HIGHLY EFFICIENT ELECTRIC SMELTERS FOR THE PLATINUM INDUSTRY – SMS SOLUTIONS FOR ENERGY SAVING

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Abstract
Submerged arc furnaces and electric smelters are applied in numerous metal and slag production lines. Particularly in ferroalloy and non-ferrous metal production, like silicon metal, platinum group metals, calcium carbide, and copper, the units are an essential part of the production technology. Most of these electric furnaces are considered to be highly energy-intensive units. The high level of required electrical power is defined by the process. SMS developed several measures to reduce the overall electrical energy consumption of these metal production lines. In particular, the following measures contributes to a lower energy consumption: improved electrical efficiency with intelligent design and application of components, minimizing the heat losses from the furnaces with a balanced cooling/refractory systems, minimization of process steps (such as elimination of agglomeration), recovery of energy, process optimization (resulting in higher metal yield) and the achievement of higher recovery rates, enlarging furnace capacity to reduce heat losses, and maximizing the power-on time. This paper gives an overview of the above-mentioned solutions.

Introduction

Metix, based in Johannesburg, joined SMS Siemag AG as part of the SMS Group in June 2011. Active in plant construction and equipment supplies for the ferroalloy industry for around ten years, Metix has carved out a leading market position regarding electric smelter technology in southern Africa, which, when combined with SMS Siemag, takes the group market share to more than 50 per cent of the western world's ferroalloys, including non-ferrous and precious metals market, ranging from platinum, silicon metal, calcium carbide, and copper. SMS Siemag is a well-known global leader in metallurgical plant and machine construction.

Previously Metix concentrated mainly on supply of equipment and plants for the production of ferrochrome and ferromanganese, but its merger with SMS Siemag expands its range into platinum, silicon metal, ferrosilicon, ferronickel, calcium carbide, and copper.

In addition, Metix now has access to new technology equipment and processes related to DC furnaces, rectangular furnaces, and gas cleaning and waste heat recovery, which should be also of great interest for the platinum industry in South Africa.

The early history of the SMS Siemag Group is linked with the development of the dynamo machine by Werner von Siemens, one of the most recognizable developments that started the industrial utilization of electrical energy. The increasing demand for ferroalloy and de-oxidation agents in steelmaking in the beginning of the 20th century led to the development of the first electric furnaces. DEMAG, for the past century a major supplier to the iron and steel industry, started with the construction of the first 1.5 MVA submerged arc furnace in 1905[1]. The 1.5 MVA unit was installed in Horst Ruhr, Germany for the production of calcium carbide and was successfully commissioned in 1906. In addition, around the same time a second furnace was installed for the production of ferroalloys. To date SMS Siemag has constructed over 700 smelting furnaces for various products

An overview of major installed AC and DC furnaces and projects that are currently under execution by the SMS group is shown in Figure 1. Generally, the furnaces are installed at locations where good-quality raw materials, as well as sufficient and lower priced electrical power, are available.

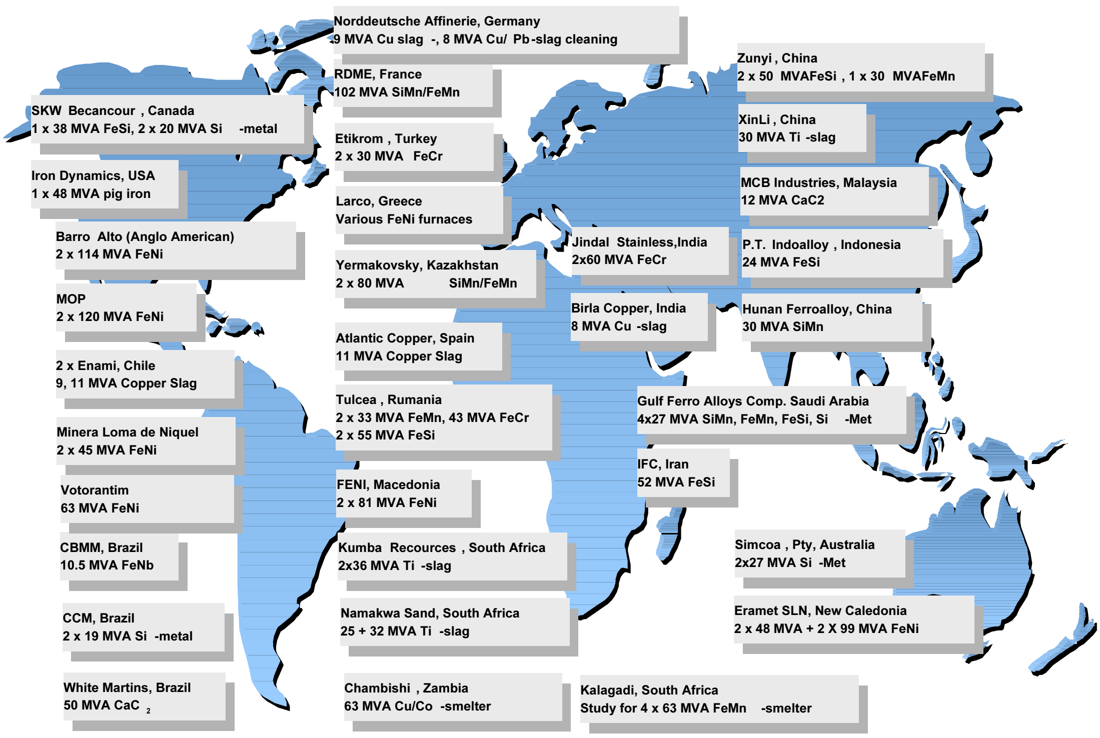

Figure 1. Selection of SMS group references worldwide[2]

