Improvement of the Copper Flash Smelting Furnace (FSF) and the Slag Cleaning Furnace (SCF) process by advice-based control of silica and coke addition

A. Schmidt[1], S. Winkler[2], E. Klaffenbach[3], A. Müller[4], V. Montenegro[5] and A. Specht[6]

1. Process Engineer, Aurubis AG, 20539 Hamburg, Germany. Email: am.schmidt@aurubis.com
2. Senior Process Engineer, Aurubis AG, 20539 Hamburg, Germany. Email: s.winkler@aurubis.com
3. Senior Manager R&D, Aurubis AG, 20539 Hamburg, Germany. Email: e.klaffenbach@aurubis.com
4. FSF/SCF Manager, Aurubis AG, 20539 Hamburg, Germany. Email: ar.mueller@aurubis.com
5. Senior Manager R&D, Aurubis AG, 20539 Hamburg, Germany. Email: v.montenegro@aurubis.com
6. Executive Director Pyrometallurgy R&D, Aurubis AG, 20539 Hamburg, Germany. Email: a.specht@aurubis.com

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ABSTRACT

In the process of primary copper smelting in Flash Smelting Furnace (FSF), the ratio of iron to silica (Fe/SiO_2 mass ratio) primarily determines the slag viscosity and magnetite formation. Viscous slag does not only cause difficulties in daily operation, such as in tapping, it also increases the copper losses to slag. Thus, keeping the Fe/SiO_2 mass ratio at the desired level is an important aspect of FSF and Slag Cleaning Furnace (SCF) operation.

In this study, the improvement of the Fe/SiO_2 mass ratio was conducted in two steps: First, the optimal Fe/SiO_2 mass ratio was derived based on thermodynamic data. Based on this analysis, appropriate control limits were determined. Second, this range of favorable Fe/SiO_2 mass ratios was implemented into operation by an advice-based control system, which suggests the addition of silica based on the analysis of SCF slag. As this approach was successful, the same advice-based control system principle was adapted for the coke addition to the SCF.

After testing the new advice-based control for several months, the production data confirm the predictions by thermodynamics: Since the prediction was implemented as an advisor, the copper and magnetite content in SCF slag is significantly reduced and viscous slag is reported less often by operations.

INTRODUCTION

In FSF operation, the Fe/SiO_2 mass ratio is an important target for controlling the slag quality, the balance is crucial as both too high and too low ratios can lead to undesirable effects. Too high Fe/SiO_2 mass ratios promote magnetite formation and increased slag viscosity, resulting in higher copper losses (Wang et al., 2021). This effect occurs also at too low Fe/SiO_2 mass ratios, as the excessive addition of silica increases the slag viscosity as well (Ma et al., 2022). An additional drawback of low Fe/SiO_2 mass ratios is that the overall slag amount increases with higher silica addition, leading also to additional copper losses. Moreover, the presence of magnetite and silica in the slag has been linked to the formation of mechanically entrapped matte particles, which contribute significantly to copper losses in the slag (Imris et al., 2005). Research indicates that the concentration of copper and minor elements in slags can be optimized by controlling the slag composition (Klaffenbach et. al, 2021). In this study a two-step approach is outlined: First, the optimal Fe/SiO_2 mass ratio is derived from thermodynamic calculations (step 1). Secondly, this optimal Fe/SiO_2 mass ratio is implemented as a target for slag control into operations by an advice-based control system (step 2). As an additional step, the same advice-based control system was adapted for the coke charging into the Slag Cleaning Furnace (SCF) for improving the slag quality further and ensuring comprehensive control over the slag quality of both the FSF and the SCF. This study describes a case of optimizing the industrial operation of Aurubis Hamburg's primary smelting process with the objective to reduce magnetite formation and hence copper losses to the slag.

