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DETERMINATION OF CONDITIONS OF THE CONVERTER SLAG REDUCTION PROCESS IN AN ELECTRIC ARC FURNACE

OKREŚLENIE WARUNKÓW PROCESU REDUKCJI ŻUŻŁA KONWERTOROWEGO W ELEKTRYCZNYM PIECU ŁUKOWYM

Research on converter slag reduction process has been carried out in the world for many years. The research objective is to implement in a commercial practice a process enabling waste-free utilization of growing slag mass. The reducer share and the process temperature depend on the slag chemical constitution and the planned chemical constitution of the non-metallic phase, which depends on product purpose. In order to determine the process parameters the FactSage software can be used, which allows to determine the chemical constitution of slag reduction process products in the equilibrium state. The paper presents an example of application of the FactSage program for determination of the basic parameters of the converter slag reduction process, in which a non-metallic phase of a chemical constitution similar to the Portland clinker constitution is obtained.

Keywords: converter slag, reduction process, non-metallic phase

Badania procesu redukcji żużła konwertorowego prowadzone są w świecie od wielu lat. Celem badań jest wdrożenie do praktyki przemysłowej procesu umożliwiającego bezodpadową utylizację narastającej masy żużła. Udział reduktora i temperatura procesu redukcji zależą od składu chemicznego żużła i planowanego składu fazy niemetalicznej, który uzależniony jest od przeznaczenia produktu. W celu wyznaczenia tych parametrów procesu można stosować komputerowy program FactSage, który pozwala na określenie składu chemicznego produktów w stanie równowagi otrzymany w procesie redukcji żużła. W artykule przedstawiono przykład zastosowania programu FactSage do określenia podstawowych parametrów procesu redukcji żużła konwertorowego, w którym otrzymuje się fazę niemetaliczną o składzie chemicznym zbliżonym do składu chemicznego klinkieru portlandzkiego.

1. Introduction

The converter slag reduction process is a single – stage process. The main objective of the process is waste-free utilization of converter slag and obtaining usable products.

The first attempt of converter slag reduction was made in Japan in 1979 [1]. The chemical constitution of the resulting phase was similar to the chemical constitution of Portland clinker. Quenching with compressed air was necessary during tapping to stabilize the resulting phase. If there were no quenching the allotropic transformation of the $\beta 2\text{CaO} \cdot \text{SiO}_2$ form into the γ form would occur resulting in increase in volume, the phase would autogenously disintegrate and loose its binding qualities.

The resulting non-metallic phase was characterized by a high carbon content of 5.9%. To remove carbon the phase had been transferred to a muffle furnace, where at a temperature of 1.450°C decarburization process occurred within 60 minutes.

Research on the slag reduction process has been carried out home and abroad until now [2÷4]. However previous research findings have not allowed to implement the process into a commercial practice, therefore the research has been constantly resumed. At the moment thermodynamic data from computer databases can be used for research. The databases are constantly updated. It is possible to compute equilibrium chemical constitutions of phases formed in the slag reduction process and to determine the basic process parameters depending on the chemical constitution of converter slag. In the study presented an attempt was made to determine basic parameters of the converter slag reduction process carried out so as to obtain a non-metallic phase of the chemical constitution similar to the Portland clinker constitution on the basis of thermodynamic computations. The findings were verified by reduction of slag carried out in a single-electrode electric arc furnace.

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2. Determination of the reduction process temperature and the reducer share

The reduction process of converter slag in an electric arc furnace is carried out at a temperature of $1.600 \div 1.800^\circ\text{C}$. During the process solid slag and carbon reducer are fed. The process temperature and the reducer share should depend on the slag chemical constitution and the planned chemical constitution of the non-metallic phase. In order to determine the process parameters the FactSage software with attached thermodynamic database FACT53 was applied. Application of the FactSage software has enabled to calculate equilibrium masses of products for specific reduction process conditions.

