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AN EXPERIMENTAL STUDY ON THE AIR DELIVERY AND GAS REMOVAL METHOD IN A MODEL OF FURNACE FOR FERROALLOY PRODUCTION

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In the paper, results of a model study on the effects of the air delivery and flue gas removal method on the intensity of gas blending in the hood space are presented. Two design solutions were compared: with one or two outlet channels for the hood gases. Moreover, two variants of air delivery through charging doors were analysed. The study results show that for technological reasons, more beneficial gasodynamic conditions are obtained when the hood is fitted with two symmetrically located gas outlet channels and the air is sucked through four charging doors.

Key words: ferrosilicon, furnace, model, distribution of gases

INTRODUCTION

Regarding the technology of FeSi alloy production, energy consumption is one of basic factors affecting the process economy. Therefore, the problem has already been deeply investigated [1, 2]. Development and analysis of the technological process energy balance components ensure selection of a reasonable method for energy recovery or reduction in the process energy consumption [3-9]. In Table 1, fractions of energy balance individual components with respect to energy input and output from the furnace space in relation to piece production are presented and expressed in per cent [10]. The furnace is mainly supplied with charge - related energy (hard coal and wood chips), which constitutes over 58 % of the total energy delivered to the furnace space and electrical energy (about 39 %). The basic components of energy being removed are: enthalpy accumulated in flue gases and energy contained in the product. Approximately 54,5 % of energy is lost when gases leave the furnace working space [10]. The amount of energy contained in flue gases depends on e.g. the amount of flue gases generated in the furnace which, in turn, is closely related to the conditions of post-reaction gas combustion. The knowledge on the effects of various solutions of the furnace design on the gasodynamics and quality of air blending with combustible gases allows for selection of the optimal variant that ensures a better thermal efficiency of the ferroalloy production process.

The aim of this experimental study was to search for optimal methods of air delivery to the furnace that ensure the most beneficial conditions of post-reaction gas combustion in the hood space.

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Table 1 **Fractions of energy balance components [10]**

Energy input	GJ/Mg	%
Raw material	43,53	58,7
Electrodes	1,56	2,1
Electrical energy	29,04	39,2
Energy output	GJ/Mg	%
Alloy	29,10	39,3
Skull	0,50	0,7
Dust	0,39	0,5
Flue gas	40,35	54,4
Radiative losses	0,54	0,7
Brickwork losses	1,45	1,9
Cooling water	1,81	2,5

EXPERIMENTAL FACILITY

In Figure 1, the research facility is presented. Based on the physical modelling principles, a cylindrical, Plexiglas, 1:9 model of the furnace hood (750 mm diameter, 310 mm height) with built-up elements that simulate devices fixed in a real object was prepared. The systems of gas delivery to and removal from the hood were fitted with necessary equipment for gas flow measurement as well as with control devices. A pipe system in the air installation ensures that clean air or air with additives is delivered to collectors of each selected nozzle type.

In Figure 2, a top view diagram of a ferroalloy smelting furnace model is presented (showing its individual elements) where: capital letters *A-H* denote ceiling nozzles, Roman numerals *I-IV* correspond to technological windows, small letters *a-d* denote charges and Arabic figures correspond to measurement ports.

ANALYSIS OF THE AIR DELIVERY METHOD

Searching for the best method of air delivery through technological windows is important for development of

