CONSIDERATIONS REGARDING REDUCING OXYGEN CONTENT IN STEELS

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Actual paper presents the industrial research and obtained results concerning influence of technological parameters upon oxygen content in steels. Industrial research was enteprised during elaboration-secondary treatement-casting steel flow, deoxydation being made through precipitation during pouring steel in ladle in Loading Furnance stage and during Vacuum Degasing treatment. Results have been represented using Matlab resulting in regression surfaces and correlation equations in order to optimize influencing factors on oxygen content from steel. Optimal variation ranges of analysed parameters are represented from technological point of view.

Keywords: steel, oxygen, secondary treatment, vacuum, deoxidation.

1. Introduction

When liquid steel makes contact with atmosphere from processing aggregates, is occuring a diffusion process of gases in molten bath, on one side, and on the other side takes place migration of gases from molten bath in aggregate atmosphere.

Deoxidising power of a deoxidizer is given by oxygen content from steel composition, in equilibrium with deoxidizer. The higher the deoxidizing power of deoxidizer is, the lower the oxygen content in steel. Is considered that the power of an deoxidizer is higher, as deoxidizer oxygen potential content is lower. Minimum oxygen content that can remain in equilibrium with deoxidizer depends on the following factors: temperature of metallic bath (deoxidizing power of a deoxidizer increases as temperature decreases)and thermodynamic activity of deoxidizer agent (the higher thermodynamic activity, the higher deoxidizer's power). For a

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deoxidizer to be efficient, has to be added in specific amount and needs to have ground composition to be able to penetrate molten steel bath and react with dissolved oxygen in steel.

Vacuum degasing is one of the most efficient deoxidizing steel process with multiple applications in steel manufacturing. Main advantage of vacuum deoxidation is represented by advanced purity of steel, due to fact that carbon is used for deoxidation, and is completely released from steel composition, unlike other deoxidizers which are precipitating, and a small part remain incorporated in steel composition and lead to non-metallic inclusions formation. Vacuum degasing is supported by the fact that metal baths are constantly agitated by bubbling with argon, which favors homogeneity of metallic bath from both thermic and chemical point of view [1-6].

In steel making practice is known that once with carbon reduction in steel the oxygen content is increasing which at the end of bubbling process oxygen content to be relatively high when carbon from molten steel bath decreases under 0.2%. To prevent sulfur inclusions formation or appearance of phenomenon of hot brittle the content of dissolved oxygen in fully killed steel does not have to overrate 0.0040 – 0.0080% (40 – 80ppm) limits and on semi killed steels and rimmed steels 150 - 300ppm [1,7-9]. On semi killed steels and rimmed steels (incomplete deoxidized), sulfides are not considered manufacturing defects because having low carbon content (under 0.20%) they are characterized as being high -temperature weldability steels and during heated plastic deformation sulfides are closing through welding process [1, 10,11]. Deoxidation is technological operation of removing oxygen until the minim established limit for each steel type (fully killed, semi killed and rimmed steel) and this process is done by precipitation, extraction/diffusion or vacuum.

On direct contact between molten steel bath and outside atmosphere of steel making aggregates gas diffusion is made by slag. The influence factors from this process are: the good quality of loading charge and auxiliary materials, good quality of additional slag, temperature of molten bath, intensity and duration of steel boiling, duration of evacuation, standstill time in the ladle and the values of processing parameters from the pouring ladle [1-3].

Regardless of the process making, pouring or rolling process in steels in its composition remain trapped impurities, non-metallic inclusions and gases, the most representative are hydrogen, nitrogen and oxygen.

During steel elaboration an essential role during degassing process is steel boiling. During this process carbon monoxide bubbles are released. At the time of bubble formation the partial pressure of hydrogen and oxygen is zero and because of this fact under the action of concentration gradients the gases diffuses inside the bubbles and then are eliminated outside the molten bath [1,12-14].

2. Experimental research

Industrial research carried out during steel elaboration process examines the possibility of reducing oxygen content from steels used in pipe manufacturing for hydrocarbon transport.