In order to determine conditions for obtaining the non-metallic phase of the chemical constitution similar to the constitution of Portland clinker, computations have been made for the reduction process of 1000 g of converter slag of the following constitution: CaO – 44.5%, SiO₂ – 16.63%, MgO – 5.26%, FeO – 23.25%, MnO – 5.40%, Cr₂O₃ – 0.16%, Al₂O₃ – 1.68%, P₂O₅ – 1.24% and S – 0.11%. Example results of calculations of masses of the resulting phases and their most relevant components obtained in the state of equilibrium with the share of carbon reducer of 2 ÷ 10% of slag mass and at a temperature of 1600 ÷ 2.000°C are presented in Fig. 1 ÷ 9.

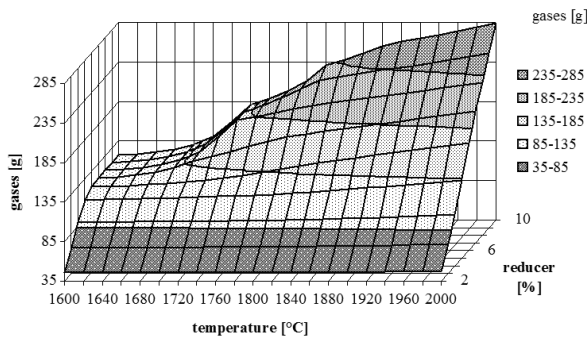


Fig. 1. The off-gas mass in the state of equilibrium