Energy consumption of electric smelters

The overall energy consumption varies depending on the process. The production of silicon metal and FeSi requires the highest specific energy consumption. The electrical power needed for a silicon metal furnace is in the magnitude of 11 000 – 13 500 kWh.

Ferronickel units have an energy consumption between 5500 – 8000 kWh per ton of FeNi. This strongly depends on the minerals and the nickel level of the product[3].

The power level, as applied for the smelting of PGM concentrate, varies between 600 - 1100 kWh per ton of concentrate.

The major part of the electrical energy consumption in smelting furnaces is for melting and reduction reactions.

A large portion of the heat energy leaves the furnace via the slag, though this is of course different for slag-free processes such as calcium carbide or silicon metal production.

Generally significantly smaller portions leave the furnace via the metal and off-gas.

Whilst energy consumption is lower in the case of PGM smelting, any reduction in power consumption must be beneficial, particularly considering the current market price for PGMS, which has made reducing production costs a prime requirement for producers in order to survive.

In the following sections, several examples are given how over the past few decades SMS has worked on possibilities to reduce the overall energy consumption of electric smelters.

Energy savings with energy recovery systems

With shortages electric power in South Africa, as well as large increases in power costs, reduction of this cost component by the use of energy recovery systems is becoming vital. Basically two main principles can be applied: recovery systems for semi-open and closed-type furnaces

Semi-open-type furnaces

In semi-open-type electric smelters, the combustible process gases, which are generated during the reduction of the feed materials, are fully burned in the freeboard. The furnaces are equipped with doors or air injection points that allow the control of the off-gas temperature. Depending on the process, the temperatures are between 550°C and 1100°C.

Figure 2 shows an energy recovery system, as currently installed at Etikrom in Turkey, for a ferrochrome application[3].

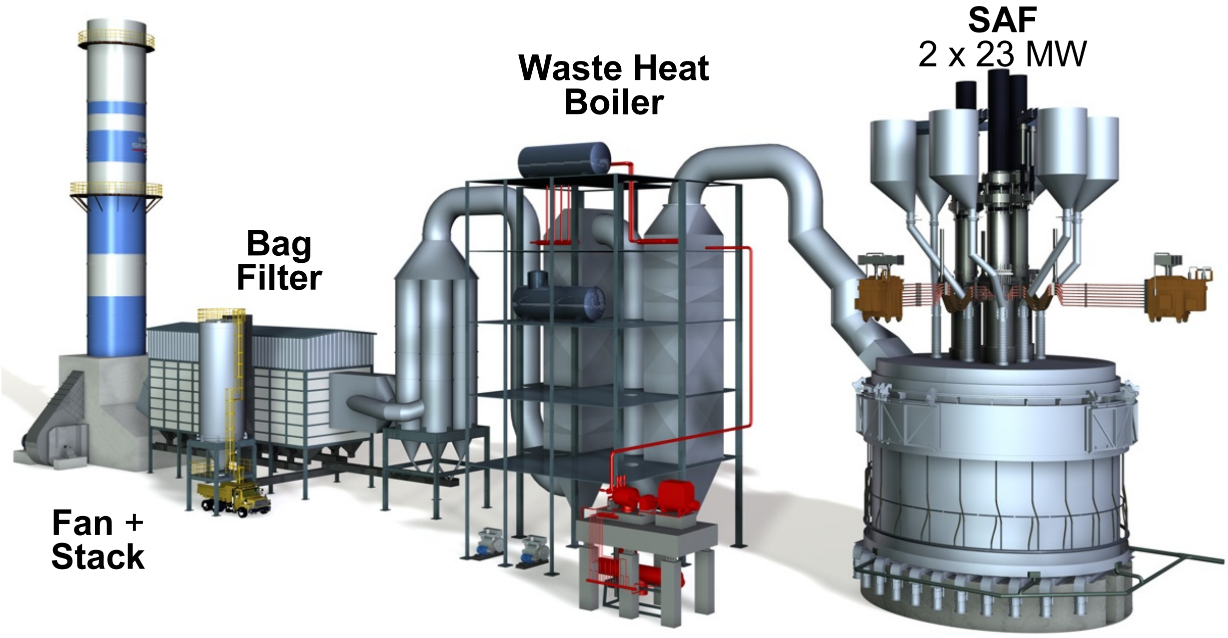

Figure 2. Energy recovery system applied to FeCr smelting, as currently installed at Etikrom, Turkey

The boiler produces 2 x 15 tons of steam per hour, which is converted in a generator to 2 x 2.5 MW electrical power. This correlates in total to an overall annual CO_2 reduction of 25 000 t. The client calculated an amortization period of less than 3.5 years for this investment. The principle of the energy recovery system is shown in Figure 3.