STEP 1: THERMODYNAMIC DERIVATION OF THE OPTIMAL FE/SIO$_2$ RATIO

Equilibrium calculations are crucial procedure in determining the conditions, at which a fully liquid slag without solid particle formation is achieved within the FSF. The calculations were conducted using FactSage 8.0 using FactPS and UQPY private database. Various solution phases including matte/metal (Liq(Matte/Metal)), slag (UQPY-SLAG), spinel (UQPY-SPIN) were considered along with the stochiometric compounds tridymite (SiO_2) and fayalite (Fe_2SiO_4). Within the calculation, the operating conditions (such as feed composition, slag composition and oxygen enrichment) were set to model the behavior of the metallurgical system in the FSF of Aurubis Hamburg. In Figure 1 the result of the calculation is illustrated, in which the impact of temperature and Fe/SiO_2 mass ratio on the calculated liquidus is shown.

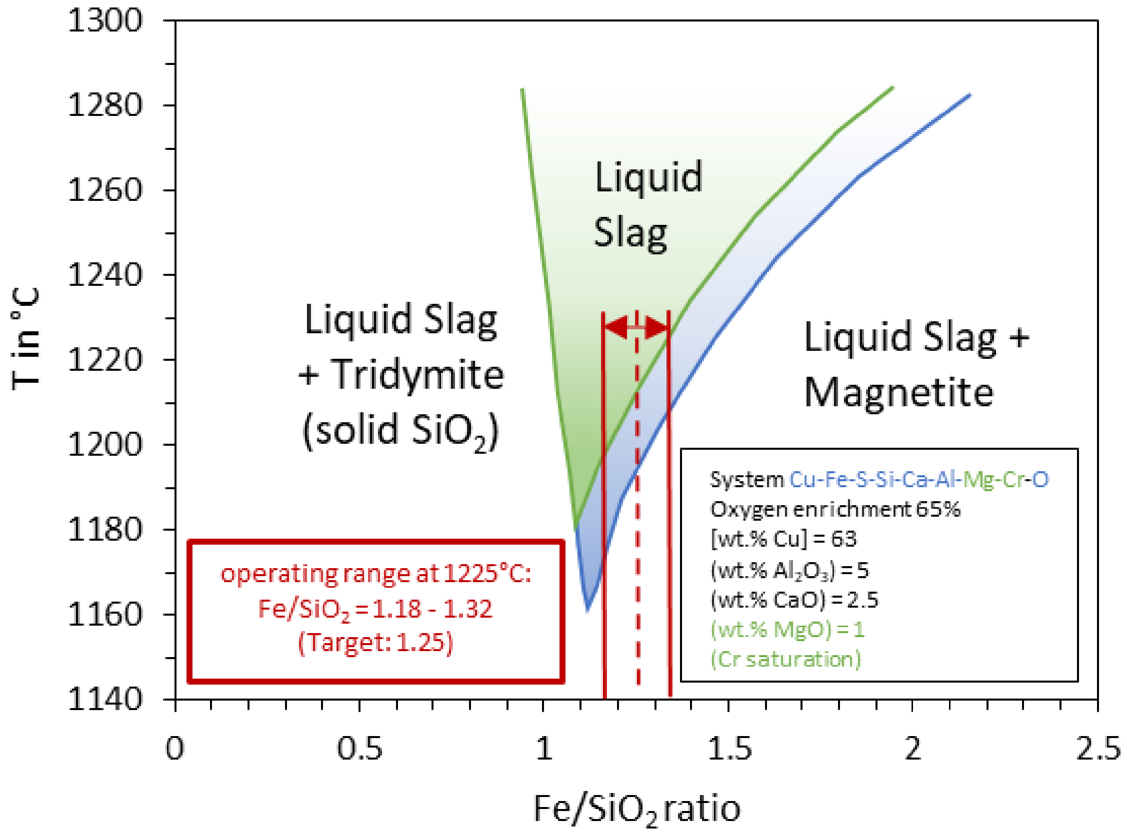

FIG 1 – Impact of temperature and Fe/SiO_2 mass ratio on the calculated liquidus of slag under conditions of Aurubis Hamburg Flash Smelter.

The calculation was conducted with and without presence of MgO and Cr_2O_3 in slag, in order to also consider the effect of interaction with magnesia chromite refractory on the slag liquidus. It can be seen that the presence of these components decreases the liquid range of the slag (green area in the diagram) as opposed to a slag without MgO and Cr_2O_3 components (blue and green area in the diagram combined). As MgO and Cr_2O_3 are likely to be present in an industrial slag, the derivation of the optimal Fe/SiO_2 mass ratios is derived from the respective liquid range.