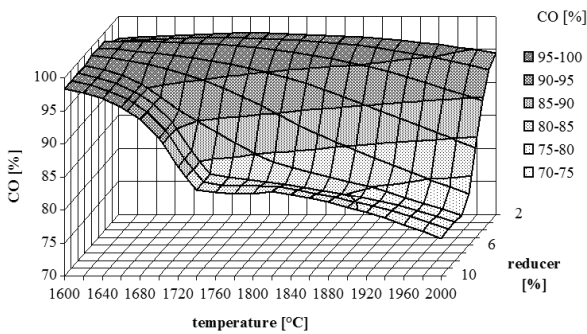


Fig. 2. The equilibrium CO content in the off-gases

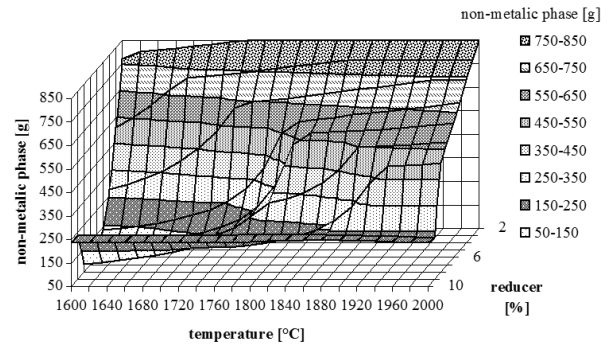


Fig. 3. The liquid non-metallic phase mass in the state of equilibrium

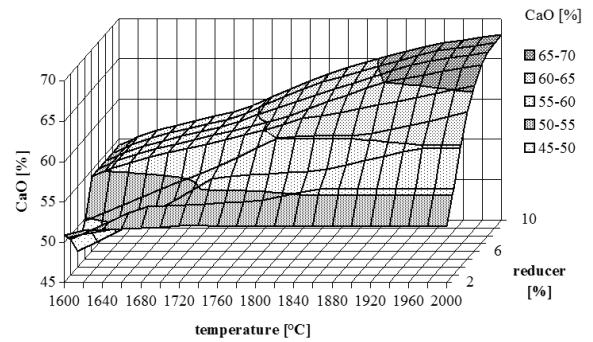


Fig. 4. The equilibrium CaO content in the liquid non-metallic phase

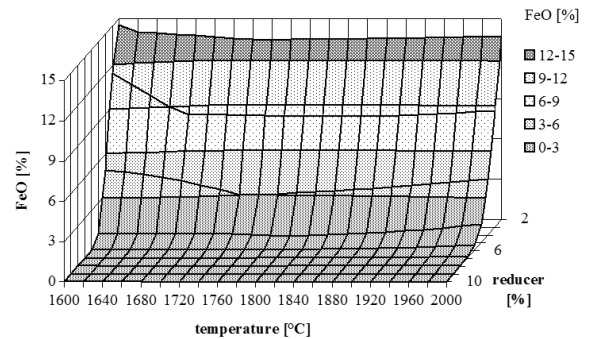


Fig. 5. The equilibrium FeO content in the liquid non-metallic phase

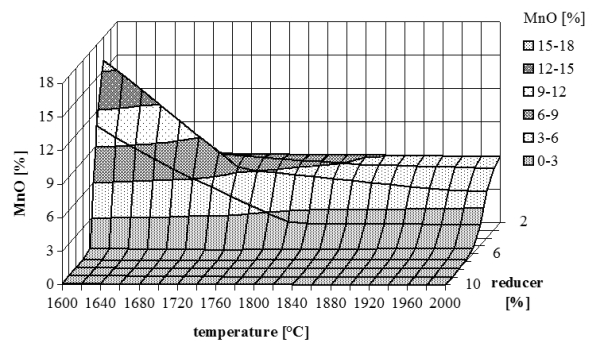


Fig. 6. The equilibrium MnO content in the liquid non-metallic phase

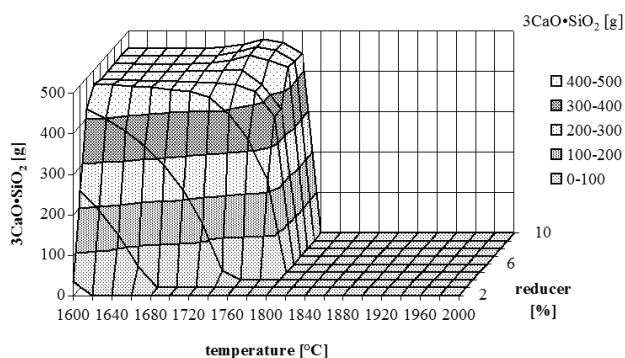


Fig. 7. The mass of solid particulates of $3\text{CaO}\cdot\text{SiO}_2$ in the liquid non-metallic phase