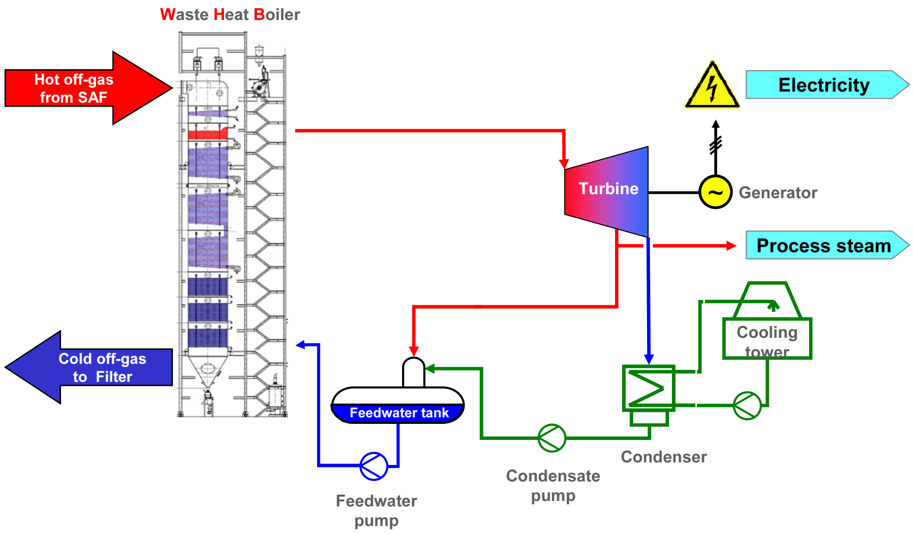

Figure 3. Flow sheet of the energy recovery system for open-type furnaces[4]

Such systems become even more economical for processes that generate large quantities of off-gas, silicon metal furnaces. Internal calculation shows, that up to 20 per cent of the input electric power can be recovered. Such a system was developed by SMS for a plant in Norway and has been operating successfully since the1980s.

Closed-type furnaces

The closed-type furnaces produce CO-rich gas, which can be utilized in various upstream and downstream processes. As an example, the calcium carbide industry uses the gas for the calcining of the limestone. SMS offers an energy recovery system for closed-type furnaces based on process gas boilers (Figure 4), which generates steam for the captive power plant[4]. The combustible off-gas can be used after a gas-cleaning step. Here SMS developed its own scrubber systems as well as innovative electrostatic filters. A part of the sensible heat can be also used to heat, for example, feed water.

Although the amount of gas generated during PGM smelting is lower, consideration of its use to generate power to replace usage of Eskom power is vital, particularly with increases in excess of 15 per cent per annum for the next three years.

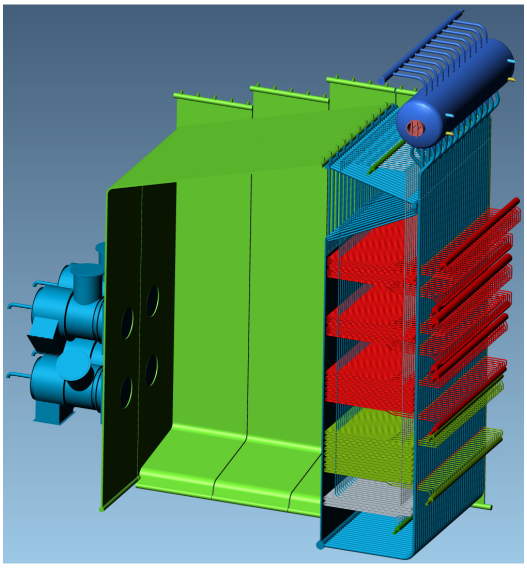

Figure 4. Illustration of the gas waste boiler

Energy savings by improvements in electrical efficiency

The design and the chosen material for the high current line, as well as for the furnace roof, can influence energy consumption. SMS optimized the high current line system in this respect to minimize the reactance of the system. The transformers are placed as close as possible to the electrodes[5]. Additionally, a larger cross-section area in the high current line system, as well as the use of a pressure ring made of copper, can reduce the overall electric power consumption.