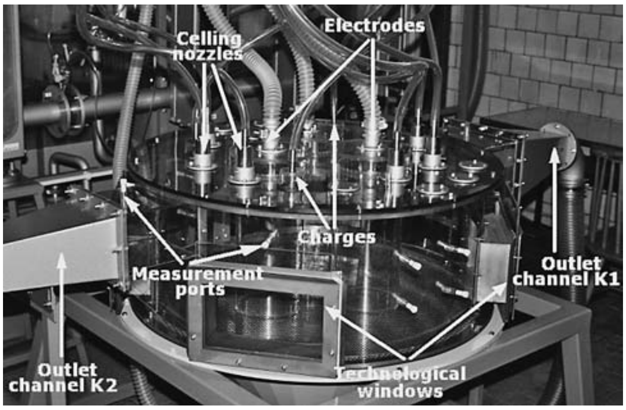

Figure 1 Experimental facility

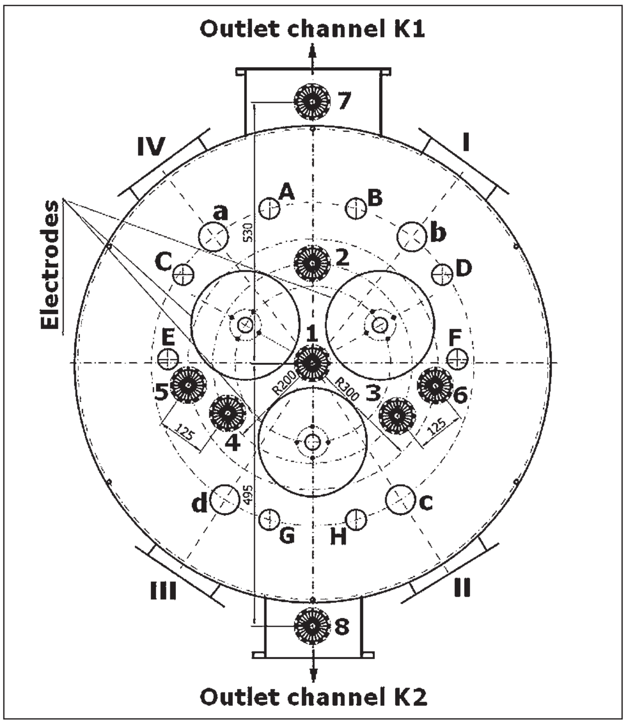

Figure 2 Design of a furnace model

the most beneficial conditions of furnace operation. Two methods of air delivery to the hood through the windows, which create different gasodynamic conditions in the furnace working space, were investigated.

The hydrodynamic and gas blending investigations were performed for: all windows opened (*I, II, III* and *IV*) at the aperture height of h = 10 mm, and two windows opened (*II* and *III*) located opposite the outlet channel at h = 19 mm while the windows *I* and *IV* were closed. The window opening level, expressed by the aperture height of h = 19 mm for the two windows opened (*II* and *III*) resulted from the assumption of maintaining identical cross-section areas of apertures in the windows (A_a = 8 900 mm^2) for both investigated air delivery methods. The flow of sucked air was constant and equalled $\dot{V}_m$ = 206 m$_n^3$/h, which means that air velocity in the window apertures for both analysed cases was w_a = 6,4 m/s.

Gas blending experiments were based on chemical analyses of gas compositions at various hood space points. A mixture of air and carbon oxide was delivered to all nozzles at the hood top part, i.e. to ceiling nozzles, nozzles in the charges and nozzles around the electrodes, while the system of technological gas simulation was supplied with a mixture of air and nitrogen dioxide. The CO and NO_2 levels were measured using a Testo 350 electrochemical analyser. The experiments were performed with the following nominal gas flows: air delivered through the technological windows ($\dot{V}_m$ = 206 m$_n^3$/h) and the technological gas ($\dot{V}_t$ = 32,6 m$_n^3$/h). The $\dot{V}_g$ = 137,3 m$_n^3$/h flow is a sum of air flows from the ceiling nozzles ($\dot{V}_{str}$ = 73,4 m$_n^3$/h), nozzles around the electrodes ($\dot{V}_e$ = 49,7 m$_n^3$/h) and nozzles in the charges ($\dot{V}_{zas}$ = 14,2 m$_n^3$/h). Thus, the total flow of air delivered to the hood was $\dot{V}_c$ = 376 m$_n^3$/h. The gas composition measurements at the measuring points *1, 3, 4, 5* and *6* were performed for three distances from the hood ceiling: H = 10 mm, 150 mm and 305 mm. A detailed method of measurements is described in the paper [1]. In Figure 3, a distribution of NO_2 concentration in the hood with all windows opened (h = 10 mm) for: $\dot{V}_t$ = 32,6 m$_n^3$/h, $\dot{V}_{NO_2}$ = 18 l/h, $NO_{2(m)}$ = 550 ppm, and in Figure 4, a distribution of CO concentration in the hood with all windows opened (h = 10 mm) for: $\dot{V}_g$ = 137,3 m$_n^3$/h, $\dot{V}_{CO}$ = 60 l/h, $CO_{(m)}$ = 440 ppm are presented. Distributions of NO_2 and CO concentrations in the hood with the *II* and *III* (h = 20 mm) windows opened and the *I* and *IV* windows closed are shown in Figures 5 and 6. The experimental parameters were as follows: for nitrogen dioxide – $\dot{V}_t$ = 32,6 m$_n^3$/h, $\dot{V}_{NO_2}$ = 11 l/h, $NO_{2(m)}$ = 330 ppm, and for carbon oxide – $\dot{V}_g$ = 137,3 m$_n^3$/h, $\dot{V}_{CO}$ = 60 l/h, $CO_{(m)}$ = 435 ppm. The highest concentrations of NO_2 (which simulated the technological gas in the mixture with air) with all windows opened were observed in the hood axis region (the measuring point *1*) at the H = 305 mm distance from the ceiling: 120 ppm (Figure 3), 2,5 - fold higher than $NO_{2(opt)}$ = 48 ppm. When the *II* and *III* windows were opened (Figure 5), the highest concentrations of nitrogen dioxide were also at H = 305 mm, the measuring point *2* : 70 ppm, approx. 2,5 - fold higher than the optimal concentration.

