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Application potential of DC smelter technology for the platinum industry in South Africa

R. DEGEL, K. SCHMALE, M. KÖNEKE, and H. SCHMIEDEN
SMS SIEMAG AG

In 1906, the first submerged arc furnace was supplied by SMS Siemag. Since then the unit has become established in various industries such as ferroalloys and non-ferrous metals and in numerous other special applications. During the 'evolution' of this technology, more efficient units with longer lifetimes were developed. Today, especially the potential of DC-based smelters raises worldwide attention and some projects have already started to implement this kind of technology. This paper evaluates SMS Siemag's general viewpoint regarding the potential application of DC smelter technology and possible options for the platinum industry. SMS Siemag is currently executing an FeCr project in Kazakhstan, where four of the world's largest closed-type DC furnaces with a power input of 72 MW will be installed. These furnaces include the latest technological features of modern DC smelters, which will be described in this paper. The main R & D projects focusing on DC application will be introduced: SMS Siemag has reached a new milestone in the upscaling of a new slag-cleaning furnace principle, allowing reduction of the metal level in the discard slag to the lowest possible level. Additionally, SMS Siemag has started a unique long-term research and development project allowing a direct comparison of AC vs. DC technology on a large scale in a recently installed 1 MVA test furnace at the IME at the University of Aachen/Germany.

Keywords: DC furnaces, electric smelter, platinum production, ferroalloys, circular furnace.

SMS Siemag's history in smelter technology

The increasing demand for ferroalloy and deoxidation agents in steelmaking at the beginning of the 20th century led to the development of the first electric furnaces. DEMAG, for the last century a major supplier to the iron and steel industry, started with the construction of the first submerged arc furnace in 1905[1]. The 1.5 MVA unit was installed in Horst Ruhr/Germany for the production of calcium carbide, was successfully commissioned in 1906 and was based on DC technology. Since then, SMS SIEMAG has been developing various DC- and AC-based smelter types for more than 100 years and has supplied a diverse market with about 700 smelting furnaces and major furnace components[2,3]. Today, the major proportion of metal-producing smelting furnaces (excluding steelmaking furnaces) represent AC-based concepts. Numerous applications have been constantly developed, serving various users. The customers are distributed all over the world, predominantly in countries with large raw material reserves and/or low energy costs (see Figure 1).

Conventional DC furnaces

The DC furnaces are generally of circular type and the electrical energy is converted into heat (in most of the processes) mainly by the arc, which is established between the electrode tip and the slag bath. The top electrode is connected as the cathode and the conductive bottom system is connected as the anode. It should be noted that SMS Siemag has patented all DC bottom anode systems, i.e. conductive hearth (Concast), billet-type (DEMAG), and pin-type (GHH). Therefore, our company was and still is involved in almost all DC-based projects all over the world.

A typical furnace with open slag-bath operation usually comprises 1 to 3 slag tap holes and 1 to 2 metal tap holes at a lower elevation. Due to the fact that the liquid slag temperature is in direct contact with the refractory material and because of the radiation heat of the arc, the furnace requires advanced cooling arrangements in the roof and sidewall area. The refractory concept has to be designed carefully to adapt to these harsher conditions. The electrode is consumed by the furnace process. The prebaked electrodes are periodically extended by new pieces[4]. Conventional concepts apply electrode arms to regulate the electrode. SMS Siemag has developed an innovative E-column specially designed for DC furnaces[5,6]. The

Figure 1. Customer distribution worldwide[3]

mechanical functions and the electrical power-transfer principles are similar to the conventional AC-based electrode columns. Figure 2 shows the roof section of a DC smelter.