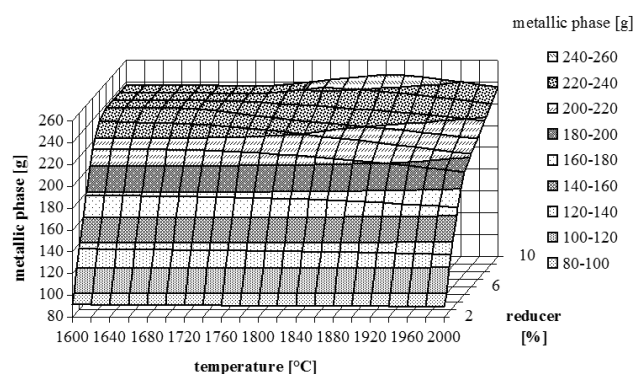


Fig. 8. The liquid metallic phase mass in the state of equilibrium

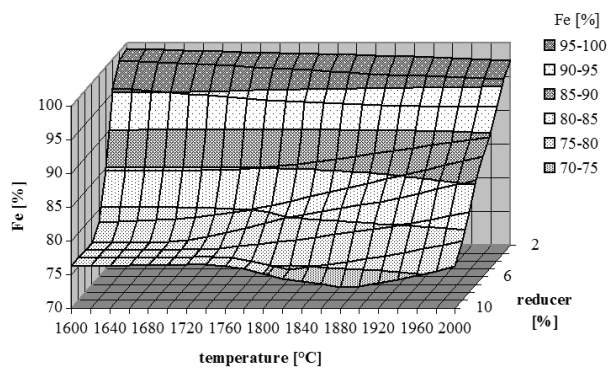


Fig. 9. The equilibrium iron content in the liquid metallic phase

On the basis of computations performed one can find that at a temperature in the range of $1.600\div 2.000^\circ\text{C}$ solid CaO , $3\text{CaO}\cdot\text{SiO}_2$, $2\text{CaO}\cdot\text{SiO}_2$ and MgO precipitates occur in the liquid non-metallic phase. The chemical constitution of the non-metallic phase obtained experimentally is assessed by determination of the oxide content in the solid state. It prevents determination of the oxide content in solid precipitates in the liquid phase and it hampers assessment of the distance between the chemical constitution obtained in the solid state and the

equilibrium constitution in the liquid state. Therefore it was assumed for simulation computations that the total mass of the non-metallic phase is made up of the liquid non-metallic phase and solid precipitates.

Comparing the chemical constitution of the converter slag concerned with typical chemical constitution of Portland clinker one can find it is necessary to reduce the FeO and MnO content below 4% and at the same time to maintain a low carbon content. Analysis of calculation results presented in Fig. 1÷9 shows that at the process temperature of about 1.800°C and the share of reducer bringing in elementary carbon in the amount of 5÷6% of the slag mass it is possible to obtain the equilibrium content in the non-metallic phase for FeO under 0.5% and for MnO under 2.0%. It is not necessary to obtain such a low content in a material intended for Portland clinker as the FeO content in clinker should be about 3.5% and the MnO content under 4% can be treated as a ballast. It allows to shorten the reduction time in relation to the time necessary to obtain the equilibrium content.

In order to compare computation results with experimental results 5 series of heats were produced in a single-electrode electric arc furnace. Each series comprised 3 heats. Converter slag of the same chemical constitution as the chemical constitution of the slag for which computations had been performed was used in the process. The process was carried out at a temperature of about 1.800°C . The converter slag mass was 1.000 g. A ground electrode bringing in elementary carbon was used as the reducer. Slag blended with the electrode was fed to a graphite crucible in the period of 6 minutes. The furnace power supply was turned off 2 minutes after completion of slag feeding. The resulting non-metallic phase was held in the crucible for 24 hours. Then the crucible was broken and the resulting non-metallic phase deposited on the walls and inside the crucible was separated from the metallic phase resting under the non-metallic phase. Also the loss of the crucible mass was determined so as to verify the elementary carbon share in the process. The resulting phases were weighted and their chemical constitution was determined. The non-metallic phase deposited on the crucible walls was not taken into account in comparison of the chemical constitution of the resulting non-metallic phase with the chemical constitution of clinker. The averaged findings of the obtained mass and most relevant components of the non-metallic phase were compared with computation results in Fig. 10÷15.

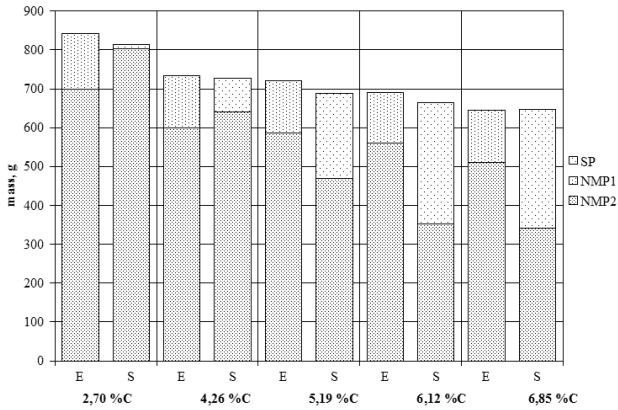


Fig. 10. The mass of the non-metallic phase obtained in the converter slag reduction process: SP – solid particulates, NMP1 – the non-metallic phase deposited on the crucible walls, NMP2 – the non-metallic phase above the melt