The industrial research were entreprised in an electric steelworks equipped with a triple aggregate EAF-LF-VD. The analyses were made on steel loads ST 52-3A hot rolled steel round bar with diameter 280mm. Loading charge consisted of a good quality steel and auxiliary materials were calcined according technological instructions. After elaboration steel on steel was applied secondary treatment in LF and VD and then continuous casted. During technological process were analyzed a series of technical parameters.

The results were plotted using computer software Matlab, which generated regression surfaces and correlation equations to optimize the influencing factors on the steel oxygen content. The scope is obtain correlations between total oxygen content in steel after vacuum (dependent parameter) and vacuum main parameters (independent parameters): vacuum duration, vacuum duration on advanced vacuum, initial and final steel temperature on vacuum degassing process, temperature reduction during vacuum, argon flow and pressure in vacuum aggregate.

For graphical and analitical representations were used following notations:
T – total vacuum duration (min);
t_v – advanced vacuum duration (min);
p_v – pressure on advanced vacuum duration (mBar);
p_{Av} – Argon pressure during bubbling treatment (atm);
ΔT – temperature reduction during vacuum degassing (^{0}C);
T_i – initial temperature at the beginning of vacuum degassing (^{0}C);
T_f – final temperature at the end of vacuum degassing (^{0}C);
Q – Argon flow (l/t.min).

Multiple correlations processed in Mathlab were established using the same parameters as in previous case of simple correlation. In that reason is used the equation (1).

$$z = a_1x^2 + a_2y^2 + a_3xy + a_4x + a_5y + a_6 \qquad (1)$$

In Figs. 1-8 regression surfaces and contour lines for parameters analyzed with the resulting correlation equations are presented.

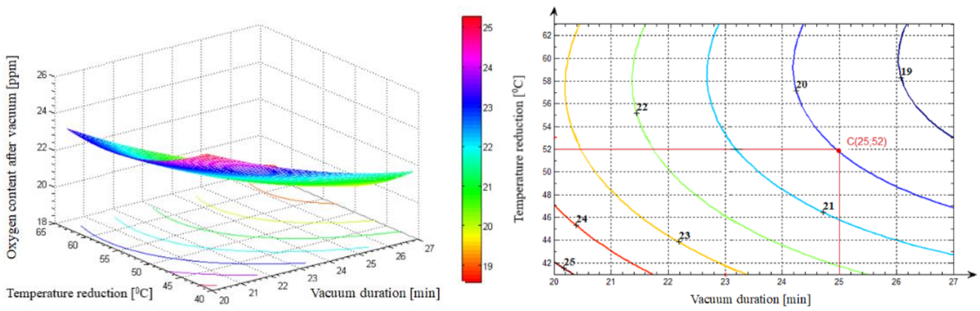

Fig 1. Oxygen content after vacuum=f(Vacuum duration, Temperature reduction)

$$O_2 = 0.037001 \cdot T^2 + 0.007779 \cdot \Delta T^2 - 0{,}006621 \cdot T \cdot \Delta T - 2.006263 \cdot T - 0.760839 \cdot \Delta T + 74.142629\,; R^2 = 0{,}854582 \quad (2)$$

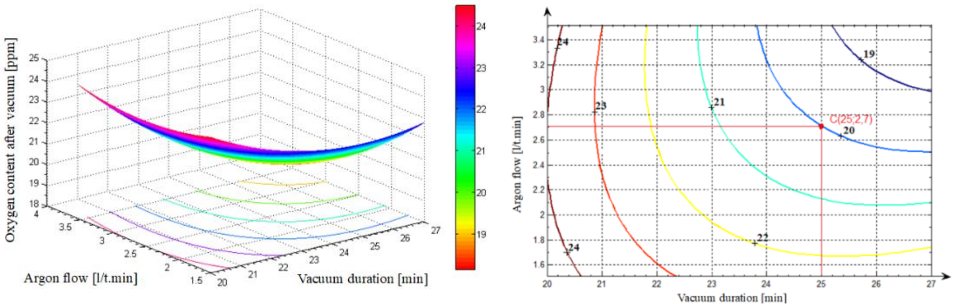

Fig 2 Oxygen content after vacuum=f(Vacuum duration, Argon flow)

$$O_2 = 0.0081470 \cdot T^2 + 0.454855 \cdot Q^2 - 0{,}319134 \cdot T \cdot Q - 3.598831 \cdot T + 4.055380 \cdot Q + 66.342935\,; R^2 = 0{,}848899 \quad (3)$$