DC furnaces can also be designed as a closed furnace type and the CO can be collected. Our strength in DC technology can be summarized as follows[7–9]:

- Unique in-house knowledge for minimizing arc deflection (bus bar routing + E-column)
- Optimized energy consumption due to combined electrode movement regulator with thyristor ignition controller and high electrode speed
- Patented reliable long-life DC-electrode column system, allowing slipping and nippling under full power (providing maximized power-on time)
- Quick-changeable centrepiece device essential for maximum operating time
- Intelligent feeding arrangement for maximizing throughput and refractory lifetime
- Robust vessel design does not allow bulging/movement
- Proven hollow-electrode charging system
- Large product portfolio of roof and sidewall cooling systems for sufficient protection at moderate energy consumption level
- Gas-tight water-cooled roof design provides high quality CO-rich gas
- Application of energy recovery system possible
- Leading supplier for DC furnaces in the metals industry.

Figure 2: Roof section of a DC smelter

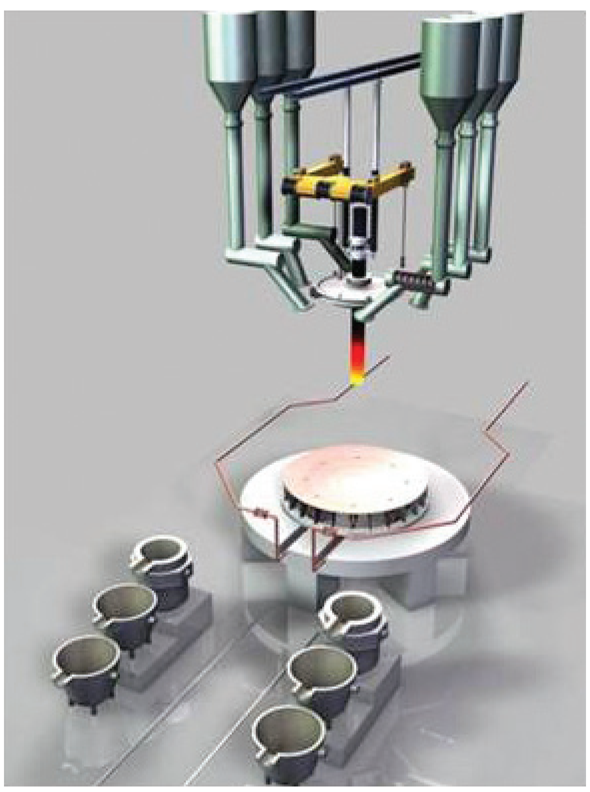

Figure 3: Electrode system of a modern DC smelter

Examples of a DC unit are illustrated in Figures 3 and 4. The DC furnace is usually operated with an open arc, which smelts the material within a very short time. The material can be charged via a hollow-electrode system (HES) directly into the arc. Investigations show that the arc is dancing at the tip of the electrode. Therefore, it is also practicable to charge the material directly around the electrode trip.

In some furnaces it is possible to pile up a sidewall protection layer with the charged material (as applied at the Co/Cu smelter at Chambishi Metals in Zambia). Most processes where the slag is overheated do not allow this kind of sidewall protection. Generally it can be stated that the overall energy consumption of DC furnaces is higher in comparison to AC smelters due to:

- The higher radiant-heat load in the furnace freeboard
- Additional furnace cooling requirement due to higher process temperatures
- High degree of metal fuming, which consumes additional energy.

The great benefit of DC technology is the direct use of fine material, eliminating the necessity for investment-intensive agglomeration steps placed upstream of the furnace. The lower price level for fine material is beneficial for the overall operating costs.

General application areas for DC smelters

More than 99% of today's ferroalloy and TiO_2 production is carried out in AC furnaces. There is no application in the

