Efficiency of slag cleaning in a magnetically induced stirring reactor

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Abstract

Slags generated in pyrometallurgical copper processes are mineral by-products governed by the regulations applicable in the building and construction industries. To extend the range of applications and safeguard its EU product classification, sustainable purification and homogenisation of the slag is required.

Experiments in two reactors were carried out as part of a collaborative project funded by the Federal Ministry of Education and Research (BMBF). The fundamentals and theoretical background to this were published at EMC 2011. A pilot-scale stirring reactor, integrated in the industrial process, was operated in a number of weekly campaigns and treated two tons per hour of slag at AURUBIS, Hamburg in a semi-continuous operation. Reproducible results prove the effect of the magnetic and electric field on the settling behaviour of metal/matte droplets in fayalitic slags.

A second, smaller demo-scale stirring reactor was designed and installed at IME, RWTH Aachen University. It facilitates shorter campaigns with synthetic slags of steady qualities and short response times. The aim is to examine the physical and metallurgical principles behind this process in more detail. This test unit allows throughputs of about 0.5 ton molten slag per hour in a 1 MW electric smelter or a 0.5 MW TBRC.

Plans to transfer this technology to other slag systems, for example from Pb, PGM or Ni production, are envisaged for future research programs.

The full paper will be published in a scientific journal soon after the conference.

Introduction and principle

SMS Siemag AG has been designing and constructing submerged arc furnaces for more than 100 years, and slag cleaning furnaces for over 50 years. Recently, SMS Siemag has been developing a new type of SAF [1] [2]. A rectangular DC furnace is equipped with an external electromagnet in order to generate intensive slag stirring using the superimposed magnetic field. The resulting droplet rotation in the first of two zones enhances the coalescence of the small matte or metallic inclusions, which have an inclusion size of 2 to 1000 µm. The second, quiet zone allows settling of the included droplets after their coalescence (see Figure 1).

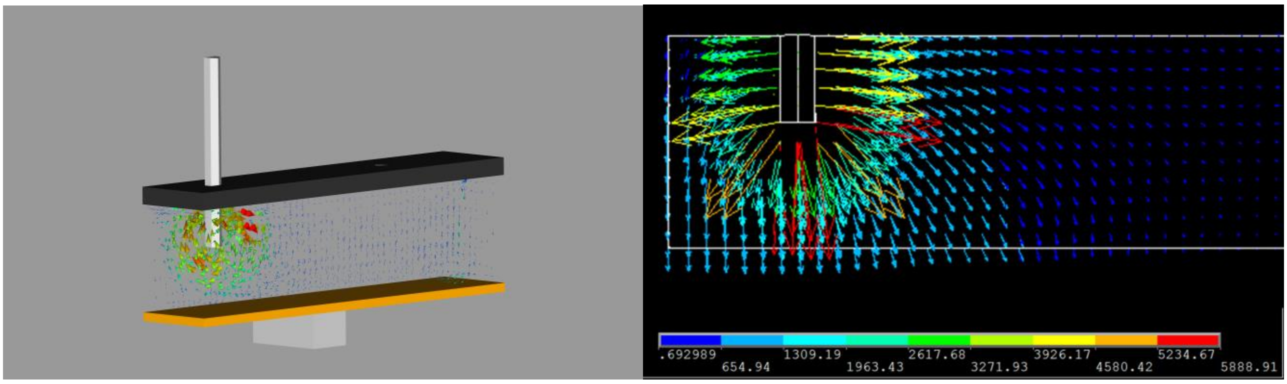


Figure 1: Principle of the DC furnace with electromagnet and resulting stirring conditions and electrical field around electrode

The settling behaviour of the droplets in the stirring reactor is influenced by several factors:

- Forced migration of metal/matte droplets under the electric field results in coalescence;
- Coalescence leads to a settling of the droplets;
- Joule's heat liberation with additional temperature increase;
- Cathodic and anodic reactions due to DC operation mode;
- Injection of additives (less reducer and fluxes);
- Enhancing of mass transfer to the reactant surface by means of the magnetic field;
- Geometry of the furnace.

Hot commissioning of the IME demo-scale stirring reactor

The Aachen stirring reactor is a joint project by SMS Siemag, Aurubis AG and the IME, RWTH Aachen as part of a public-funded research project (BMBF: Federal Ministry of Education and Research). As already presented at the European Metallurgical Conference 2011 in Düsseldorf, the stirring reactor is installed at the IME Research Recycling Center (IRRC) at RWTH Aachen University.