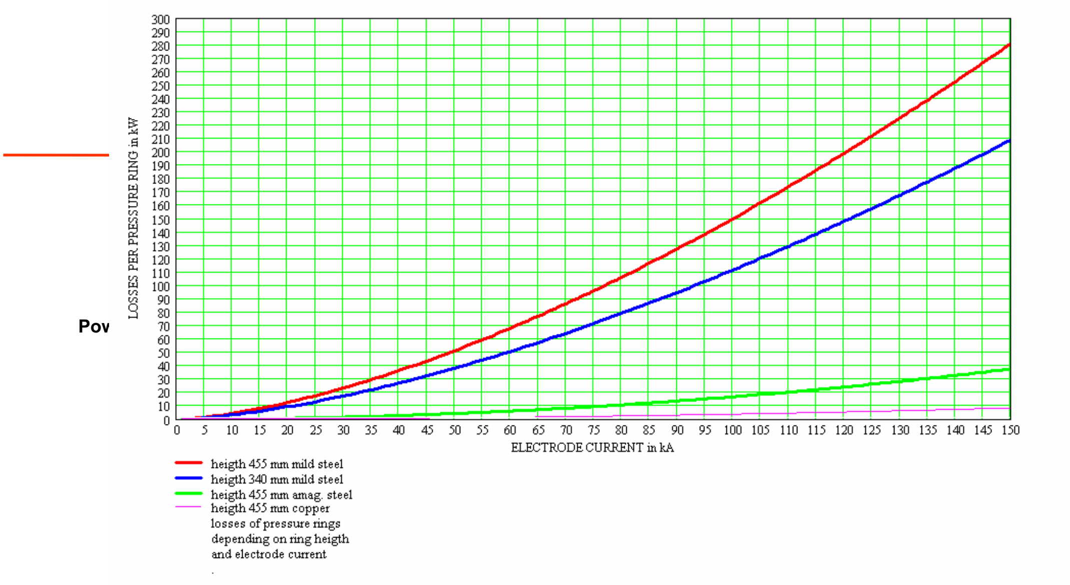

Figure 5. Power saving potentials with the copper pressure ring

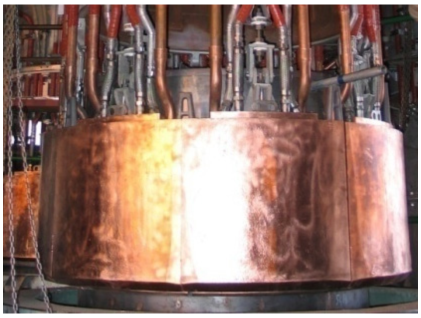

Figure 6. Energy-saving copper pressure ring for Söderberg electrodes

Figure 5 illustrates the potential of power savings when applying the copper pressure ring (Figure 6). The potential power savings increase with increasing furnace power capacity[6, 7]. The choice of the type of pressure ring influences these power savings, and which Metix can offer a suitable solution for.

Energy savings with advanced cooling concepts

For many furnaces, certain cooling systems with a specifically designed refractory lining are required to prolong the furnace campaign period. It is SMS's philosophy that the furnace needs to be cooled sufficiently, but not to an extent that too much heat is removed from the process. A new kind of roof cooling system has been developed to lower the overall energy consumption considerably[8]. For Kazchrome, Four 72 MW DC-based furnaces incorporating this system are under construction for Kazchrome. A new cooling/refractory system lowers the overall heat losses of the furnace by more than 3 MW in comparison to conventional DC technology, as offered by other companies. Figure 7 shows an illustration of the furnaces.

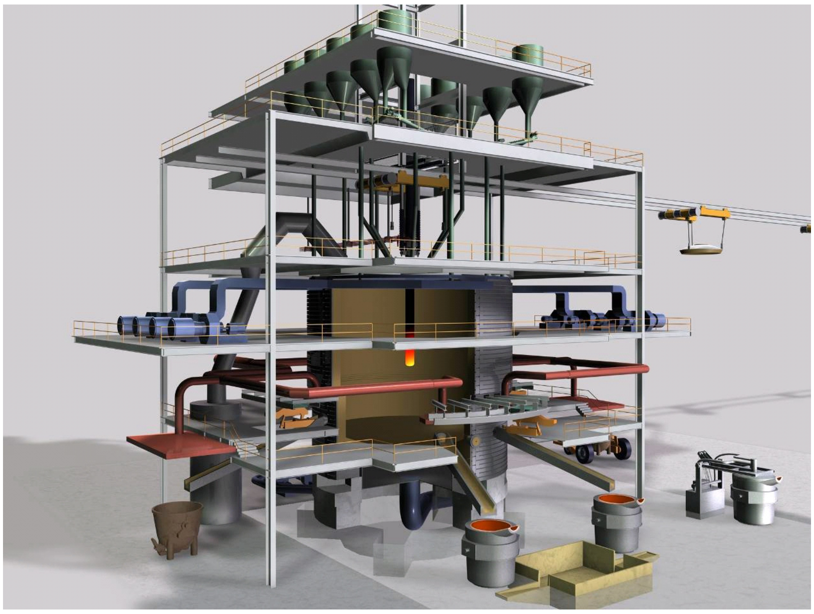

Figure 7. Illustration of the DC furnace being built for Kazchrome, Kazakhstan

The roof as well as the sidewall is lined with high-quality alumina-based material. The closed-type roof, as well as the bottom anode, is air-cooled. The sidewall is cooled by a channel water cooling system.