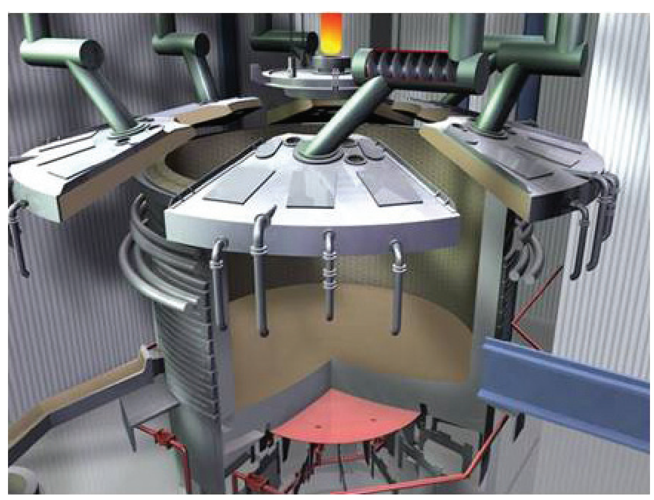

Figure 4. Illustration of a modern DC smelter with conductive hearth

pyrometallurgy for DC furnaces that has not already been carried out in AC furnaces. A partial substitution of AC furnaces by DC furnaces has been considered only by a few customers (mainly for the application FeCr, FeNi, TiO_2, PGMs), as will be further described in the following chapters[9].

DC application for ferrochrome

The increasing proportion of fine ore has driven some ferrochrome producers to make the decision to process the material directly as fines. The application of DC furnaces was investigated in the 1970s in South Africa due to the accumulation of huge FeCr ore fines. A first pilot 16 MVA furnace was operating at Palmiet Ferrochrome in Krugersdorp in South Africa in 1983, and five years later a 62 MVA furnace was commissioned at Middelburg Ferrochrome. Currently there are only two furnaces in operation at Samancor (40 MW and 60 MW). SMS Siemag is currently installing 4 × 72 MW furnaces for Kazchrome in Kazakhstan. The units will produce approx. 440 000 tons per year of liquid ferrochrome[4]. The plant will also include a converter shop with a capacity of 50 000 tpy of M.C. ferrochrome. A preliminary layout of the plant is shown in Figure 5.

DC application for TiO_2 slag production

Smelting can be carried out in a DC or AC furnace, depending mainly on the preference of the producer. Most of the TiO_2 slag is produced in AC furnaces. Numerous AC-based plants are in operation in Scandinavia, Canada, China and South Africa. During the last decade, companies have also implemented DC technology.

SMS Siemag was strongly involved in the introduction of DC technology in this segment. Currently, one 36 MVA furnace will go on-stream for XinLi/China. The first furnaces were developed in the 1990s for Namakwa Sands (1 × 27 MVA and 1 × 34 MVA) and Ticor (2 × 36 MVA) in South Africa. Namakwa Sands was commissioned in 1999 and Ticor in 2003.

In this process, pretreated ilmenite ore is smelted in a submerged arc furnace to form TiO_2-rich slag and hot metal (pig iron) (see Figure 6).

SMS Siemag has supplied two SAFs for ilmenite to Exxaro in South Africa. Furthermore, key equipment from SMS Siemag is used in the two furnaces at Namakwa Sands. The latest reference of SMS Siemag is a 30 MW DC smelter for XinLi in Kunming/China, which was commissioned this year[4].

Application for PGM industry

Mintek has developed an alternative technological solution compared to the conventional AC-based matte smelting furnace for the smelting of PGMs. This process, known as ConRoast, is centred on the smelting of low-sulphur feed materials in a DC arc furnace, resulting in the production of an iron-based alloy[13].

The sulphide concentrate is dead-roasted in a continuous fluidized-bed roaster. Successful pilot-plant smelting tests on UG2 concentrates at Mintek demonstrated the technical feasibility[13].

Test furnace at the IME in Aachen/Germany

SMS Siemag has recently supplied a new electric smelter test furnace to the IME (Institute for Metallurgical Processes and Metal Recycling) at the Technical University of Aachen/Germany.

The unit will allow the testing of various metallurgical smelting processes, such as steel production, ferroalloys, non-ferrous metals, mineral wool, slag cleaning, steel-mill waste recycling and also the recycling of non-ferrous wastes and ferroalloy residues in DC as well as AC mode (see Figure 8). This will provide important comparative results between the two basic process principles[4].