At low Fe/SiO_2 mass ratios, tridymite (solid SiO_2) would be formed, meaning that in practice incomplete melting of silica would occur. At high Fe/SiO_2 mass ratios magnetite would be formed. Both should be avoided to achieve a slag with low viscosity, ensuring undisturbed settling of the copper containing particles within the given time. At the same time, only a minimum amount of slag should be produced, so that a high Fe/SiO_2 mass ratio is favoured. It was found that the Fe/SiO_2 mass ratio in operation has a variability of ±0.07 around the setpoint. For this reason, the targeted Fe/SiO_2 mass ratio at a process temperature of 1225 °C is Fe/SiO_2 = 1 .25 with an upper limit of 1.32 and a lower limit of 1.18. By the upper limit it is ensured that magnetite formation is prevented, the lower limit prevents excessive production of slag and also occurrence of non-molten silica.

STEP 2: IMPLEMENTATION INTO OPERATION BY AN ADVICE-BASED CONTROL SYSTEM

The Fe/SiO_2 mass ratio in the FSF slag is controlled by sampling and analysing the SCF slag. Depending on the iron and silica content in slag, the ratio is then adjusted by manual changes to the silica addition to the feed. In practice, this leads to the following steps:

1. Sampling and analysis of SCF slag. Thereby, the chemical components are analysed by XRD and standard Satmagan.
2. Review of the SCF slag composition by the operators.
3. Manual calculation of the Fe/SiO_2 mass ratio and decision on the addition or reduction of silica.
4. Adjustment of the silica flow.

This process contains an inevitable time delay from sampling until the SCF slag analysis is available. Hence, the in-house developed advice-based control system for SiO_2 aims to shorten the reaction time from this point on until the ratio is adjusted by the operators by giving advice on the necessary addition or reduction of silica, thus simplifying step 2 and 3.

The slag analysis is directly retrieved from laboratory data into a separate calculation tool, which then calculates the instantaneous Fe-SiO_2 ratio. Afterwards, the Fe/SiO_2 mass ratio is compared automatically to the target Fe/SiO_2 mass ratio, giving direct advice to the operators in the control room, on whether to increase or reduce the silica flow.

As shown in Figure 2, this approach has been well accepted by the operators and was very successful in reducing the amplitude of fluctuations in the Fe/SiO_2 mass ratio, causing a reduction of outliers outside of the target Fe/SiO_2 mass ratio range by 70% compared to before the implementation of the new advice-based control system.