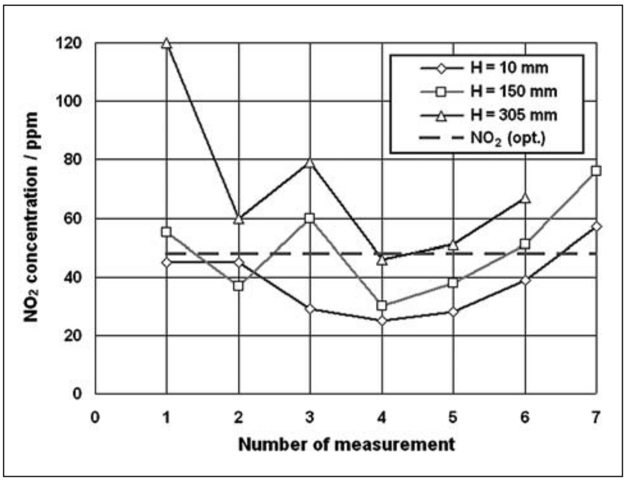

Figure 3 Distribution of NO_2 concentration in the hood with all technological windows opened

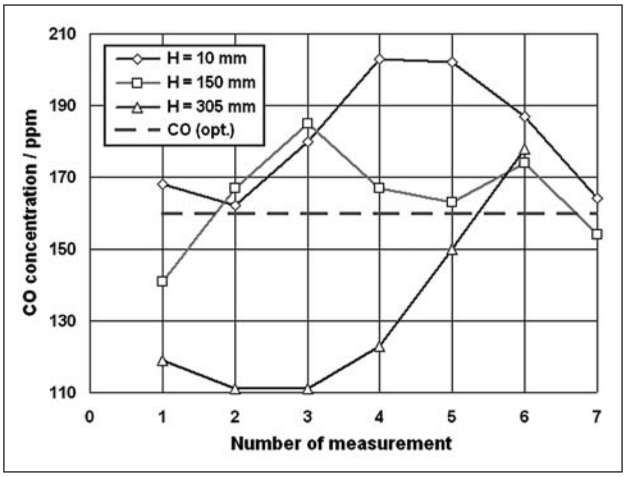

Figure 4 Distribution of CO concentration in the hood with all technological windows opened

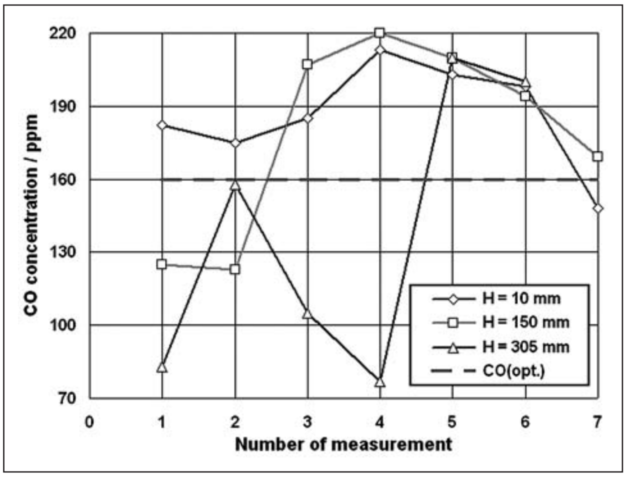

Figure 6 Distribution of CO concentration in the hood with the *II* and *III* windows opened and the *I* and *IV* windows closed

