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SOME ASPECTS OF MODEL CALCULATIONS OF CONVERTER SLAG REDUCTION PROCESS

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A numerical method was used to study influence of the charge mass change on the process of converter slag reduction. A numerical simulation was performed with three different quantities of reduced slag. The relation between changes of Cu_2O concentration and duration of the reduction process as well as between the rate of Cu_2O reduction in the slag and Cu_2O concentration were analysed. It was found out that the duration of the process is proportional to the amount of the treated charge. The rate of Cu_2O reduction from converter slag decreases with the process duration and increases with increasing concentration of Cu_2O in the slag.

Key words: Cu_2O, reduction, converter slag, chemical composition, numerical modelling

INTRODUCTION

In the one stage process of copper concentrates smelting in the flash furnace the following products are generated: blister copper and flash - smelting slag. The slag is subjected to copper removal in an electric furnace with production of a useful CuPbFe alloy. Refining of CuPbFe alloy leads to generation of a converter slag. It has a high lead concentration of 25 - 45 mas. %, and contains also 15 - 25 mas. % of copper. After the reduction process the slag contains less than 5 mas. % of Cu and 30 - 55 mas. % of Pb. The slag of such high concentration of Pb is further processed in rotary - rocking furnaces to produce crude lead. In this way lead is taken out of the copper smelter production cycle [1].

The relation between the content of Cu_2O and PbO (converted to Cu and Pb in % mas.) in the slag during the reduction process is presented in Figure 1.It indicates that in the state of thermodynamic equilibrium the PbO reduction begins when the concentration of Cu in the form of Cu_2O is less than 5 mas. % [1 - 3].

The process of converter slag reduction is carried out in a rotary furnace of Hoboken type. The furnace in HM Głogów has an internal length of 7,69 m, and internal diameter of 3,2 m. The furnace is equipped with three nozzles which supply natural gas with air for heating and reduction. The furnace is lined with chromite - magnesite materials, while in the zone of the nozzle magnesia spinel materials were used.

The converter slag reduction process is influenced by many factors, and one of them is the amount of the treated charge. The paper presents results of numerical analysis of the influence of the changes in the treated charge mass on the reduction process.

E. Kolczyk, Z. Miczkowski, J. Czernecki, Institute of Non-Ferrous Metals, Department of Pyrometallurgy, Gliwice, Poland

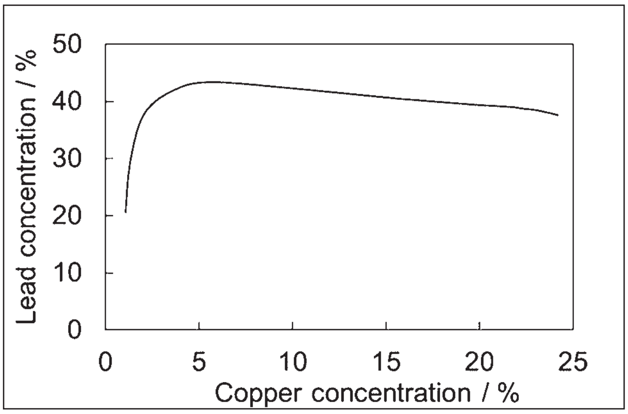

Figure 1 Relationship between the concentration of lead and copper in slag equilibrium state

METHODOLOGY

A numerical model was developed with application of Phoenics software [4 - 6]. The numerical model is composed of the following elements:

- liquid slag,
- natural gas inlet (one nozzle),
- gas outlet (top layer of slag surface).

The geometrical model of the furnace with three nozzle system was limited to its 1/3 internal length with one nozzle in the central location.

The analysed domain had dimensions 2,54x3,19x1,17 m. The generated structural grid contained about 20 000 differential elements.

The calculations were made for the transient state.

The following slag properties were applied in calculations:

- temperature 1 100 °C
- density 6 500 kg m^{-3}
- thermal conductivity 0,15 W m^{-1} K^{-1}

- specific heat capacity 565 J kg^{-1} K^{-1}
- kinetic viscosity 1,54 m^2 s^{-1}.

Table 1 **Chemical composition of converter slag before and after reduction - industrial data**

Chemical composition	Before reduction / mas. %	After reduction / mas. %
Pb	42	52,5
Cu	25	4
As	4,5	4,5
Fe	4	6
SiO_2	10	15
CaO	4,5	6,5

Based on the technological data it was decided to use 100 Mg of the slag as its initial mass. The chemical composition of the converter slag is shown in Table 1. Reduction of 100 Mg of the slag lasted was two hours. Then calculations for treatment of 80 and 120 Mg of the slag were made.

RESULTS

Results of the calculations were used in development of the time dependence of the concentration of copper oxide Cu_2O which was reduced from the slag (Figure 2) for three different amounts of the treated charge. Table 2 lists concentrations of copper oxide in the slag after the selected time steps.

It takes 120 minutes to reduced 100 Mg of the slag down to 5 mas. % of Cu_2O. When the mass of the reduced charge was brought down to 80 Mg the time required to achieve the desired level of Cu_2O concentration in the slag was shorter. The total reduction time was 96 minutes, and the reached Cu_2O concentration level was 5,09 mas. %.

Increase of charge mass to 120 Mg resulted in reduction time of 144 minutes to reach the required level of 5 mas. % of Cu_2O in the slag.

Analysis of concentrations of Cu_2O in the slag - presented in Table 2, shows that the concentration of the copper oxide (compared to the 100 Mg average mass of the treated slag) was lower after each time step when the amount of the treated slag was 80 Mg and higher when there was 120 Mg of the slag. For example, Cu_2O concentration after 90 minutes was lower by 40 % for 80 Mg and 25 % higher for 120 Mg of the slag.

