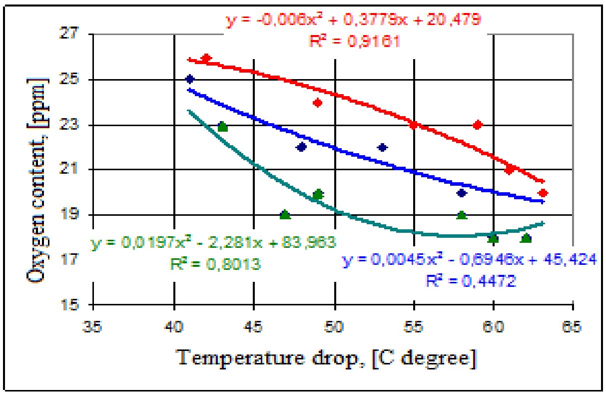


Figure 5. Correlation between oxygen content and the temperature drop

A particular importance for the steel treatment technologies in the ladle ("Ladle Metallurgy") has the process of chemical and thermal mixing of the metal bath, which is achieved in most cases by of inert gas stirring (usually argon, less by electromagnetic stirring) [13]. From the correlation presented in Figure 6 results that with the increasing of argon flow rate it is made a reduction in oxygen content, which is explained by increasing technological surface interphase steel-gas, so the surface diffusion of steel-argon bubbles. The minimum value of the oxygen content from correlation is by (5.40; 18.70) and for correlation that representing the lower limit of the variability, the minimum point has coordinates (3.29; 16.01); therefore can be considered that the argon flow rate should not be increased (there is a risk of slag entrainment in the steel, on the one hand, and on the other hand, an increasing of ladle refractory erosion). Maximum flow rate of argon, recommended by technological instructions, is 5 l/to.min.

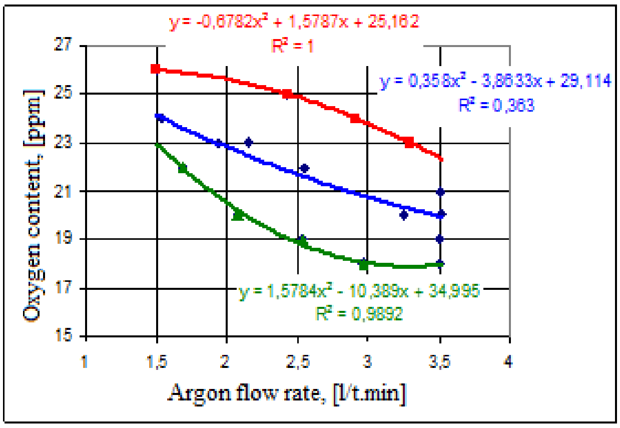
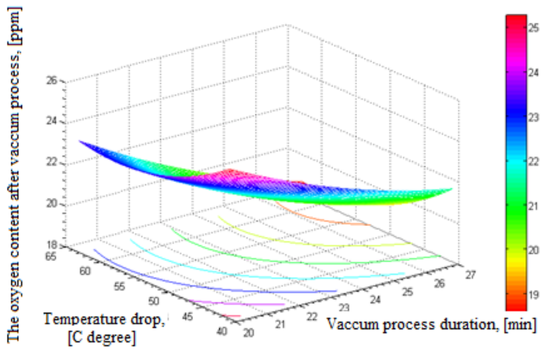
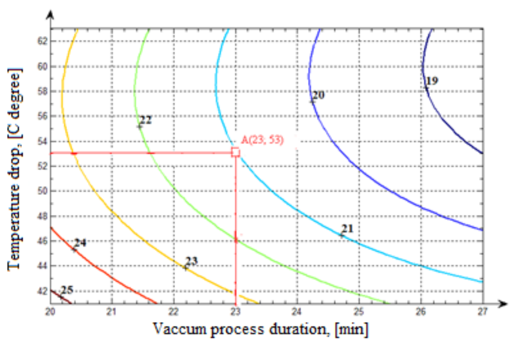