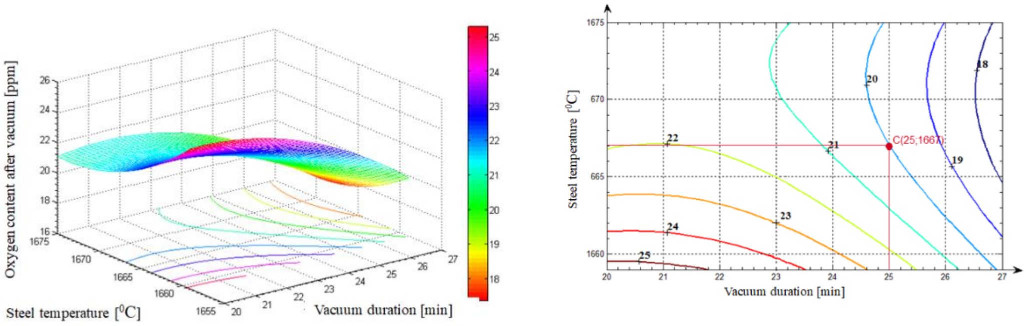

Fig 3. Oxygen content after vacuum=f(Vacuum duration, Steel temperature)

$$O_2 = -0.11856 \cdot T^2 + 0.019332 \cdot T_f^2 + 0{,}019183 \cdot T \cdot T_f - 27.029464 \cdot T - 65.099306 \cdot T_f + 54769.241855\,; R^2 = 0{,}867153 \quad (4)$$

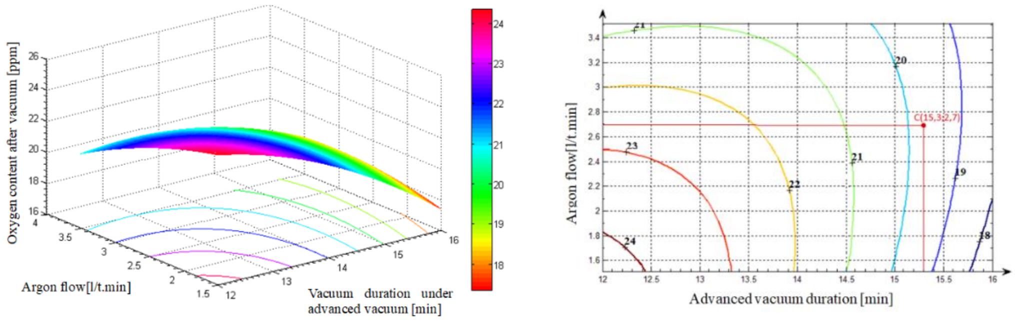

Fig 4. Oxygen content after vacuum=f(Advanced vacuum duration, Argon flow)

$$O_2 = -0.272637 \cdot t_v^2 - 0.434313 \cdot Q^2 + 0{,}5687389 \cdot t_v \cdot Q + 5{,}029522 \cdot t_v - 6.443282 \cdot Q + 3{,}659968 ;\ R^2 = 0{,}777176 \quad (5)$$

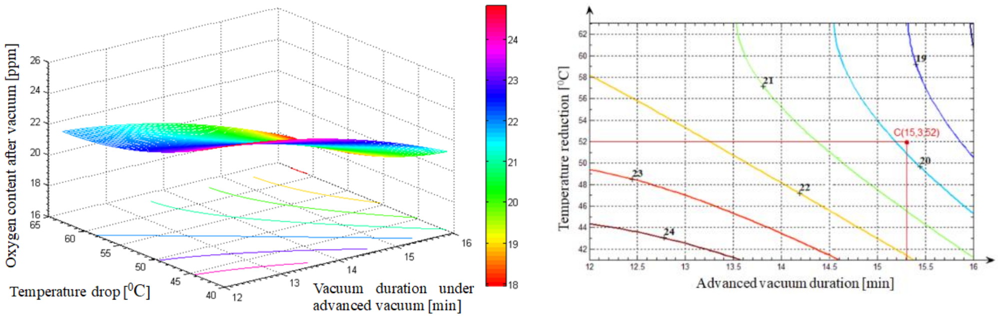

Fig 5. Oxygen content after vacuum=f(Advanced vacuum duration, Temperature reduction)