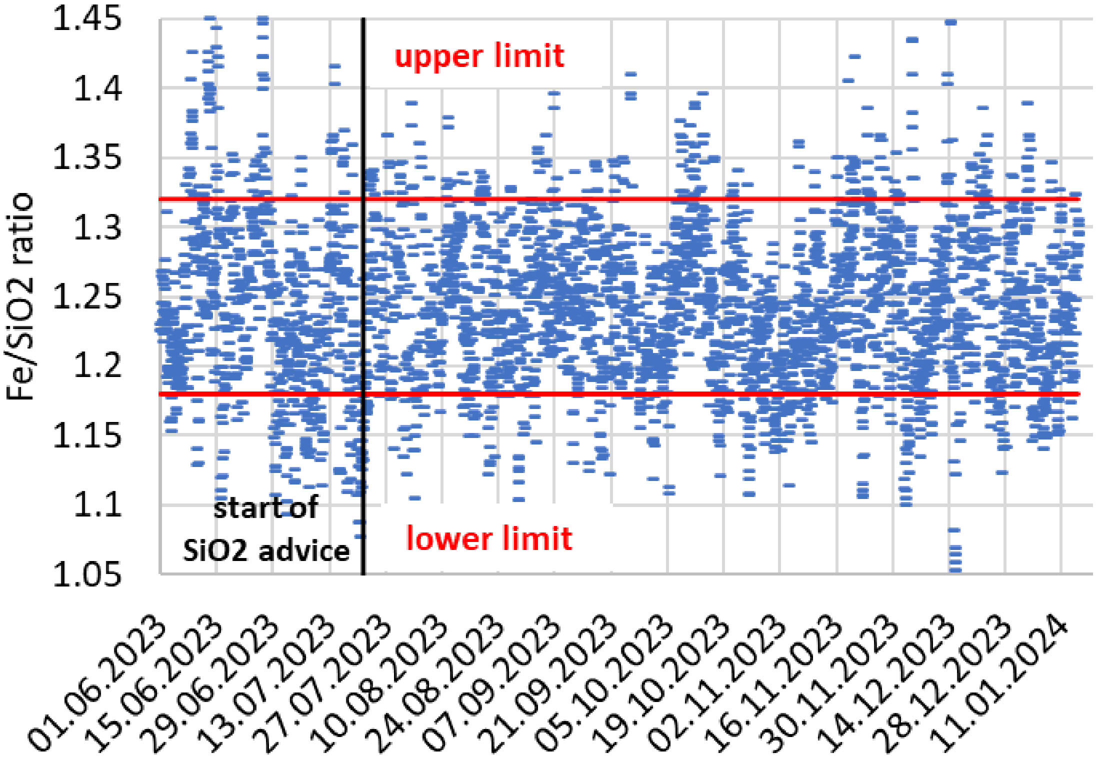

FIG 2 – Fe/SiO_2 mass ratio in SCF slag before and after implementation of the advice-based control system for SiO_2

Since the Fe-SiO_2 was well implemented in the FSF, this control system was adapted to also give advice on the coke charging into the SCF in order to improve the slag quality further. Thereby, the coke already fed into the SCF is calculated based on the bunker weights, giving real-time advice on when and how much coke to charge until the daily target value is reached. The development of the coke charging is shown in Figure 3, proving the significant stabilization of the process after implementation of the advice-based control system.

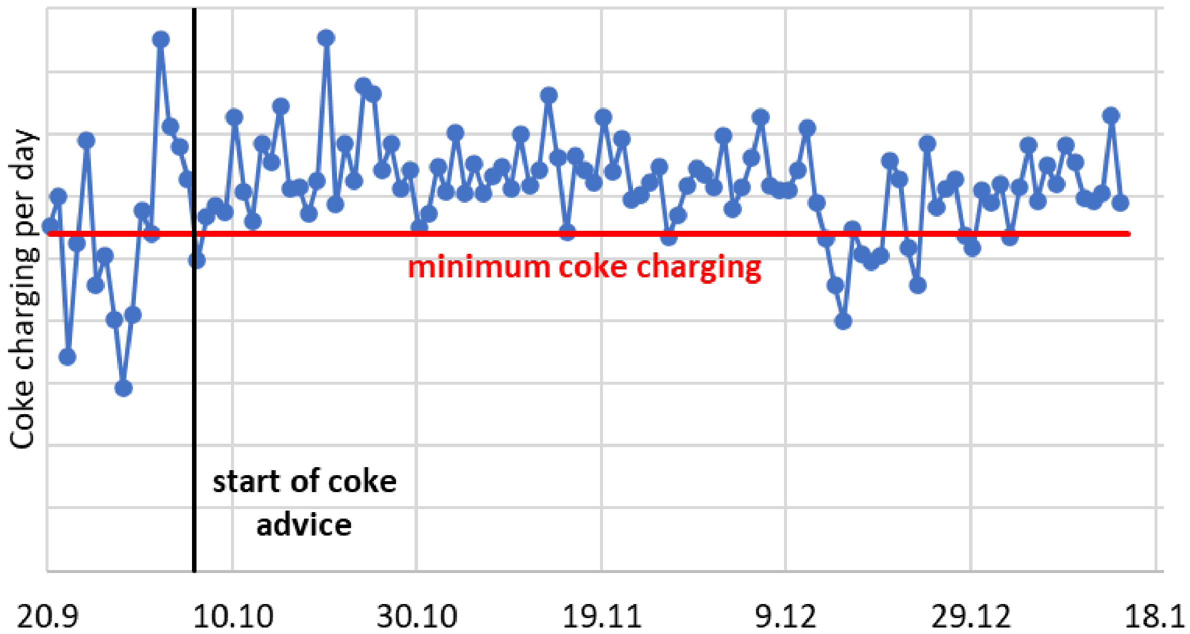

FIG 3 – Daily coke charging before and after implementation of the advice-based control system for coke

In accordance with the thermodynamic predictions described in step 1, the magnetite content of SCF stabilized and dropped significantly after the SiO_2 advice and the coke advice were implemented, as shown in Figure 4. Finally, a magnetite reduction by 41.9% was observed, this improvement is stable for several months by now. Accordingly, the reports of viscous slag by operation have dropped by 56%.