Figure 6. Correlation between oxygen content and the argon flow rate

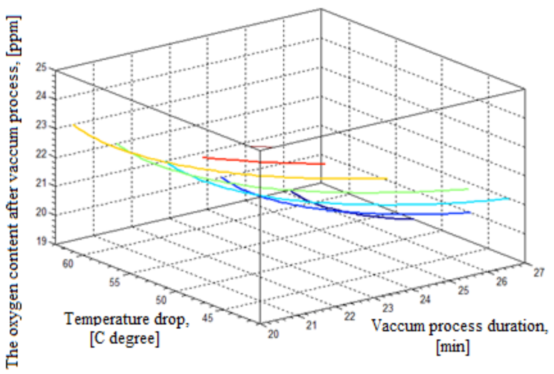
The data has been processed in MATLAB computing program, in Figures 7-14 are presented the correlation surfaces, the plane representation of the level curves and the spatial representation of the level curves. Also, are presented the correlation equations between oxygen content - as a dependent parameter and, as independent parameters: vacuum process duration, vacuum process duration under high vacuum, steel temperature, temperature drop during the vacuum cycle, the argon flow rate.



1) The correlation surface



2) Plane representation of the level curves



3) Spatial representation of the level curves

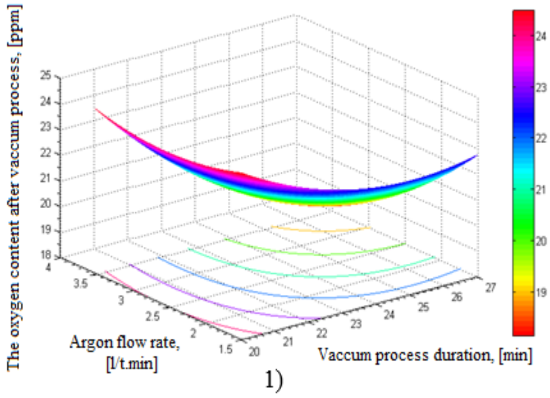
Figure 7. The oxygen content after vacuum process depending on the process duration and temperature drop

The correlation equation is:

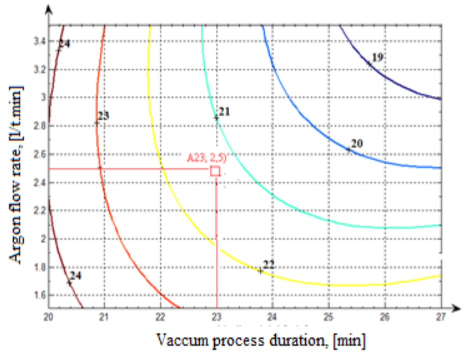
$$Q_{O2}= 0.037001\cdot D_v^2+0.007779\cdot \Delta T^2-0.006621\cdot D_v\cdot \Delta T- 2.006263\cdot D_v-0.760839\cdot \Delta T+ 74.142629 \quad (6)$$

The correlation coefficient is:

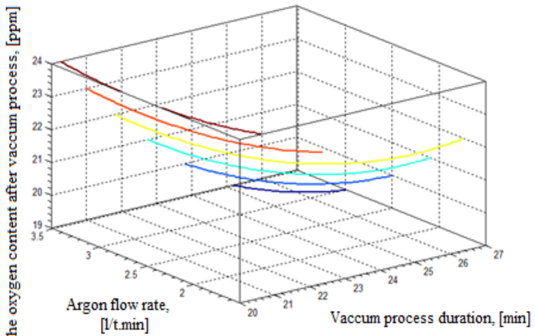
$$R^2= 0.854582$$



1)
The correlation surface



2)
Plane representation of the level curves



3)
Spatial representation of the level curves

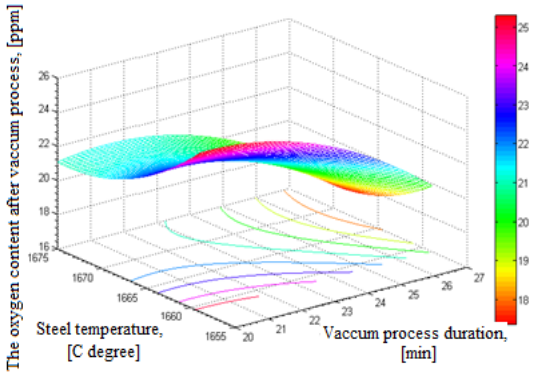
Figure 8. The oxygen content after vacuum process depending on the vacuum process duration and argon flow rate