Additionally, SMS provides special cooling arrangements for PGM and ferronickel furnaces based on copper plates inserted in the sidewall. This cooling system extracts less energy in comparison to available waffle coolers or copper staves, as supplied by others. This cooling arrangement is working successfully and reliably in the largest furnaces (Figure 8*) and can result in electrical energy saving levels of more than 1.5 MW for larger furnaces[9, 10].

The heat losses from large-capacity furnaces are relatively less than from smaller units. This is also one of many reasons why the trend is towards larger units based on rectangular furnaces applying 6-in-line electrode systems.

The largest rectangular furnaces operating in the world have been supplied by SMS for the production of ferronickel and for the slag cleaning processes as applied in the copper industry. The first-generation systems were installed in the 1960s and 1970s based on a conventional column structure (former Demag design). A significant improvement was achieved in the 1980s by applying the so-called frame structure design. Today, the frame structure design principle is applied in all of SMS's larger-scale rectangular furnaces. Reference for these larger furnaces are the recently installed units of Anglo American, Brazil (2 x 114 MVA ferronickel furnaces); Vale, Brazil (2 x 120 MVA ferronickel furnaces); Eramet, New Caledonia (2 x 99 MVA ferronickel furnaces). Apart from some refractory design changes, this same rectangular furnace design is also applicable to PGM furnaces.

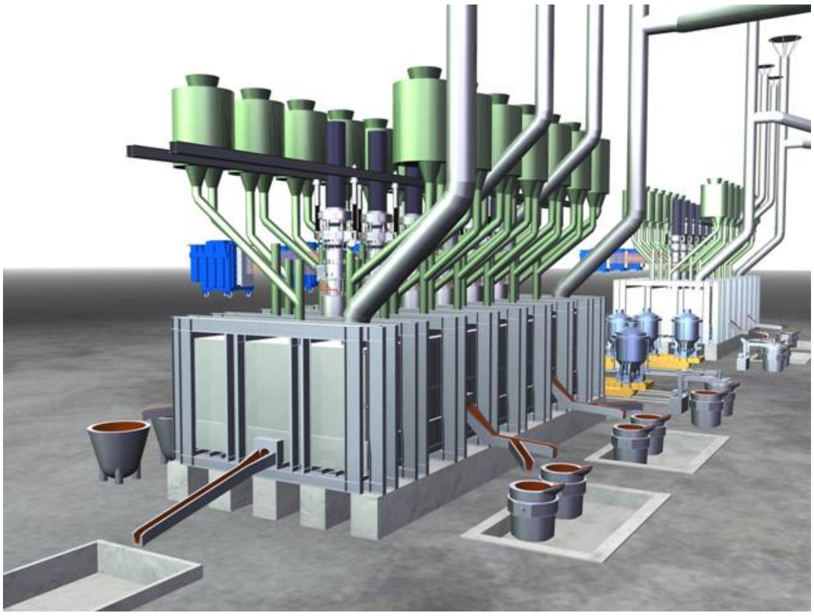

Figure 8. Rectangular furnace with copper cooling system for the sidewall[10]

SMS applies a balcony-shaped sidewall. While the refractory is expanding during the start-up of the furnace, the forces of the refractory bottom are directed into the corner underneath the balcony[11]. This design minimizes these forces pushing into the vertical direction of the furnace. The counter-force is established by the weight of the roof and the sidewall lining. No down-holding system is required. The end walls of the furnace can move and are tightened by tie rods (Figure 9).

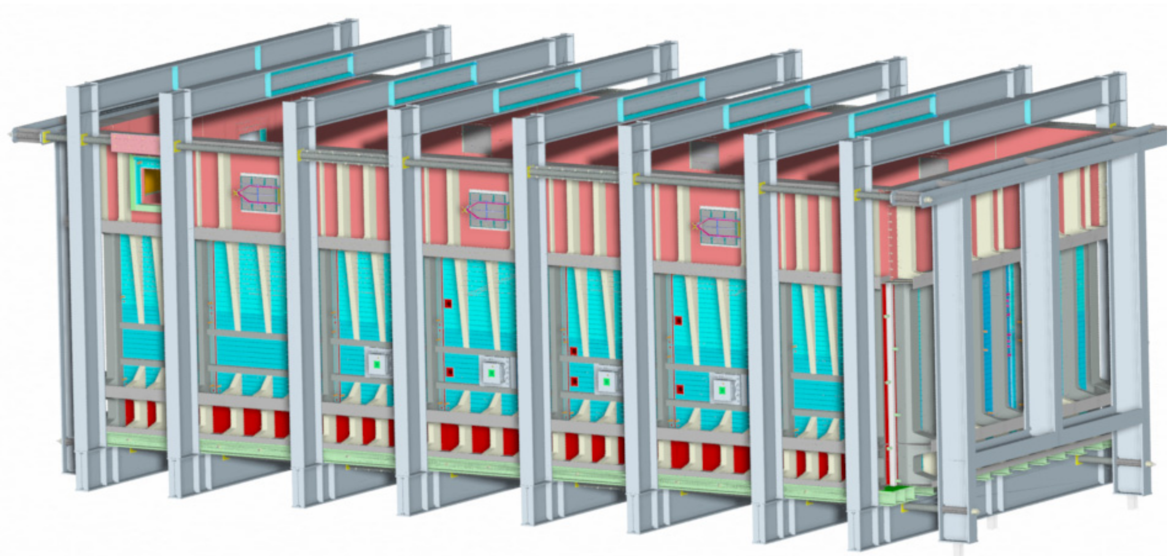

Figure 9. Principle a rectangular furnace with frame structure[12]