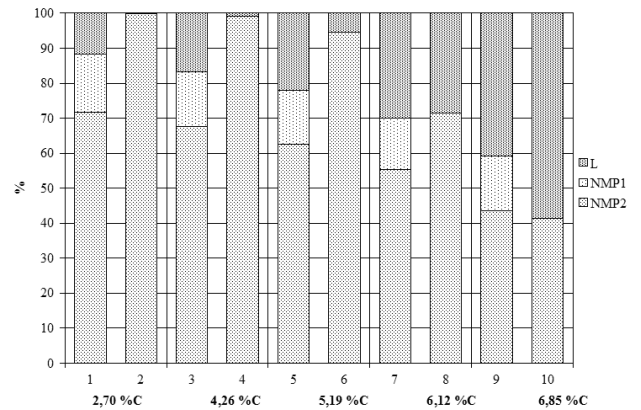


Fig. 13. Breakdown of the MgO content in converter slag: L – losses, NMP1 – the non-metallic phase deposited on the crucible walls, NMP2 – the non-metallic phase above the melt

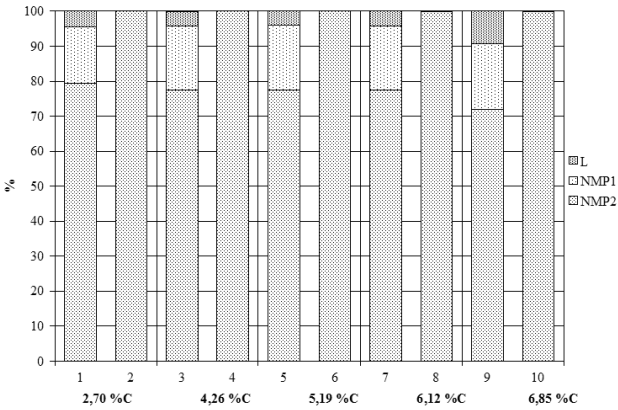


Fig. 11. Breakdown of the CaO content in converter slag: L – losses, NMP1 – the non-metallic phase deposited on the crucible walls, NMP2 – the non-metallic phase above the melt

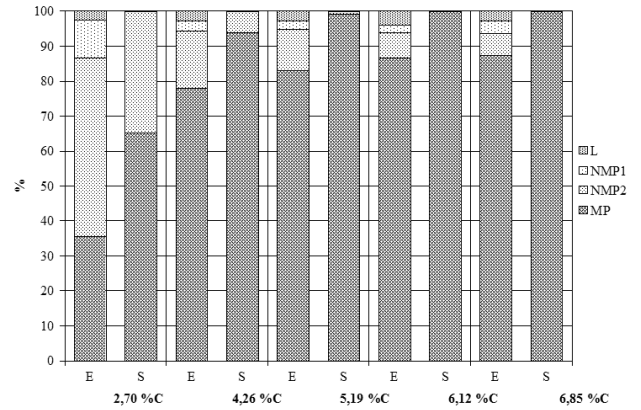


Fig. 14. Breakdown of the FeO content in converter slag: L – losses, NMP1 – the non-metallic phase deposited on the crucible walls, NMP2 – the non-metallic phase above the melt, MP – metallic phase

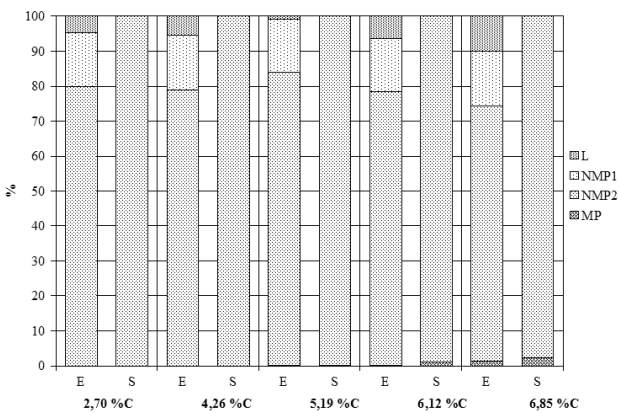


Fig. 12. Breakdown of the SiO₂ content in converter slag: L – losses, NMP1 – the non-metallic phase deposited on the crucible walls, NMP2 – the non-metallic phase above the melt, MP – metallic phase

