MAIN DESIGN CHARACTERISTICS OF LANCES FOR STEELMAKING FURNACES

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Abstract

Production of crude steel with the help of oxygen processes will produce, according to forecasts also in the future, large portion of the world-wide steel production. In the connection with this fact the blowing systems are being further developed and improved both in case of oxygen converters, hearth furnaces and in case of electric furnaces or their combinations. These systems, for example, serve both for blowing of refining oxygen on the bath surface or into the melt and for blowing of additional combustion oxygen or blowing of the gas mixture with powdered substances. This paper deals with the main design characteristics of the lances for blowing of refining oxygen on the melt surface. These design characteristics help designers and engineers to design systems that meet the high demands on quality, efficiency and operational reliability.

Keywords: Oxygen blowing, oxygen converters, hearth furnace, tuyeres for oxygen blowing, steelmaking

1. INTRODUCTION

At the projection of blowing systems and at the constructional solution of single lances and nozzles itself there is necessary to respect certain criteria the deduction of which follows, on the one hand, from laws valid for fluids flowing with the considering the thermal energy supply into the flowing medium and effect of medium friction on the walls of flow tube, on the other hand, from long-term experience and knowledge gained in this branch [1]. It is necessary that these lances and nozzles designs also respect the requirements on the lances and nozzles service life, and, in this connection on production aggregate service life as well.

2. OXYGEN MASS FLOW RATE AND TOTAL PRESSURE

For blowing of fining oxygen the so called multistrand tuyeres are developed with convergently-divergent shape of nozzles the number of which depends on oxygen blowing intensity [2], [3].

For determination of oxygen mass flow rate for oxygen converter derived regression dependency wchich is expressed as a function of the maximum value of the oxygen mass flow rate $Q_{m\text{-}max}$ (kg·s^{-1}) to the weight of the melt G_{tav} (t) is used in following shape

$$Q_{m-\max} = 0.0731 G_{tav}^{0.996} \tag{1}$$

Above equation was derived from the parameters of operated oxygen converters. For hearth (tandem furnace) relation listed below is recommended

$$Q_{m-\max} = 0.0086 G_{tav}^{1.208} \tag{2}$$

Graphic representation of relations (1) and (2) is in **Figure 1**.

Value of the oxygen stagnation pressure before the nozzle p_o (MPa) is another characteristic which is one of the determining parameters of the flow momentum values and also of blown oxygen concentration.

For converter operation following relation was established

$$p_0 = 0.6755 G_{tav}^{0.104} \tag{3}$$

For hearth furnace an analogous relation is valid

$$p_0 = 0.5041 G_{tav}^{0.107} \qquad (4)$$

Graphic representation of relations (3) and (4) is in **Figure 2**.