$$O_2 = -0.171459 \cdot t_v^2 + 0.005995 \cdot \Delta T^2 - 0{,}001519 \cdot t_v \cdot \Delta T + 3{,}922981 \cdot t_v - 0.740859 \cdot \Delta T - 23{,}483942 ;\ R^2 = 0{,}809316 \quad (6)$$

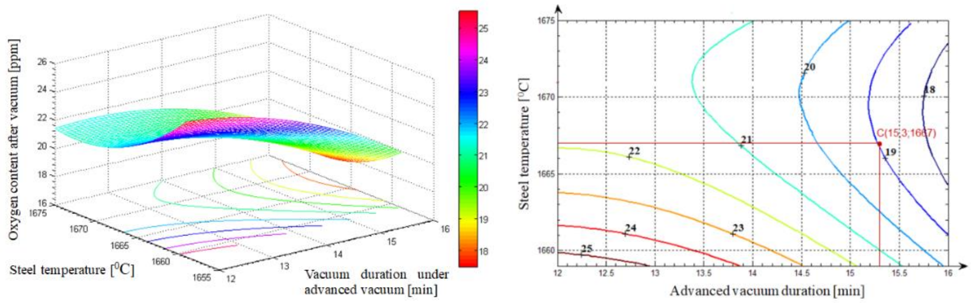

Fig 6.Oxygen content after vacuum=f(Advanced vacuum duration, Steel temperature)

$$O_2 = -0.276601 \cdot t_v^2 + 0.024543 \cdot \Delta T^2 + 0{,}041170 \cdot t_v \cdot \Delta T + 61.973022 \cdot t_v - 82.579114 \cdot \Delta T + 69438.211722 ;\ R^2 = 0{,}873801 \quad (7)$$

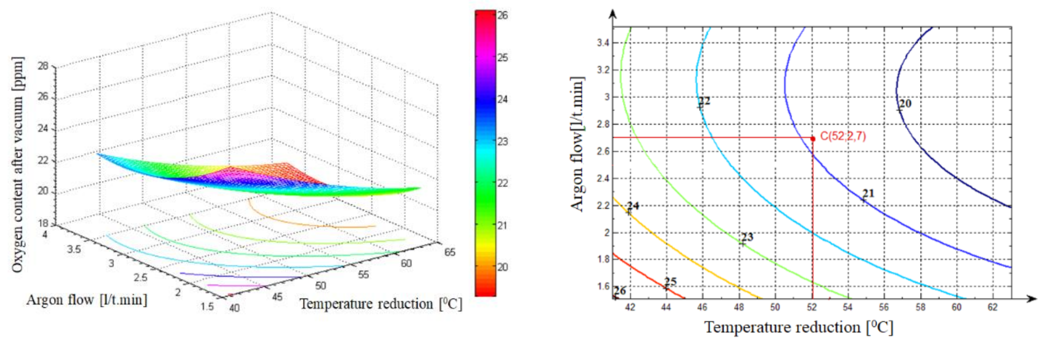

Fig 7. Oxygen content after vacuum=f(Steel temperature, Argon flow)

$$O_2 = -0.003447 \cdot \Delta T^2 - 1.082846 \cdot Q^2 + 0,275710 \cdot \Delta T \cdot Q - 12.464834 \cdot \Delta T - 455.100290 \cdot Q + 11217.090875 \,; R^2 = 0,794606 \quad (8)$$