The correlation equation is:

$$Q_{O2}= 0.081470 \cdot D_v^2+0.454855 \cdot Q_{Ar}^2-0.319134 \cdot D_v \cdot Q_{Ar}-3.598831 \cdot D_v+ 4.055380 \cdot Q_{Ar} +66.342935 \quad (7)$$

The correlation coefficient is:

$$R^2= 0.848899$$



1)
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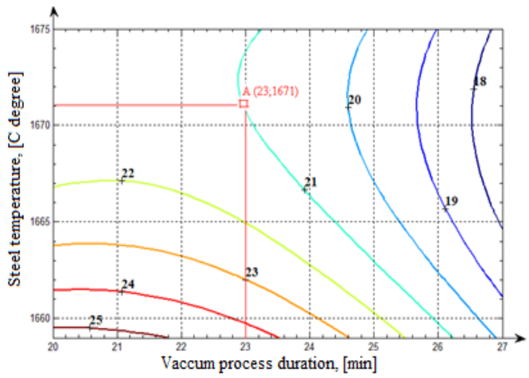
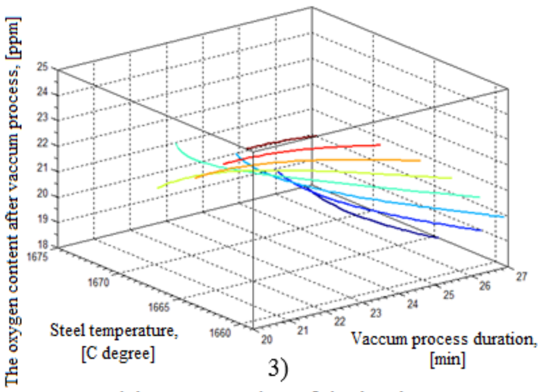


2)
Plane representation of the level curves



3)
Spatial representation of the level curves

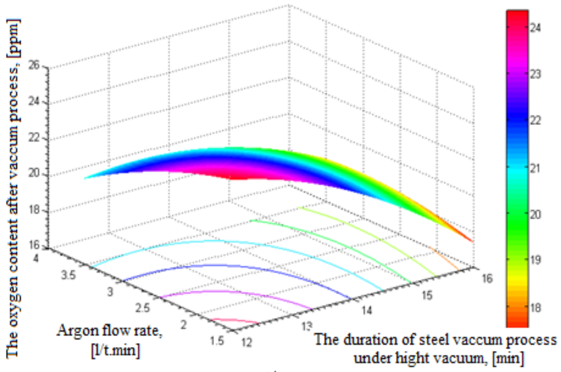
Figure 9. The oxygen content after vacuum process depending on the steel temperature and the vacuum process duration

The correlation equation is:

$$Q_{O2}= -0.118565 \cdot D_v^2+0.019332 \cdot T^2+0.019183 \cdot D_v \cdot T-27.029464 \cdot D_v-65.099306 \cdot T + 54769.241855 \quad (8)$$

The correlation coefficient is:

$$R^2= 0.867153$$



1)
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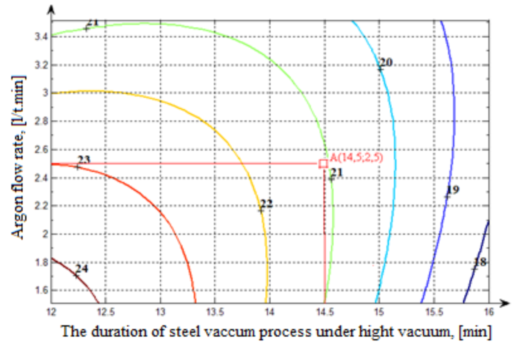
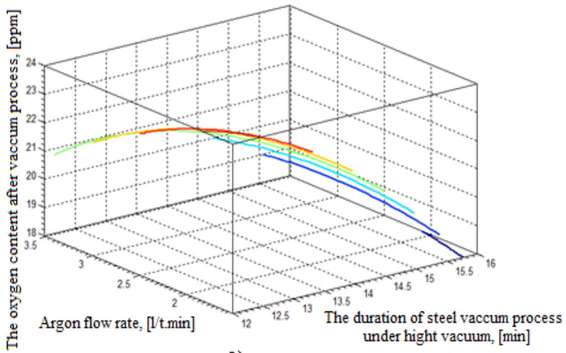