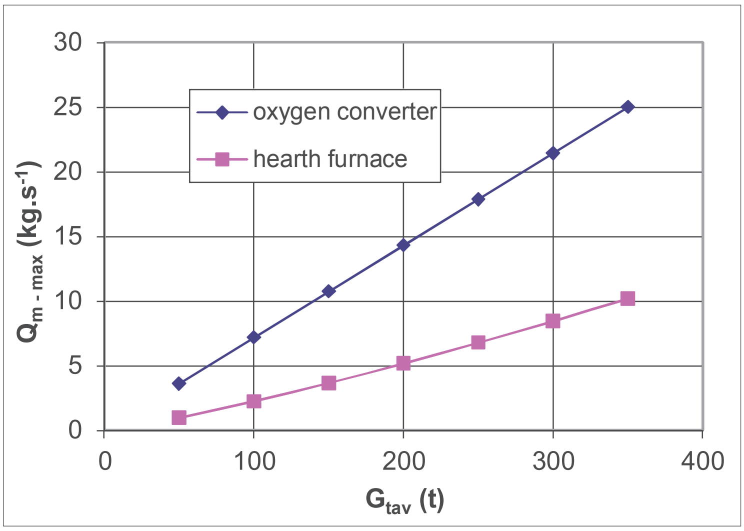

Figure 1 Functional dependence $Q_{m\ max} = f(G_{tav})$

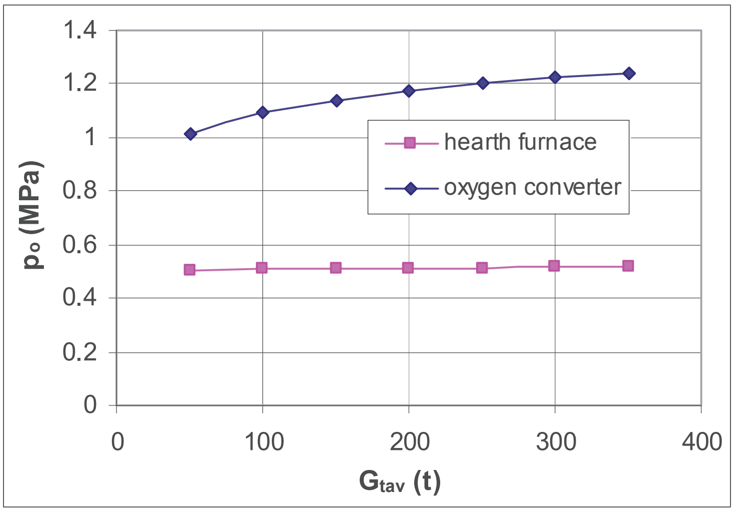

Figure 2 Functional dependence $p_o = f(G_{tav})$

Convergent-divergent nozzles with the neck of a cylindrical shape are the most commonly used. Diameter of the cylindrical shape neck together with nozzle outlet diameter are other important characteristics.

Important thing is that in design flow mode of oxygen through the nozzle and considered one-dimensional isentropic flow of ideal gas without considering flowing losses so called flow critical state occurs in the throat. Throat diameter is then nozzle critical diameter d_{kr}. Value of critical diameter d_{kr} (m) is calculated from known values of stagnation pressure p_0 (MPa) and stagnation temperature T_0 (K) at corresponding oxygen mass flow ($Q_{m\ max}$) and at selected number of nozzles in tuyere **n** (-) according relation

$$Q_{m-\max} = 0.04212 \frac{\pi}{4} d_{kr}^2 \frac{p_0}{\sqrt{T_0}} n \qquad (5)$$

3. NOZZLE GEOMETRIC PARAMETERS

Among the number of nozzles in the tuyere **n**, the diameter d_{kr} and melt weight G_{tav} following relationship is valid

$$d_{kr} = 0.00751 G_{tav}^{0.446} \frac{1}{\sqrt{n}} \tag{6}$$

Graphic representation of relations (6) is in **Figure 3**.

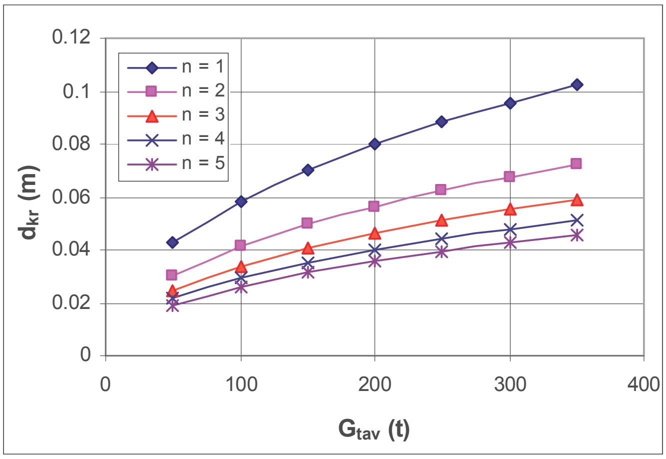

Figure 3 Functional dependence d_{kr}= f(G_{tav})

An important characteristic of the oxygen nozzle is the ratio of the output and critical cross-section (S_v and S_{kr}) expressed depending on the ratio of the stagnation pressure in front of output cross-section of the nozzle p_{ok} (surrounding environment pressure) and stagnation pressure in front of the nozzle p_o. For convergent-divergent nozzle in design mode, condition $p_{ok} = p_v$ is valid, where p_v is the static pressure in the output cross-section. Then following relation is valid

$$\frac{S_v}{S_{kr}} = \frac{0.24943}{\left[\left(\frac{p_{ok}}{p_0}\right)^{1.46} - \left(\frac{p_{ok}}{p_0}\right)^{1.73}\right]^{0.5}} \tag{7}$$