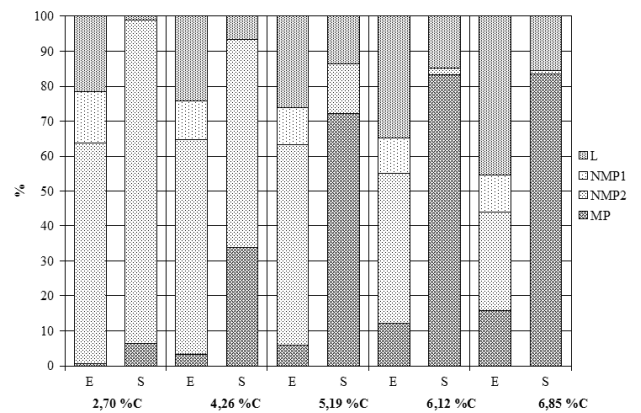


Fig. 15. Breakdown of the MnO content in converter slag: L – losses, NMP1 – the non-metallic phase deposited on the crucible walls, NMP2 – the non-metallic phase above the melt, MP – metallic phase

Results of calculations and experiments indicate that the mass of resulting products changes with the change in the reducer share. The mass of the non-metallic phase and the mass of the metallic phase increases with the increase in the reducer share. The total mass of the non-metallic phase obtained by the experiment was on par with the mass of the phase that could be obtained in the state of equilibrium. At the same time the metallic phase mass was 15÷45% lower than the equilibrium mass.

The losses of oxides in relation to their initial mass were much higher during experiments than the losses of oxides calculated for the equilibrium state due to blow out of fine slag particles during its feeding and electric arc reaction.

The electrode cross-section area accounted for 16% of the internal crucible area. The liquid phase temperature in this zone increased up to 3.000°C in the peripheries of the arc reaction and it was much higher in its axis. At such a high temperature there were much higher evaporation losses of elements reduced than at the temperature for which the equilibrium state was determined.

Comparing the experimental results of the non-metallic phase chemical constitution with the computation results one can find that during experiments the state of equilibrium was not reached which indicates that the process time was too short. At the same time one can say that during the process CaO and MgO are not reduced and slight reduction of SiO₂ is possible if the elementary carbon share exceeds 6%. Iron and manganese are reduced to the metallic phase. At the temperature of 1.800°C also MgO is reduced and the magnesium reduced fully evaporates as its temperature of change of state from liquid to gaseous is 1.095°C.

Experiments carried out allowed to find that application of the FactSage software enables to determine the reduction process temperature and the reducer share depending on the slag chemical constitution. As a result of the slag converter reduction process one can obtain the FeO, MnO and MgO content in the non-metallic phase on par with the content required for clinker. It is necessary however to use corrective additions of calcium in order to obtain the CaO content within the range of 63÷67% required for clinker.

3. Conclusion

During the converter slag reduction process it is necessary to determine the process temperature and the reducer share depending on the slag chemical constitution. The above mentioned parameters decide on the chemical constitution of the non-metallic phase in the state of equilibrium. The FactSage software can be used to determine these parameters.

The FactSage program allows to determine the chemical constitution of the liquid non-metallic phase and solid particulates occurring in this phase depending on chemical constitution of converter slag, process temperature and reducer share. As the chemical constitution of the non-metallic phase obtained experimentally is determined in the solid state it is necessary to assume that the total mass of the metallic phase obtained in the computer calculations is made up of the mass of the liquid phase and the solid particulates. Such assumption allows to compare computation results with experimental findings.

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