The heart of the 1 MVA furnace is an intelligent power connection allowing the following modes:

- Three-electrode AC operation mode
- Two-electrode AC mode
- One-three-electrode DC mode.

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 would provide important

Figure 5. 3D illustration of a modern DC-based FeCr plant

Figure 6. Slag and metal tapping area of a DC-based TiO_2 smelter

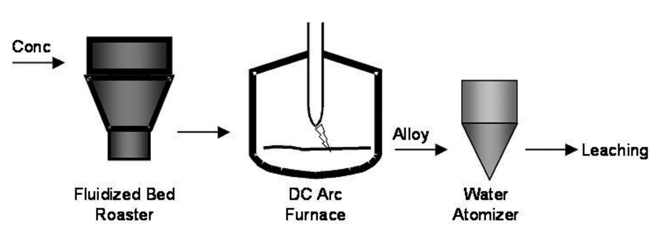

Figure 7: Basic flowsheet of the ConRoast process[13]

information for upgrading of new processes. SMS Siemag expects the furnace to be commissioned soon.

New DC-based intensive slag-stirring reactor

The new intensive slag-cleaning reactor was jointly developed by SMS Siemag and the University of Chile in Santiago. During the last few years, numerous fundamental tests, CFD modelling and pilot-scale tests have been carried out in Chile and Europe. Basically, the intention is to lower the remaining precious and/or base metal contents in the slag to their lowest possible levels by means of a new type of electrodynamic slag-stirring reactor (channel-type DC furnace with perpendicular magnetic field)[14].

Process principles

Coalescence of very small matte/metal inclusions is required to separate them from the slag phase. The role of slag motion on the inclusions' coalescence and recovery of nickel and PGMs in an electric furnace as a function of electrode immersion was clearly demonstrated by the experience reported in the Polokwane smelter[14]. The new process developed for slag cleaning combines a rectangular DC reactor with an extra magnetic field generated by electromagnets and with several phenomena contributing to an improved metal/matte recovery[15].

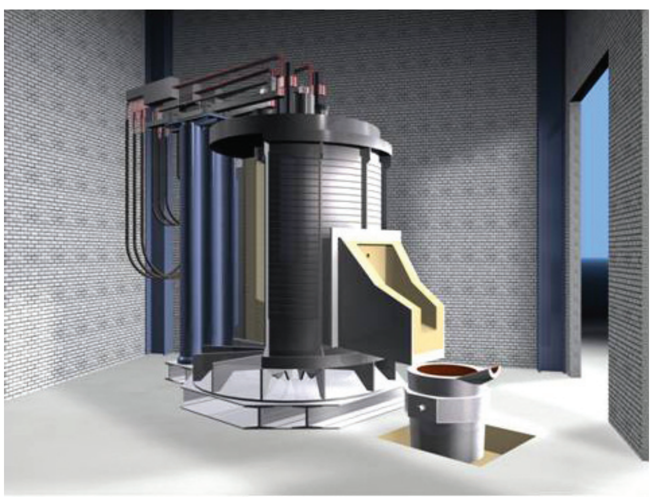

Figure 8. New AC/DC-based 1 MVA test furnace at the IME in Aachen/Germany

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 (see Figure 9) 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 cause a stirring pattern inside the slag layer[15].

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 part of the reactor represents the reactive stirring zone whereas in the right part excellent setting conditions are present. Due to the ability to further reduce the valuable metal content and to the stirring pattern in the first zone of the furnace, the unit has the in-house nickname 'washing machine'.

In principle, the intensive cleaning effect is caused by several coexisting overlapping effects:

- Joule's heat liberation for additional temperature increase
- Additional chemical reduction => accelerated rate of reduction
- Cathodic and anodic reactions => accelerated rate of reduction
- Injection of alternative reduction agents such as CaC_2 to accelerate the rate of reduction (option)
- Enhancing of mass transfer to the reductant surface due to stirring by the magnet
- Forced migration of metal/matte droplets under the electric field (electro-capillary motion phenomenon)
- Coalescence of metal/matte inclusions due to the stirring
- Improved settling through gravity as a result of coalescence into larger metal/matte inclusions
- Destabilizing of the emulsion of matte or metal inclusions in the slag.