Moreover, this method of air delivery results in a mixture that is richer in the technological gas (contrary to the solution of two opened windows) in the outlet channel axis region (the measuring point *7*). A consequence of the variant where air is delivered through two charging windows located opposite the outlet channel is a shift of a region with the highest concentrations of the technological gas towards this channel. This observation maysuggest that through two opened charging windows (*II* and *III*), more air is delivered to the central space between the electrodes (measuring point *1*) and less air reaches the region behind the electrodes (measuring point *2*). In Figures 4 and 6, CO concentration distributions at individual measuring points for both analysed variants are presented. The CO concentrations at the half-height (H = 150 mm) of the hood, measured at the *3-6* points, were within 163 ÷ 185 ppm for all the windows opened, while for the *II* and *III* windows opened, they were higher: 194 ppm at the point *6* to 220 ppm at the point *4*. The analysis of blending intensity of air delivered through the hood ceiling nozzles allows for an observation that its more uniform blending with the other gases occurred when all the charging windows were opened. Application of only two technological windows (*II* and *III*) for air delivery to the hood space leads to a higher gas separation and less effective blending. The analysis of both methods of air delivery through the charging windows allows for an observation that better gas blending in the hood is achieved when air is delivered through all technological windows.

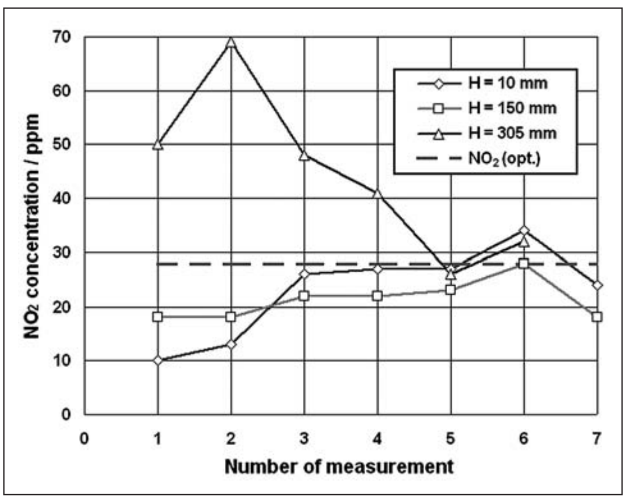

Figure 5 Distribution of NO_2 concentration in the hood with the *II* and *III* windows opened and the *I* and *IV* windows closed

INVESTIGATIONS OF VARIANTS OF GAS REMOVAL FROM THE HOOD

A physical design of the model furnace hood allowed for the analysis of two flue gas removal methods: with one outlet channel *I* (cross-section area A = 35 370 mm^2) or with two identical, symmetrically located outlet channels (the total cross-section area A = 35 370 mm^2). In both cases, maintaining the same gas outlet surface area ensures (at constant gas flows) the same velocity in the outlet channels. Investigations of the one-outlet channel (*I*) variant were performed with a completely covered outlet channel *II* using a properly profiled element which was a hood side surface here. During investigations of the variant with two outlets, the outlet channel *II* was uncovered and the channel *I* was filled with a Styrofoam element which ensured the same sizes of both channels whose total active surface area was equal to the surface area of entirely opened channel *I*. The investigations were performed with all charging windows opened (h = 10 mm) and the same gas flow parameters as those used during the investigations of the effects of air delivery method through the technological windows. The study results are presented as follows: for the one-channel system – Figures 3 and 4, and for the two-channel variant – Figures 7 and 8 where the results obtained at the measuring point *8* are related to the outlet channel *II*.