2)
Plane representation of the level curves



3)
Spatial representation of the level curves

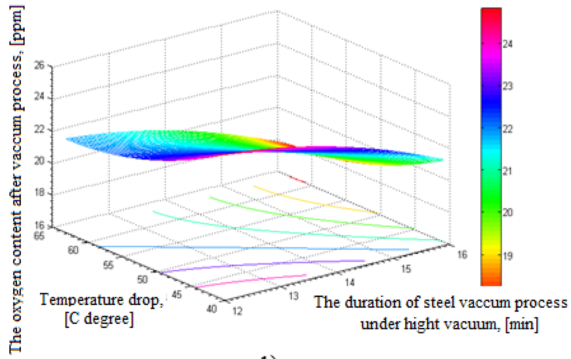
Figure 10. The oxygen content after vacuum process depending on the argon flow rate and the duration of steel vacuum process under high vacuum

The correlation equation is:

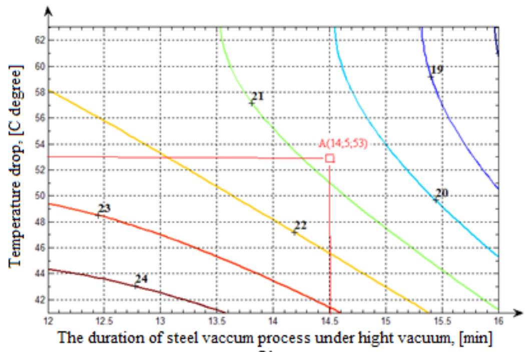
$$Q_{O2}= -0.272637 \cdot D_{a.v}^{2} - 0.434313 \cdot Q_{Ar}^{2} + 0.5687389 \cdot D_{a.v} \cdot Q_{Ar} + 5.029522 \cdot D_{a.v} - 6.443282 \cdot Q_{Ar} + 3.659968 \qquad (9)$$

The correlation coefficient is:

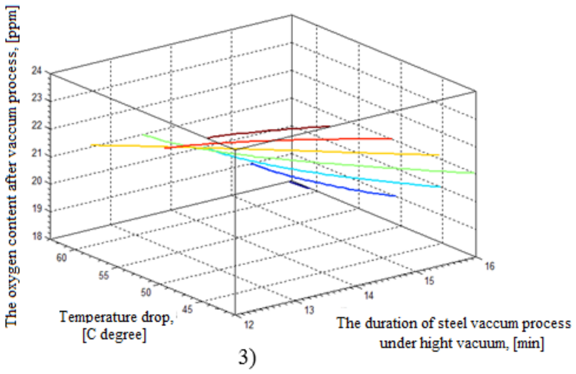
$$R^2 = 0.777176$$



1)
The correlation surface



2)
Plane representation of the level curves



3)
Spatial representation of the level curves

Figure 11. The oxygen content after vacuum process depending on the temperature drop and the duration of steel vacuum process under high vacuum

The correlation equation is:

$$Q_{O2}= -0.171459 \cdot D_{a.v}^{2} + 0.005995 \cdot \Delta T^{2} - 0.001519 \cdot D_{a.v} \cdot \Delta T + 3.922981 \cdot D_{a.v} - 0.740859 \cdot \Delta T - 23.483942 \qquad (10)$$

The correlation coefficient is:

$$R^2 = 0.809316$$

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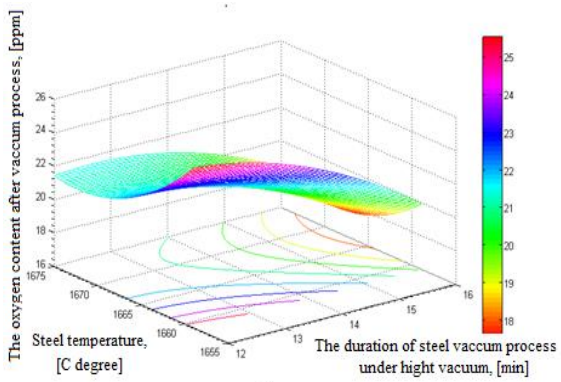