According to most refractory suppliers, this design is the best available mechanical system for large-scale rectangular furnaces, allowing a controlled expansion and tightening of the refractory and a long lifetime of the lining. The maintenance of the tie rods is low and the overall system is reliable, and no metal/matte penetration into the lining has been observed during furnace operations. After the furnace start-up, the system needs only to be checked by observation. Under normal operating conditions, adjustment of the tie rod tightening requires less than 20 per cent of the maintenance effort compared to conventional systems. The design improves the efficiency of sidewall copper cooling systems for the slag level area. The forces between the refractory surface and copper cooler surface provide a good heat transfer coefficient[13-15].

Energy saving by increasing furnace availability and campaign life

Heat losses and electrical losses are additionally reduced when a furnace is operating constantly at or above nominal load at a constant load, and when the furnace parameters, including the raw materials, are kept constant. Furnace interruptions, particularly, have a great adverse impact on the energy consumption due to the additional energy required for heating up the furnace and for re-stabilizing the process [15-17]. Additionally constant and stable operation lowers the idle time when auxiliary equipment and water treatment plants are still running and consuming energy[18]. SMS is well known for supplying reliable and efficient smelters world-side, with designs that assures the highest availability levels. Some of the units operate for several years with an availability of nearly 100 per cent at nominal furnace load.

Energy savings by process optimization

Submerged-arc furnaces are also applied for slag cleaning. SMS developed a continuous-operating rectangular furnace that ensures a better recovery rate in comparison to circular shaped furnaces. SMS recently commissioned furnaces for Mopani Copper in Zambia and for KazZink in Kazakhstan, where such a unit is placed downstream of an ISASMELT type of primary smelter[19]. The copper level can reach below 0.7 per cent in the discharged slag. Figure 10 shows an illustration of this unit.

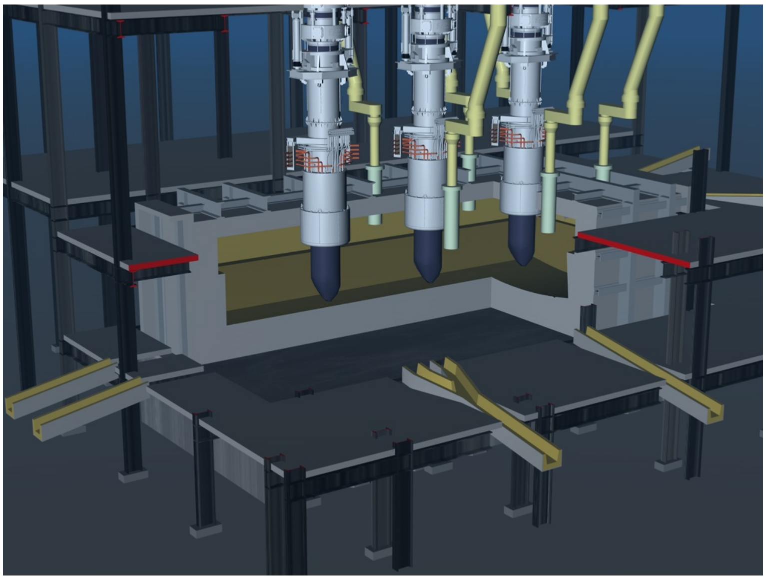

Figure 10. Copper slag cleaning furnace at Mopani Copper in Zambia

The furnace in Zambia has a transformer connection of 11 MVA, while the unit in Kazakhstan is connected to 12 MVA transformers[19].

SMS/Metix received an order from the Kansanshi Mining plc, which is owned by First Quantum Minerals and based in Zambia, for the supply of a rectangular 6-in-line furnace (see Figure 11). This furnace is also connected with an ISASMELT furnace. The unit has a transformer connection load of 24 MVA.