In Figure 7, a distribution of NO_2 concentration in the hood with two outlet channels is presented for: $\dot{V}_t$ = 32,6 m_n^3/h, $\dot{V}_{NO_2}$ = 18,5 l/h and $NO_{2(m)}$ = 565 ppm, while in Figure 8, a distribution of CO concentration in the

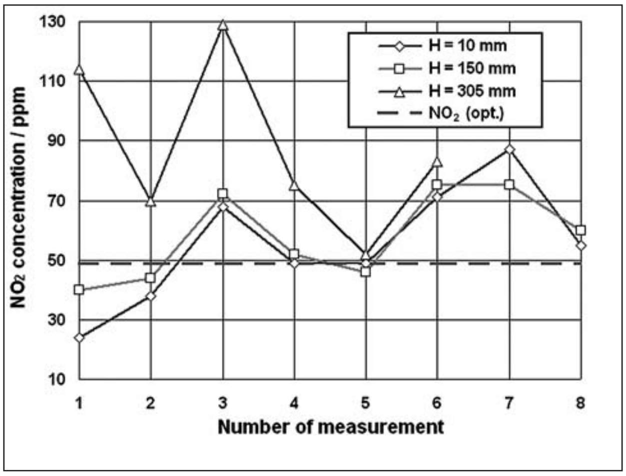

Figure 7 Distribution of NO_2 concentration in the hood for the two-outlet channel variant

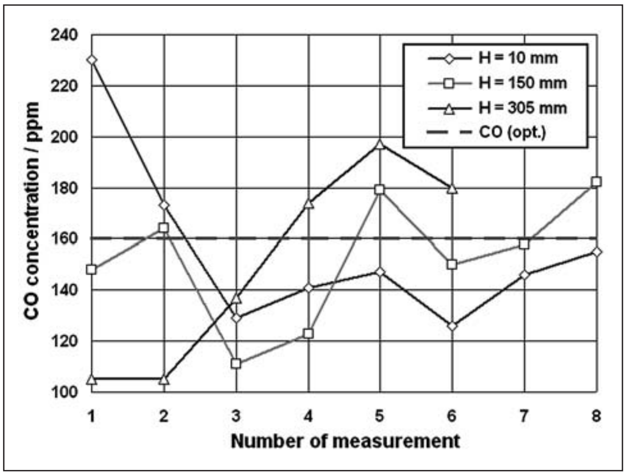

Figure 8 Distribution of CO concentration in the hood for the two-outlet channel variant

hood with two outlet channels is shown for: $\dot{V}_g$ = 137,3 m_n^3/h, $\dot{V}_{CO}$ = 60 l/h, $CO_{(m)}$ = 440 ppm. The distributions of nitrogen dioxide (that simulates the technological gas in the mixture with air) concentrations for both analysed variants are comparable. In the axis region of the hood outlet channels, slightly higher NO_2 molar fractions than the optimal values $NO_{2(opt.)}$ (measuring points *7* and *8*) were observed. The highest concentrations of carbon oxide, CO = 230 ppm (Figure 8), for the two-channel variant were found at the measuring point *1*, *H* = 10 mm from the ceiling, while for the one-channel solution, they were observed at the measuring points *4* and *5*: just above 200 ppm (Figure 2). CO concentrations in the horizontal plane at *H* = 10 mm, measured at the points *3-6*, were within 126 ÷ 147 ppm and they were lower than $CO_{(opt.)}$ = 160 ppm for the two-channel variant, while for the one-channel solution, they were higher than $CO_{(opt)}$: 163 ppm at the measuring point *5* to 185 ppm at the point *3*.

CONCLUSIONS

- A consequence of the variant where air is delivered through two charging windows located opposite the outlet channel is a shift of a region with the technological gas highest concentration towards this channel. Through two opened charging windows (*II* and *III*), more air is delivered to the central space between the electrodes and less air reaches the region behind the electrodes.
- Application of only two technological windows for air delivery to the hood space leads to a higher gas separation and less effective blending than in the case of all charging windows opened.
- The solution of two outlet channels causes more intense penetration of the air sucked through the charging windows to the space under the ceiling around the electrodes compared to the one-channel system.

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Note: The responsible translator: Olga Rochowska-Siwiec, Katowice, Poland