1)
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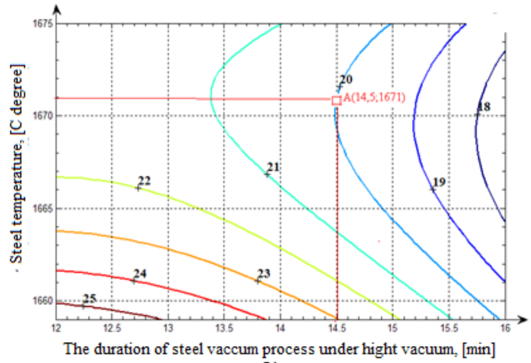
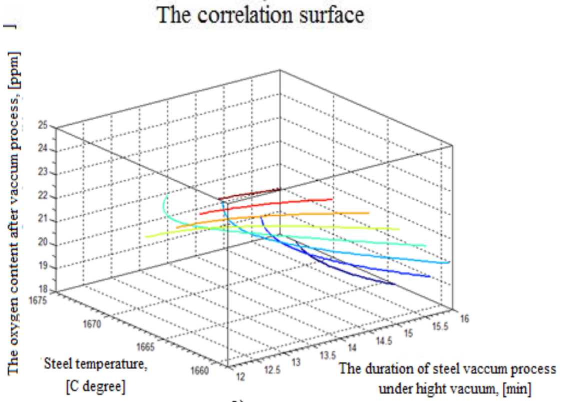


2)
Plane representation of the level curves



3)
Spatial representation of the level curves

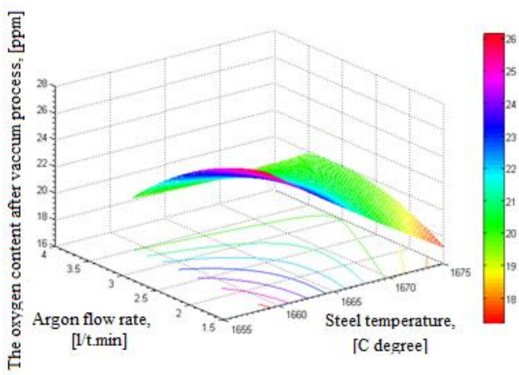
Figure 12. The oxygen content after vacuum process depending on the steel temperature and the duration of steel vacuum process under high vacuum

The correlation equation is:

$$Q_{O2}= -0.276601\cdot D_{a.v}^{2}+0.024543\cdot T^{2}+0.041170\cdot D_{a.v}\cdot T - 61.973022\cdot D_{a.v}-82.579114\cdot T + 69438.211722 \qquad (11)$$

The correlation coefficient is:

$$R^2= 0.873801$$



1)
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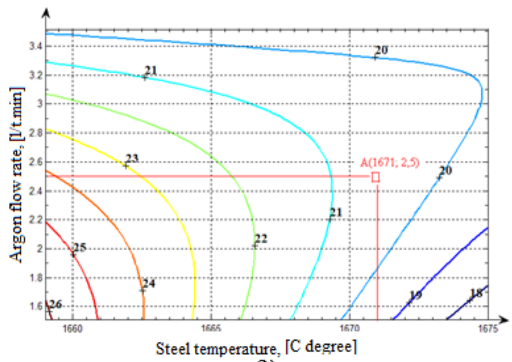

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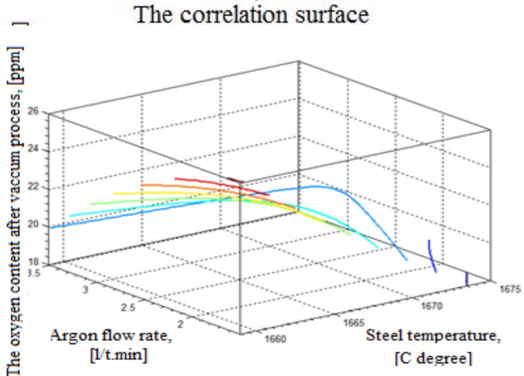