In the first step, the slag is remelted in a top blown rotary converter (TBRC). This furnace has a capacity of 500 litres. The necessary energy is provided by a 0.5 MW burner. The burner setup can be steplessly changed from a gas/air to a pure oxygen/gas operation mode (desired setting for the air/fuel ratio). The rotation speed of the converter can be adjusted between 0 und 8 rpm. The tilting angle can be adjusted to any position. The feedstock material is charged by a vibratory conveyor into the TBRC during burner operation at a maximum speed of 1500 kg/h. Once the slag has been remelted and the desired temperature reached, the slag is charged into the stirring reactor via a casting channel and inflow area.

The Aachen stirring reactor has an operating volume of 350 l. The "technical-scale rectangular SAF" is heated by a DC electrode (diameter 80 mm) with a maximum power of 140 kW. The electromagnet is installed on the stainless steel frame of the stirring reactor. The slag is charged through the inflow area, and once the maximal volume of the reactor is reached any subsequently charged slag leaves the reactor via an overflow on the other side. The reactor is emptied via a bottom matte taphole at the end of the melt campaign. The process off-gas is cleaned by a state-of-the-art system which includes a hot ESP, baghouse and scrubber. [3] The following images demonstrate the casting of slag from the TBRC in the stirring reactor. The Aachen stirring reactor is shown on the right.

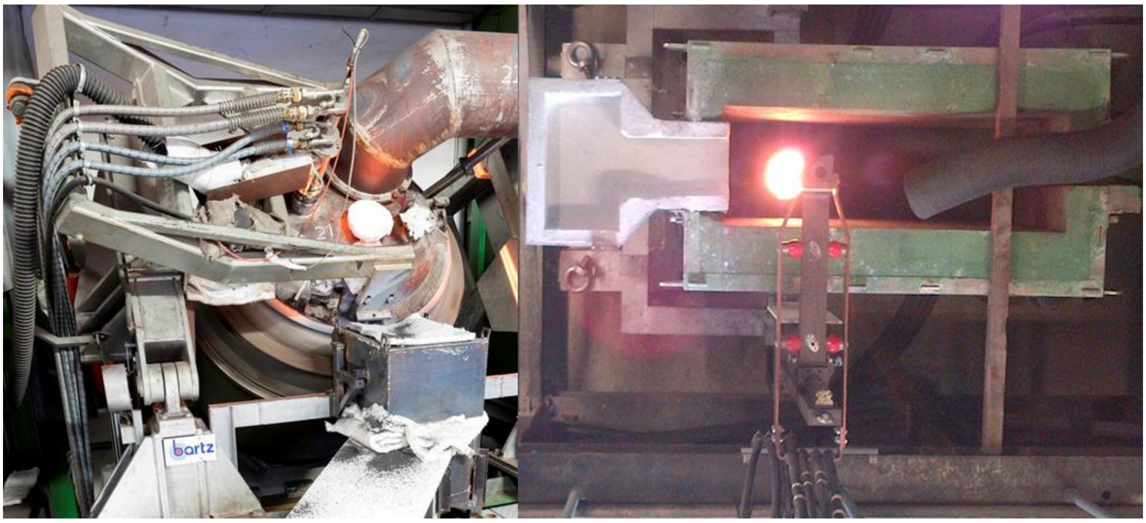


Figure 2: TBRC for slag remelting (left), top view of the IME stirring reactor with open cover (right)

The main advantage of the experimental set-up at the IME is that individual parameters can be examined in detail. For example, different slags can be conditioned to a near constant chemical composition to meet the requirements for redundant experiments. In comparison to up-scaled slag-cleaning units deployed in industrial processes, the Aachen reactor can be charged with a synthetic pre-mixed slag. Moreover, several parameters, e.g. the electrode or magnet position, can be changed with less effort compared to up-scaled electric smelters. After the successful hot commissioning, first trials were already carried out. The main focus of the trials was to examine the improvement of the slag cleaning process using the DC magnet (see figure 1). During a one-day melt, approx. 1.5 t of slag were cleaned in the stirring reactor at the IME research recycling center. The following figure illustrates the melting procedure:

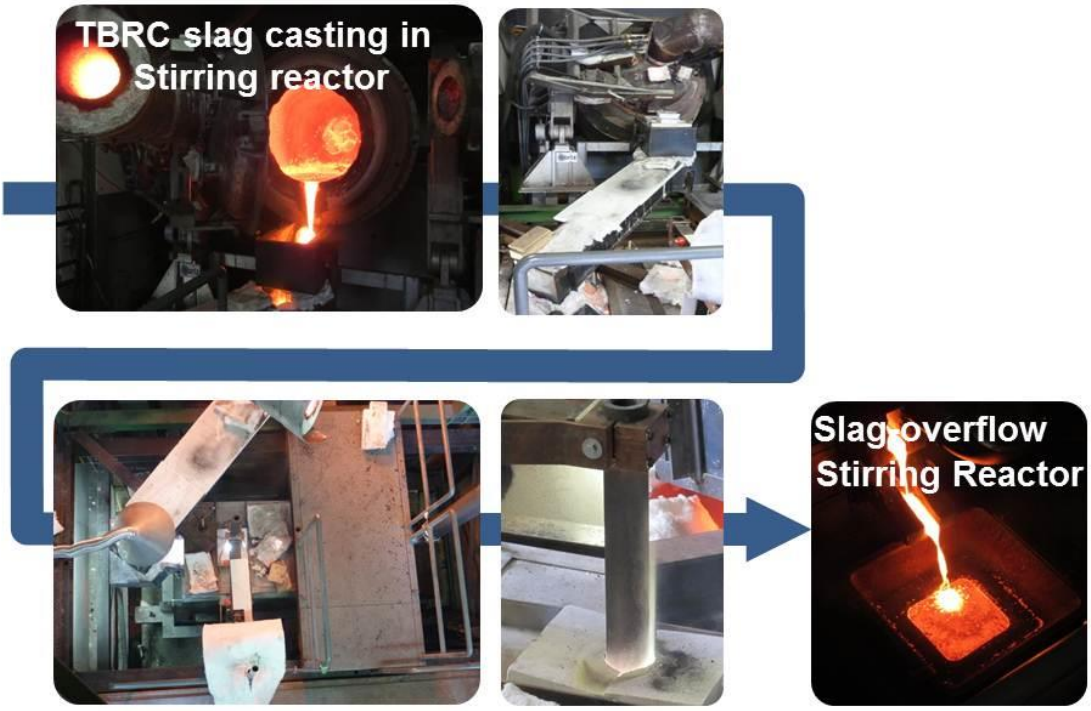


Figure 3: Flow diagram of intensive copper slag treatment with TBRC and stirring reactor at the IME research recycling center (TBRC, launder, stirring reactor with magnet, energy input DC, slag overflow)

Initial results of the trials revealed a significant, positive effect on copper recovery. Verified chemical analysis and additional trials were still in progress at time of going to press but will be presented at the conference. A series of basic tests with different slag systems in the Aachen stirring reactor is planned in future.