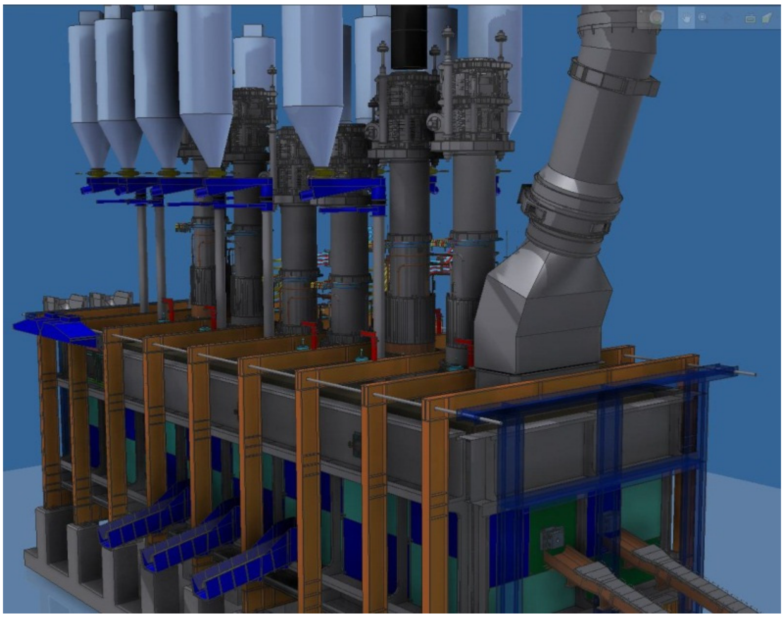

Figure 11. Illustration of a 6-in-line rectangular furnace for slag cleaning

SMS is currently developing a new type of slag cleaning unit that allows the recovery of metals to a low level[20]. The smelter is based on DC technology and applies an additional magnet. The physical conditions in the furnaces improve the coagulation of the metal droplets and the settling conditions in the furnace. The process principle is illustrated in Figure 12 and has been described extensively elsewhere[20].

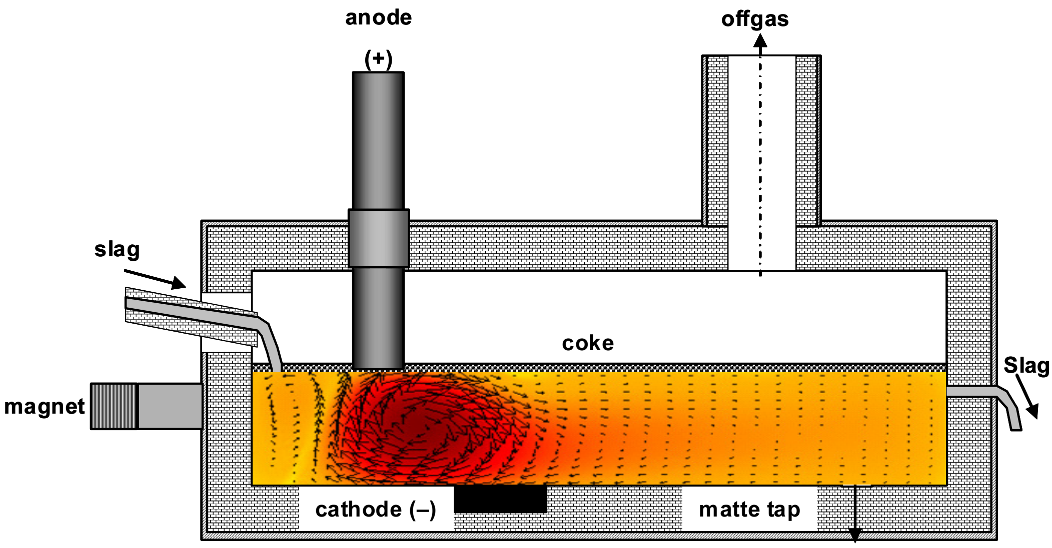

Figure 12. Intensive copper slag cleaning unit of SMS

Coalescence of very small matte/metal inclusions is required to separate them from the slag phase. The role of slag motion on the coalescence of inclusions and recovery of nickel and PGMs in an electric furnace as a function of electrode immersion was clearly demonstrated by the experience reported at the Polokwane smelter[19]. The new process developed for slag cleaning combines a rectangular DC reactor with an extra magnetic field generated by electromagnets and with several other innovations that contribute to an improved metal/matte recovery[20].

The slag is charged into the reactor continuously via a launder situated at the short side and is tapped on the opposite side via an overflow. This overflow maintains a constant bath level, eliminating the necessity for electrode control. Matte is tapped periodically. A floating coke bed on the slag surface, in contact with a graphite electrode, serves as the anode. The copper matte layer, in contact with a graphite block, is present as a liquid cathode on the furnace hearth. This provides an electric field between the slag and the metal/matte layer. Magnetic poles are placed outside the furnace shell on the long side in the vicinity of the underside of the electrode tip and provide a strong magnetic field in this area. The resulting main Lorenz forces, occurring primarily under the electrode tip, create a strong movement of the slag and induce a stirring pattern in the slag layer[20].

The utilization of a DC electric furnace with a superimposed permanent magnetic field for treatment of slag generates a set of complex phenomena occurring in parallel. Basically, the left-hand part of the reactor (in Figure 12) represents the reactive stirring zone, whereas in the right-hand part excellent settling conditions are present. Due to its ability to further reduce the valuable metal content of the slag and to the stirring pattern in the first zone of the furnace, SMS has given the unit the nickname 'the washing machine'.