3)
Spatial representation of the level curves

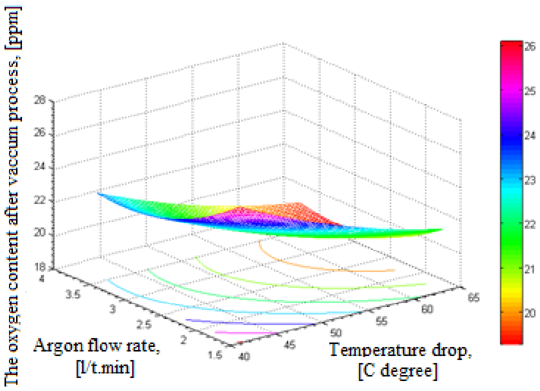
Figure 13. The oxygen content after vacuum process depending on the steel temperature and argon flow rate

The correlation equation is:

$$Q_{O2}= 0.003447\cdot T^{2}-1.082846\cdot Q_{Ar}^{2}+0.275710\cdot T\cdot Q_{Ar} - 12.464834\cdot T - 455.100290\cdot Q_{Ar} + 11217.090875 \qquad (10)$$

The correlation coefficient is:

$$R^2= 0.794606$$



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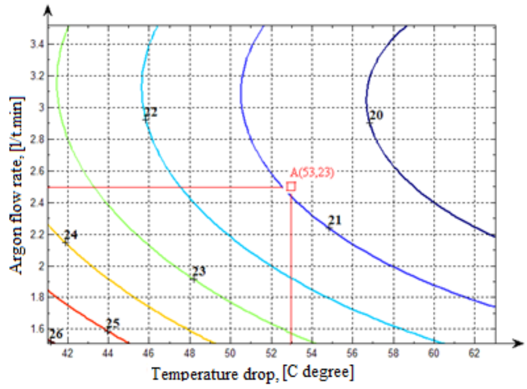

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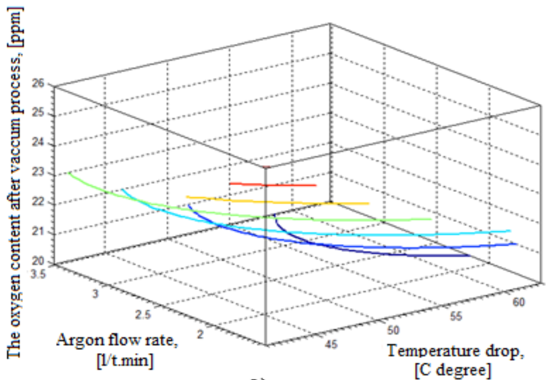

3)
Spatial representation of the level curves

Figure 14. The oxygen content after vacuum process depending on the temperature drop and argon flow rate

The correlation equation is:

$$Q_{O2}= 0.003921\cdot\Delta T^2+1.090357\cdot Q_{Ar}^2+ 0.016134\cdot\Delta T\cdot Q_{Ar} - 0.632286\cdot\Delta T - 7.550576\cdot Q_{Ar} + 53.335814 \quad (13)$$

The correlation coefficient is:

$$R^2= 0.755482$$

5. Conclusion

From the research data for study of the effect of deoxidation to the vacuum steel treatment, results the following conclusions:

- treatment of liquid steel in the LF and VD facilities, will allow an increase in purity and an advanced degassing of steel, reflected in the high quality of this;
- by processing the data in the Excel and MATLAB software, were obtained representative correlation equations, both in terms of the values of correlation coefficients and technology interpretation;
- obtained values for oxygen content, using multiple correlation equations, was under 21ppm (max 30ppm content), confirm, on the one hand, the validity of correlations obtained and, on the other hand, the possibility of using these in industrial practice;
- obtained equations are useful for industrial practice, they allowing choosing and correlation of the values for the independent parameters, so as to obtain the semi finished cast products (treated LF and VD facility) a lower oxygen content (obviously at the same time for H and N) [14], [15].

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