This function is graphically shown in the **Figures 4 and 5**

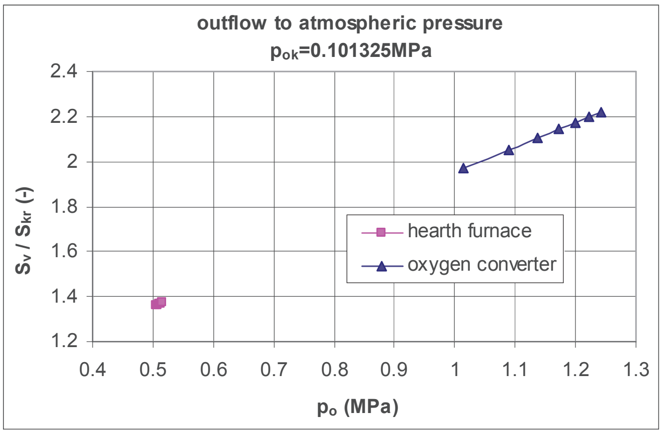

Figure 4 Functional dependence S_v / S_{kr}= f(p_o, p_{ok}=0.101325 MPa)

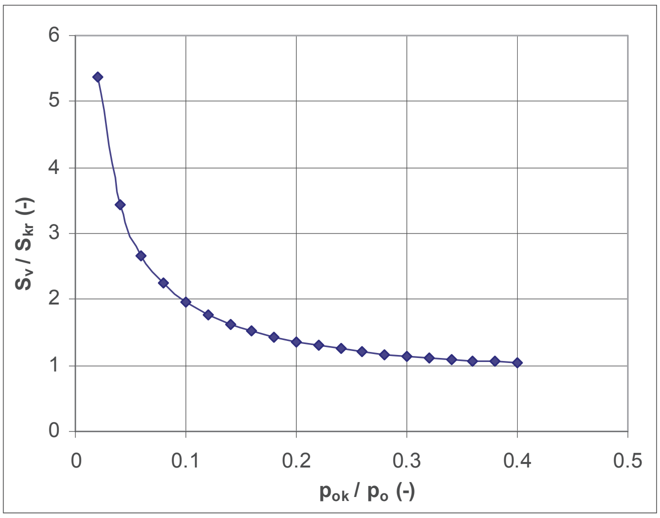

Figure 5 Functional dependence $S_v / S_{kr} = f(p_{ok} / p_o)$

Dependence $d_v = f(G_{tav}, n)$ for the converter and hearth furnace is shown In **Figures 6 and 7**.