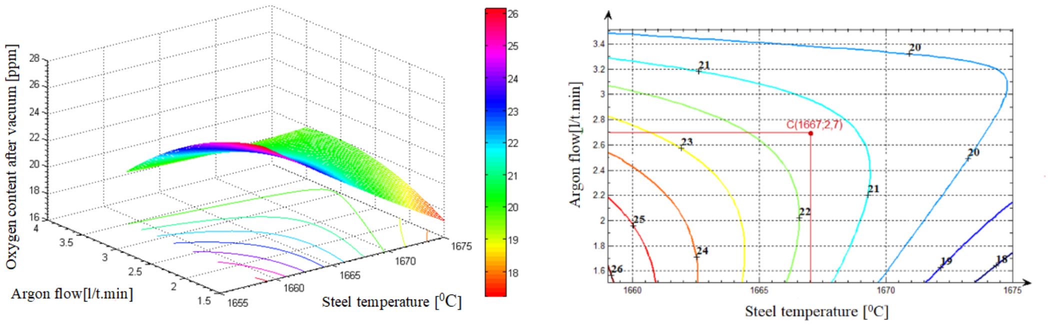

Fig 8. Oxygen content after vacuum=f(Temperature reduction, Argon flow)

$$O_2 = -0.0039211 \cdot \Delta T^2 - 1.090357 \cdot Q^2 + 0,016134 \cdot \Delta T \cdot Q - 0,632286 \cdot \Delta T - 7.550576 \cdot Q - 53.335814 \,; R^2 = 0,755482 \quad (9)$$

3. Results and discussions

By analyzing data in Mathlab (Fig1 – Fig8) from technological point of view is showed that double correlations in both mathematical and technological meaning are the same as simple correlations, moreover is accentuated decrease of oxygen content. For oxygen content have been chosen reference value of 20ppm.

By analyzing regression surfaces and contour lines is resulting that:

- for correlation (2) presented in Fig 1 very good results are obtained for a vacuum duration treatment between 20 – 28min and a temperature reduction between 40 – 70^{0}C, in that reason is obtained an oxygen content of 24 ppm
- for correlation (3) presented in Fig 2 very good results are obtained for argon flow between 2.5 – 3.5l/t.min and vacuum duration between 20 – 28min in that reason is obtained an oxygen content of 24ppm
- for correlation (4) presented in Fig 3 very good results are obtained for steel temperature between 1665 - 1685^{0}C and vacuum duration between 20 – 28min and in that reason is obtained an oxygen content between 24ppm
- for correlation (5) presented in Fig 4 very good results are obtained for argon flow between 2.5 – 3.5l/t.min and vacuum duration under advanced vacuum between 12 – 20min, in that reason is obtained an oxygen content between 24ppm
- for correlation (6) presented in Fig 5 very good results are obtained for a temperature variation between 50 – 90 ^{0}C and vacuum duration under advanced vacuum between 12 – 20min, in that reason is obtained an oxygen content between 24ppm
- for correlation (7) presented in Fig 6 very good results are obtained for steel temperature between 1665 - 1685^{0}C and vacuum duration under advanced vacuum between 12 – 20min, in that reason is obtained an oxygen content between 24ppm
- for correlation (8) presented in Fig 7 very good results are obtained for argon flow between 2,5 – 3,5l/t.min and steel temperature between 1665 - 1685^{0}C, in that reason is obtained an oxygen content between 24ppm
- for correlation (Fig 9) presented in Fig 15 very good results are obtained for temperature reduction between 40 – 70^{0}C and vacuum duration under advanced vacuum between 12 – 20min, in that reason is obtained an oxygen content between 24ppm

4. Conclusions

By analyzing from technological point of view of double correlation equations and from their graphical representations it results that by implementing them in technological flow are established the optimal ranges of parameter variations.

By framing independent technological parameters in certain domains of variation by establishing correspondence between them it results lower oxygen content at the end of degassing treatment in vacuum process.

Double correlation were obtained in practice for 5 samples and for vacuum durations between 22 – 28min, vacuum duration under advanced vacuum between 15 – 17min, temperature reduction during vacuum treatment with values between 45 – 70^{0}C, argon flow between 2.5 -3,5l/t.min the obtained oxygen content have values between 18.2 – 23.48ppm.

Oxygen content determined in samples taken from molten steel at the end of vacuum treatment it was with 0.2 – 0.4ppm higher then ones obtained with correlation equations, respectively graphical representations. All industrial obtained data represent the applicability in practice in industrial plant where research have been enterprised and are available on industrial operators site.

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