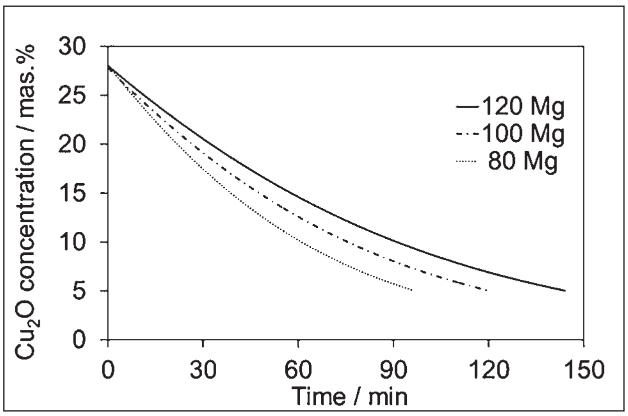

Figure 2 Concentration of Cu_2O over time vs. mass of the treated charge

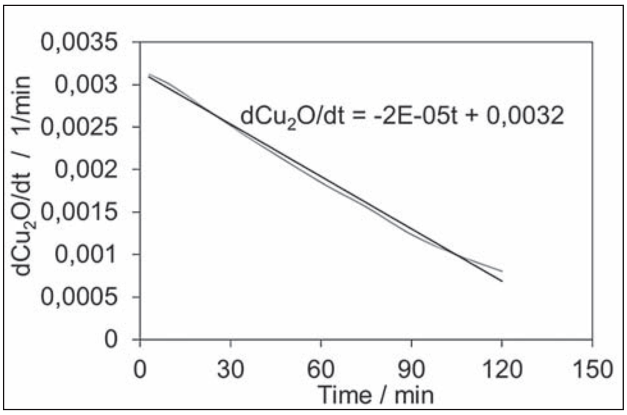

Figure 3 Rate of Cu_2O reduction over time

Table 2 **Change of copper oxide concentration during reduction process vs. mass of the treated slag**

Reduction time / min	Cu_2O concentration / mas. %		
	80 Mg	100 Mg	120 Mg
30	17,46	19,12	20,56
60	10,2	12,6	14,62
90	5,73	8,1	10,15
120	-	5,1	6,92
144	-	-	5,05

Graphs showing changes in the rate of reduction of the copper oxide from the slag during the process and changes in the rate of reduction of the copper oxide Cu_2O depending on its concentration were developed for 100 Mg slag mass (Figures 3, 4).

A decrease in the rate of loss of Cu_2O from the slag was observed since the very beginning of the process. The rate of reduction gradually decreased over time, which is related to the decreasing concentration of copper oxide in the slag. The change in the rate of Cu_2O reduction with the time, which was described by the equation presented in the graph (Figure 3), shows linear character.

That statement is valid for a specific mass of the reduced converter slag and accepted ranges of Cu_2O concentrations in the slag before and after reduction.

The linear character of the rate of reaction versus time indicates that the second derivative of this function will present a constant value.

$$\frac{d^2 Cu_2O}{dt^2} = -2 \times 10^{-5} \ / \frac{1}{min^2} \tag{1}$$

Based on the above a conclusion can be drawn that in the examined range the process of slag reduction takes place with a constant decrease of the rate of reduction.

Table 3 presents results of changes of dCu_2O/dt after various periods of the process.

Table 3 **Rate of Cu_2O reduction vs. reduction process duration**

t / min	dCu_2O/dt / 1/min
2	0,0032
10	0,003
30	0,0026
60	0,002
90	0,0014
120	0,0008

The rate of Cu_2O reduction is the highest in the beginning of the process - 0,0032 [1/min]. The copper oxide decrement becomes reduced with the time, reaching the value of 0,0008 [1/min] in the final stage of the process.

Figure 4 shows the decrease of the rate of Cu_2O reduction from the slag with decreasing concentration of Cu_2O in the slag.

CONCLUSIONS

A numerical method was used for analysis of the influence of changes in the mass of the treated slag on the process of converter slag reduction.

The performed calculations made drawing of the following conclusions possible:

1. When compared to the initial mass of 100 Mg of the treated converter slag and the reduction process duration of 120 minutes the increase or decrease of the charge by 20 Mg results in increase or decrease of reduction process duration by 24 minutes. Therefore, the time of reduction process is proportional to the mass of the treated material.
2. The rate of Cu_2O reduction from the converter slag decreases with the process time and increases with increasing concentration of Cu_2O in the slag. The course of the changes in the analyzed concentration ranges has linear character.

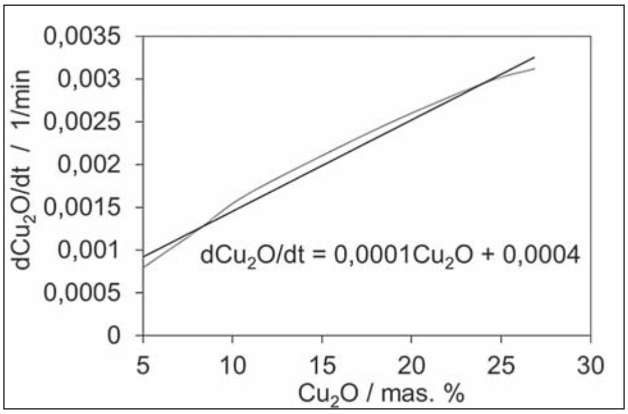

Figure 4 Rate of Cu_2O reduction from the slag vs. Cu_2O concentration

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Note: The responsible translator for English language is Witold Kurylak, Gliwice, Poland