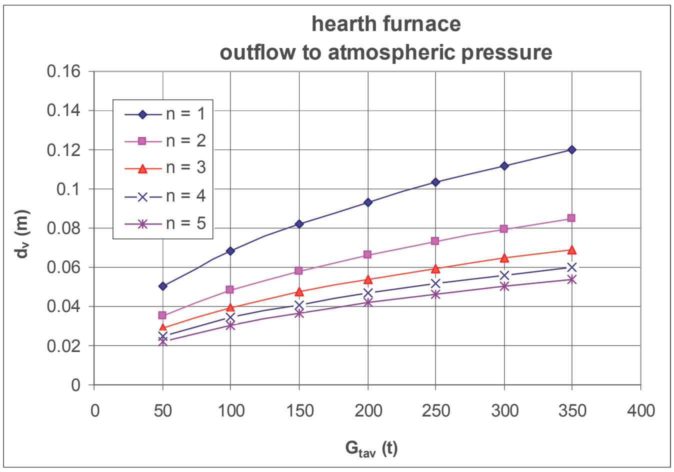

Figure 6 Functional dependence $d_v = f(G_{tav}, n)$ for hearth furnace

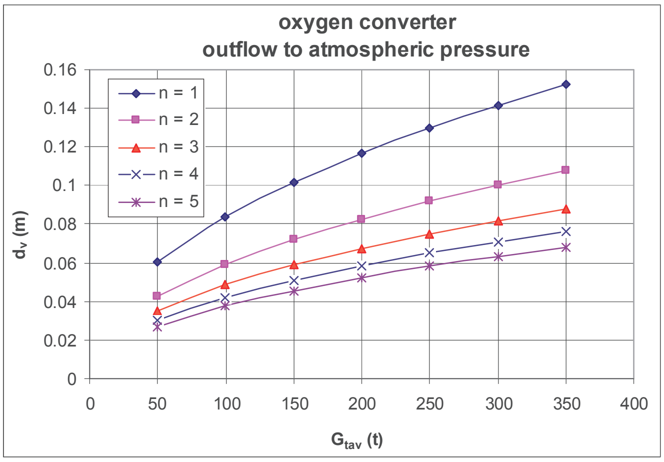

Figure 7 Functional dependence $d_v = f(G_{tav}, n)$ for oxygen converter

4. FORCE EFFECTS OF THE OUTPUT FLOW

We can determine the value of the output cross-section S_v and total flow impulse I_p (N) from equation (7). Flow impulse I_p expresses the force of the outlet flow acting on the melt bath.

Ratio of I_p to the flow output pressure force in the critical cross-section of fthe nozzle expressed by the product of stagnation pressure p_o (Pa) and neck area S_{kr} (m^2) is another characteristic of the refining blowing system and it is called force effect coefficient C_F (-).

Then $$C_F = \frac{I_p}{p_0 S_{kr}} \qquad (8)$$

Force effect coefficient C_{Fmax} corresponds to the maximum value of the acting force. In case when $C_{Fmax} = C_F$ acting force value is maximal. With the growth of p_{ok} / p_o and Mach number **M** the flow force effect decreases.

With the p_{ok} growth the intensity of pressure waves in the outlet increases, thus leading to decrease the ratio C_F / C_{Fmax} and therefore to reduction force effect on the melt bath.

All these parameters depend on the flow momentum H_{pi} (N), on the nozzle angle inclination to the longitudinal axis of the lance α and on distance of the nozzle from the bath h_ϕ (m). For dependence L / $h_\phi = f(H_{pB})$ and $H_{pB}=f(H_{pi}, \alpha, g, \rho_{tav}, h_\phi)$, the following regression functions are valid

$$\frac{L}{h_\phi} = 4.469 H_{pB}^{0.66} \qquad (9)$$

$$H_{pB} = \frac{H_{pi}\cos\alpha}{g\rho_{tav} h_\phi^3} \qquad (10)$$

Band of function validity is balanced by the specified limits. Similarly, it is possible to determine the relationship between diameter of the reaction region D (m), and the position of the nozzle h_ϕ on dimensionless flow momentum H_{pB}' which is given by the equation

$$\frac{D}{h_\Phi} = 2.813 H_{pB}^{'0.282} \qquad (11)$$

while $$H_{pB}' = \frac{nH_{pi}}{\rho_{tav} g h_\phi^3}(1+\sin\alpha) \qquad (12)$$

Depth of penetration of the flow into the bath **L** (m) and diameter of the reaction zone **D** characterize effect of outlet flow to the melting bath. The ratio L / D is so-called flow penetrability **P**. Flow penetrability essentially means its ability to penetrate to the molten bath. Its value is particularly affected by the bath distance from the nozzle h_ϕ, stagnation pressure in the nozzle p_o, the number of nozzles **n**, their shape, dimensions and inclination angle α.

Values of **L**, **D** and **P**, from the above characteristics, may be assembled during the blowing, because p_{ok}, h_ϕ, ρ_{tav}, p_o are changing and d_v and α are given by nozzle design, and they are therefore constant. Operating mode of blowing or the most appropriate shape of the nozzle is designed using the analysis and evaluation of the calculated values.

The values determined using the above formulas are used also in the design of the working space of the furnace (reactor).

5. CONCLUSION

Quality of blowing systems for high-temperature reactors for metal production and processing is a necessary prerequisite for quality and continuous production. Utility properties of blowing systems depends, among other things, especially on high-quality design of their construction. Selected main design characteristics that were mentioned in the submitted contribution help designers and engineers to design systems that meet the high demands on quality, efficiency and operational reliability.

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