Contribution on the influence of steel ladle processing (LF) upon the nitrogen removal rate

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Abstract. Nitrogen, which is present in the composition of steel either dissolved or as a gas, represents an element, which is generally unwanted, except for the cases when the aim is to obtain nitrides or to increase the austenitic domain in stainless steels. The paper shows the results obtained in increasing the nitrogen removal rate during the secondary treatment of steel meant for oil industry pipes, into a Ladle Furnace-type installation. The processed data allowed the determination of variation domains, respectively graphical and analytical correlations between the nitrogen removal rate and the parameters of the secondary treatment process (bubbling duration, steel temperature and argon pressure).

1. Introduction
Nitrogen, similar to other gases, is undesirable in the liquid steel because it causes problems when it remains trapped in the solidified steel.

Nitrides, which are not removed, remain finely dispersed in the steel, where they serve as centers of crystallization, and unbound nitrogen that is found as nitrides in ferrite - together with oxygen - it increases the tendency to cold brittleness and aging.

In liquid steel, the nitrogen has partial solubility, which required its replacement as bubbling gas. However, with this technological limitation, nitrogen is present in the structure of steel, penetrating the liquid steel from the atmosphere of the steel making and secondary treatment department and/or casting department [1-3].

2. Industrial data
Data was taken from the steel pipe making process, on the followed technological flux: steel making (in EAF type EBT) secondary treatment (a LF facility). In order to determine the nitrogen content, it was sampled at steel evacuation in the ladle from the furnace, but in particular during the second treatment. In this way, there have been identified the argon bubbling parameters in LF facility (argon flow, bubbling duration, bubbling pressure) and thermal parameters, respectively the way is modified steel temperature during secondary treatment. It was intended a temperature at four different times: at the beginning, 20 minutes, 40 minutes from treatment start and final temperatures of steel [1].

All this data (considered as independent parameters) are presented in the following figures and analytical dependences, depending on the nitrogen removal efficiency.
Figure 1. The influence of the argon flow on nitrogen removal efficiency

Figure 2. The influence of the bubbling duration on nitrogen removal efficiency

Figure 3. The influence of the argon pressure on nitrogen removal efficiency
It should be noted that, during the secondary treatment, liquid steel temperature is adapted according to its variation, reflected in the temperatures analysis presented in Figure 4 - Figure 7. At the end of treatment, the steel temperature is within technological limits necessary for the following secondary treatment, continuous casting process respectively.

![Figure 4](image4.png)

**Figure 4.** The influence of the steel temperature at the beginning of the secondary treatment on the nitrogen removal efficiency

![Figure 5](image5.png)

**Figure 5.** The influence of the steel temperature after 20 minutes from the start of secondary treatment on the nitrogen removal efficiency
3. Discussions and results
Analysing the obtained results, presented in Figure 1-7, the following were found:
- for the correlation of the nitrogen removal efficiency depending on the argon flow at bubbling (Figure 1), the peak has the coordinates (561.69; 34.98) within the limits of the argon flow 525-595Nm$^3$/h, it leads to obtain a 25-35% nitrogen removal efficiency if we consider the correlation equation, or 25-45% if we take into account the correlation that is the upper limit of the range of variation;
- for the correlation of nitrogen removal efficiency depending on the bubbling (Figure 2), the peak has the coordinates (88.34; 34.99); the bubbling length is between 58-115 minutes, and it leads to a nitrogen removal from 25 to 35% if we take into account the correlation equation, or 25-45% if we take into account the correlation that is the upper limit of the range of variation;
- for the correlation of the nitrogen removal efficiency depending on the argon pressure at bubbling (Figure 3), the peak has the coordinates (4.43; 37.62); the argon pressure is between 4.1 to 4.75 bar and it leads to obtain a nitrogen removal yield between 23-35% if we consider the correlation.
equation, or 23-45% if we take into account the correlation that is the upper limit of the range of variation;
- in what concerns the influence of the metal bath temperature on the nitrogen removal efficiency (Figure 4 - Figure 7), it is found that an increase of the temperature at the beginning and during the treatment, gives an increasing value for the dependent parameter; extreme points coordinates (minimum or maximum) are outside the technological domains, except for the correlation presented in Figure 5 that has the maximum point of coordinates (1648.18; 34.87);
- in terms of steel temperature, during processing in the LF facility, increasing its value determines the increase of the nitrogen removal efficiency at maximum; only one correlation has the point of maximum (for $T_2$=1648.18°C, $R_N$=34.87%) located at the upper limit of temperature variation domain, other two correlation have the minimum point ($T_3$ and $T_4$) located outside of temperature variation domain, below the lower limit of the domain and a correlation that is of the first degree).

4. Conclusions

Analysing the data and the discussions above, several conclusions can be drawn:
- from the mathematical point of view in all studied cases, the correlations are of the form of 2nd degree polynomial functions;
- for each case are presented the upper and lower variation limits, expressed both as analytical and graphical correlations;
- in three cases, the extreme point of the polynomial function is located within the technological limits, which from the technological point of view means that for the nitrogen removal efficiency a maximum value is reached for a given value of the technological independent parameter;
- for the nitrogen removal efficiency there were monitored possible values to be obtained, the independent technological parameters of the process being set into the limits required by the nitrogen removal efficiency;
- from the technological point of view, increasing the liquid steel temperature during the LF treatment, leads to a reduction in viscosity of the steel, which gives a higher diffusion of nitrogen from the steel in the argon bubbles, on the one hand, and on the other hand, a lower resistance to the movement of argon bubbles;
- increasing steel temperature must be within technological limits, exceeding the upper limit may cause a re-oxidation of the bath, or to a more intense absorption process than desorption process;
- framing temperatures during secondary treatment between technological limitations in hydrogen removal provides values for nitrogen removal efficiency within 25-45%.

References

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