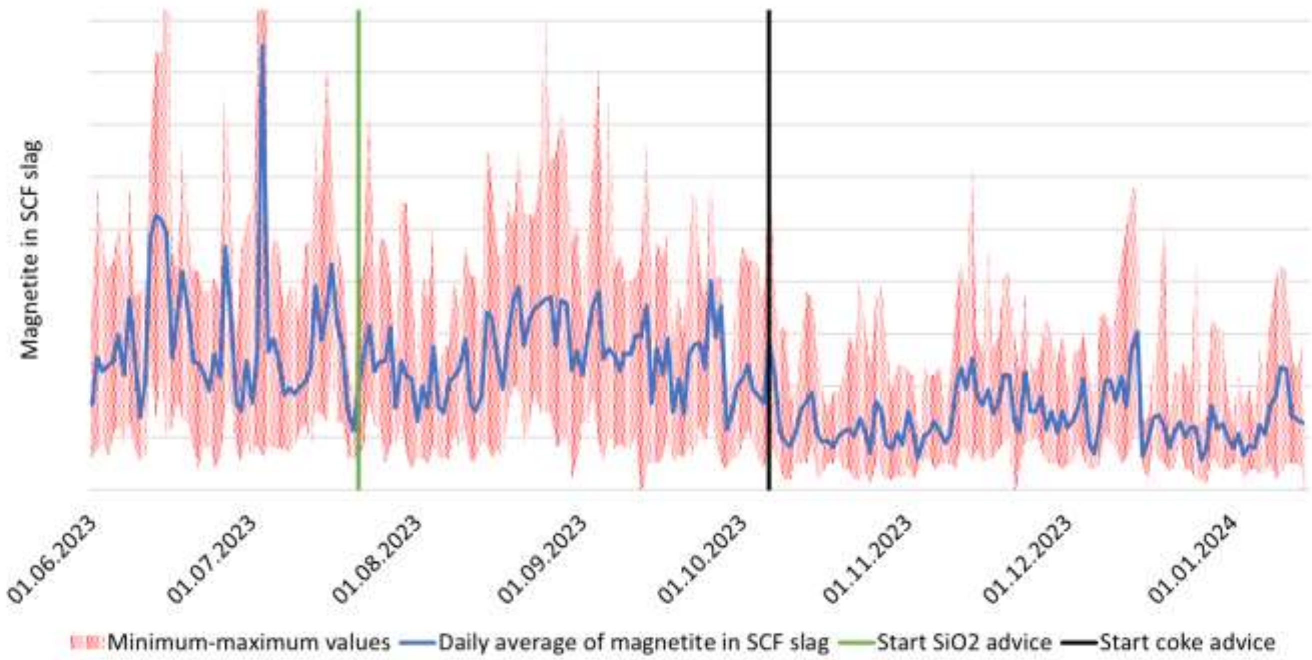

FIG 4 – Development of magnetite content in SCF slag after implementation of the SiO2 advice and the coke advice

The implementation of the advisors in the FSF and the SCF also caused a drop in copper losses, which currently accounts to a reduction of 6% compared to before implementation of the advice-based control system.

CONCLUSIONS

The new advice-based control system was tested for several months and caused a visible stabilization of the Fe/SiO_2 mass ratio and of coke addition to the SCF. In total, both measures caused a reduction of magnetite in SCF slag by 41.9%. This reduction in magnetite led to a significant reduction in reports of viscous slag by operations and caused a reduction in copper losses by 6%, proving that the thermodynamic predictions are correct and that they are an effective measure for improving slag quality. Both measures are still in operation and further data will be evaluated.

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