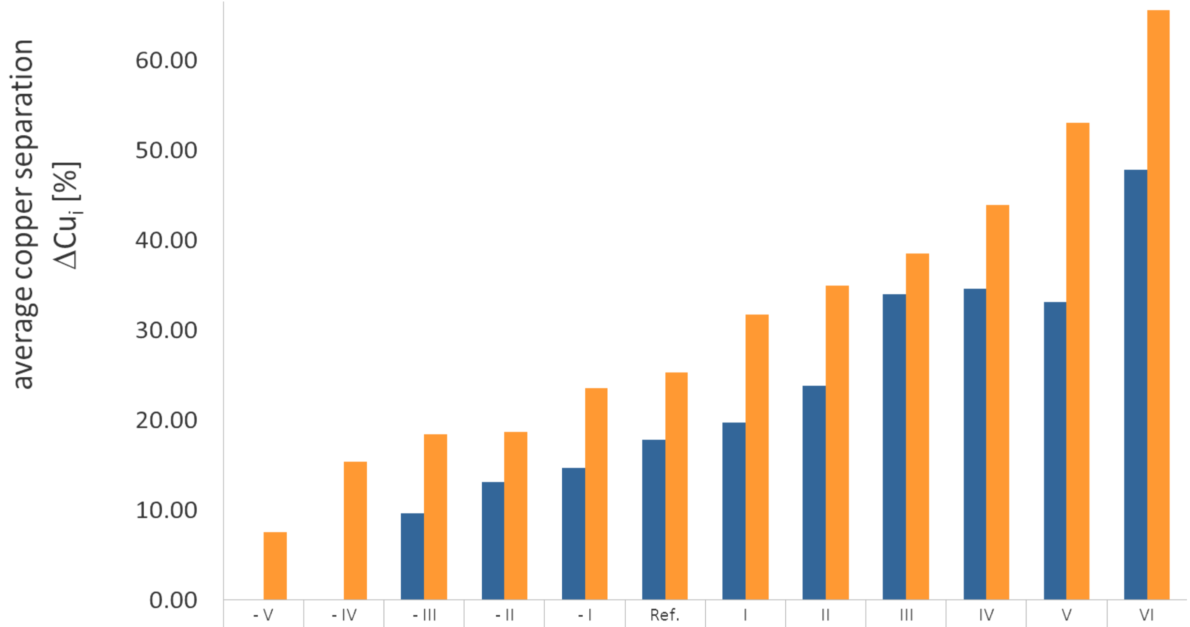
Hamburg pilot plant

The pilot plant in Hamburg, integrated in the production process, is achieving reliable results in terms of the subsequent scale-up to an industrial operation. Although it involved more planning than originally expected, in the end it provided the opportunity of testing the process under realistic conditions and enabled a targeted analysis of individual components.

The furnace was designed for a throughput of 2-3 t/h feed material. The charging of the liquid slag from the existing slag cleaning furnace is performed with specially converted ladles which are conveyed by the special-purpose lift trucks from the slag tapping area of the SAF to the stirring reactor, and then charged by crane with a constant mass inlet flow. The furnace was designed as a DC rectangular furnace, equipped with two electrodes on electrode arms with hydraulic regulation, a bottom electrode and an inside hearth area of approx. 1.6 m². For reasons of simplification, in this pilot furnace the bottom electrode was constructed as a carbon block in the bottom lining. As a semi-enclosed slag cleaning furnace, the furnace is designed with an overflow, i.e., causing the inflowing slag to displace the cleaned slag present in the furnace. The power supply was provided by the works network via an 825 kVA transformer and a rectifier for each electrode, thus enabling a highly variable power input. The main challenge, however, was the electromagnet which was to provide a magnetic force of approx. 200 gauss in the middle of the furnace between an air gap of 1400 mm. In order to avoid any loss of magnetic power or undesired magnetization of individual components, the entire furnace shell was ultimately constructed from stainless steel. The plant control system, developed by Aurubis and SMS, was designed as a semi-automatic system.10 campaigns were run at the pilot plant over a period of more than two years. The duration of each campaign was 8 to 10 days, including the heat-up phase for 2-3 days and the operating period for the rest of the time. The results obtained were evaluated by CFD simulation parallel to the test trials in the pilot plant in Hamburg. This provided the link between the simulation and physical test operation in the pilot plant. Following several improvements with regard to material flow and process control, the overall power-on time gradually increased from 70 % during the first two campaigns to > 90 % after campaign V. 647 ladles of slag were treated within an operating period of 1566 hours.

Results of pilot plant campaigns

In examining the results obtained several parameters like temperature, concentration of magnetite, slag basicity and others were taken into account, however there was one main influencing factor – the copper concentration of the feed material. Figure 4 illustrates the average copper separation between the overflow iron silicate product and the feed material. The classification of the copper concentration for the feed material is shown on the x-axis. On the y-axis the average copper separation was determined for each process status on the one hand and for each class on the other hand.



	- V	- IV	- III	- II	- I	Ref.	I	II	III	IV	V	VI
without enhanced stirring [%]	0	0	10	13	15	18	20	24	34	35	33	48
enhanced magnetic stirring [%]	7	15	18	19	24	25	32	35	39	44	53	66

Figure 4: Comparison of copper separation without and with enhanced magnetic stirring depending on the copper concentration of the feed material [4]

The driving force for separating copper from the feed material increases as the copper concentration rises. This means that even at high copper concentrations in the feed, sufficient separation to low copper concentrations in the overflow iron silicate product is feasible. Determining the copper separation ratio between the enhanced stirring status and the status without stirring, the value is > 1 for every histogram class. This means that – irrespective of the copper concentration of the feed material – the application of the magnetic field results in better copper separation than the reference unit without enhanced stirring. At low copper concentrations (- IV, -V) in the feed, copper can be separated by applying the magnetic field, whereas this was not observed without additional stirring.

Acknowledgement

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