The experience gained from the modeling as well as from tests in Chile established the basis for a newly projected pilot plant in Europe.

The new unit has several more features (more flexible and powerful magnets, two electrodes, injection options) allowing a reliable test phase with the possibility of investigating the influence of various parameters in order to evaluate the full potential of this process principle (see Figures 13 and 14).

Figure 13. Pilot-scale intensive slag-stirring reactor – front view

Figure 14. Overflow of the intensive slag-stirring reactor

SMS is also in the planning phase for implementing this technology on an industrial scale. Capacities of up to 100 t/h should be possible. Additionally, the lower metal and arsenic content in the final slag might also allow sale of the cleaned slag to potential offtakers in the iron, steel, cement, and construction industries[21].

Besides the processing of slag from conventional slag cleaning furnaces, investigations are being made as to whether such a process is capable of treating slag from a copper flash smelter, Teniente converter, or ISASMELT/Ausmelt-type furnaces.

Currently talks are being held with the PGM industry in Africa related to the above technology. SMS sees great potential for this technology in this field. A recovery of > 50 per cent of the lost PGM-containing matte as inclusions at a specific electric energy consumption of 50 –70 kWh/t of slag might be feasible, according to the test work[20].

SMS also envisages good potential for the new technology in existing PGM production lines, where conventional electric slag cleaning furnaces and various primary smelters (such as Ausmelt furnaces – as utilized at Anglo Platinum in South Africa) are in use. The process principles are the same and good additional recovery rates are expected.

Constant innovation through R&D

SMS has supplied a new electric smelter test furnace to the IME (Institute for Metallurgical Processes and Metal Recycling) at the Technical University in Aachen, Germany[22].

The unit will allow the testing of various metallurgical smelting processes, such as ferroalloys, non-ferrous metals, mineral wool, slag cleaning, steel mill waste recycling, waste recycling of non-ferrous and ferroalloy residues, and steel production in DC as well as AC mode (Figure 15). This will provide important information comparing the two basic process principles. The pilot plant will also allow the testing of new refractory and cooling concepts as well as an accurate determination of the mass and energy balances of new processes. The heart of the 1 MVA furnace is an intelligent power connection allowing the following modes of operation:

- Three-electrode DC-operation mode with AC-mode simulation
- Two-electrode AC mode
- One- to three-electrode-DC mode.

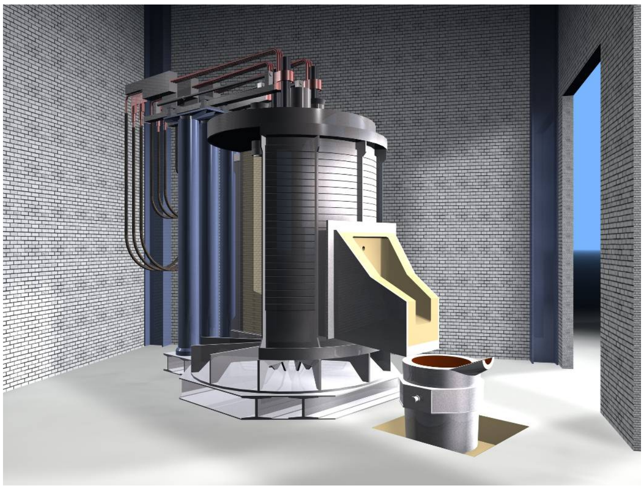

Figure 15. New AC/DC-based 1 MVA test furnace at the IME in Aachen, Germany[22]

The furnace is equipped with a conductive hearth. The charge can be fed either via charging tubes or hollow electrodes, which facilitates the evaluation of optimized feeding patterns. The unique multiple section design allows the testing of various sidewall cooling systems such as spray cooling, channel cooling, and intensive copper cooling. The size of the furnace provides important information for upscaling of new processes.

Conclusion and outlook

Since the early 19th century SMS has instituted remarkable developments in smelting technology, and submerged arc furnaces are now operating in at least 20 different major industrial fields. SMS looks back proudly on the significant role of the company in the history of these unique and highly efficient units – for both AC-based furnaces as well as DC-based furnaces. Most of these electric furnaces are considered to be optimized energy-intensive units. The high level of required electrical power is defined by the process.

SMS developed several measures to reduce the overall electrical energy consumption of these metal production lines. In particular, the following measures contribute to a lower energy consumption:

- improved electrical efficiency through intelligent design and application of components
- minimizing the heat losses from the furnace with balanced cooling/refractory systems

- minimization of process steps (such as elimination of agglomeration)
- recovery of energy
- process optimization (resulting in higher yield) and higher recovery rates
- enlarged furnace capacities to lower the relative heat losses
- maximizing the power-on time and optimization of the calcining and pre-reduction stages (e.g. for ferronickel smelters).

With ongoing innovation and adaptation to customer and market requests, we are convinced that the units will be also successful in the future. To avoid drawing conclusions based solely on traditional viewpoints, SMS has started a longer-term research and development project to compare AC with DC operation, which is jointly carried out with the Technical University in Aachen, Germany.

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