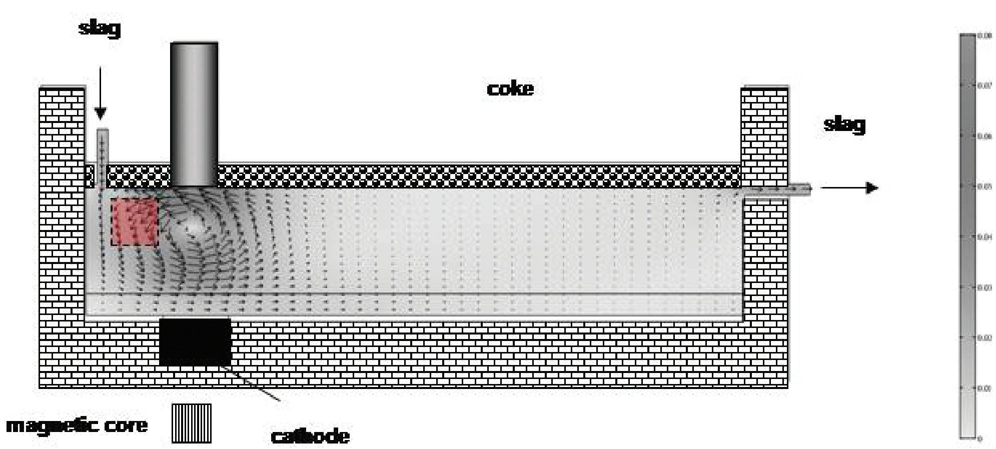

Figure 9: Velocity distribution in the liquid phase (I = 20 kA, B = 0.01)[3]

Alternatively, the principle can also be operated in batch mode following the main process steps:

1. Charging period: filling of the furnace with the liquid discard slag
2. Stirring period: intensive stirring with a multiple magnet system situated on the long side of the reactor
3. Settling period: switching off the magnets while maintaining the power input, resulting in forced settling by gravity combined with electrocapillary motion phenomena
4. Tapping period: tapping of the slag and metal/matte.

Overview of past activities

During the past few years, numerous development milestones have been achieved:

- 2000: Theoretical evaluation of the process principles
- 2002: Extensive fundamental R&D at UDC in Chile
- 2003: Continuous 10 kg/h tests at two test units at the UDC
- 2005: Detailed CFD modeling to support an upscale of 1–2 t/h pilot plant and a 100 t/h industrial plant
- 2007: Test on 1–2 t/h pilot plant at Anglo American, Chagres in Chile
- 2007: Conceptual engineering completed for industrial plant
- 2008: FEM and CFD modelling, basic and detailed engineering and manufacture of a 4 t/h pilot plant
- 2009: Supply of a 4 t/h pilot plant to a European metal producer
- 2010: First tests on the 4 t/h pilot plant.

Overview of some results

Extensive CFD modelling had been carried out to optimize the settling conditions in the reactor. Examples of flow topology and velocity for continuous operation are illustrated in Figures 10 and 11. Distribution of slag velocity is indicated in colour and flow direction is represented by arrows. The maximal velocity is about 0.08 m/s, two orders of magnitude higher than slag motion induced by convection in the case shown without a magnetic field.

The modelling of industrial-scale furnaces (approx. 100 tph) shows specific unitary energy consumptions of approx. 50 kWh/t.

The first smaller semi-pilot DC channel furnace in Chile has a hearth of 0.7 m in length, 0.1 m in width and 0.2 m in height. The current intensity was kept in the range of 200–250 A at a voltage between electrodes of 20–25 V. The copper content decreased from 4.4 to 0.8–1.0% and the magnetite content decreased from 8 to 4–6%. It was noticed that during the switch-off period of the magnets, the system responded with a rapid increase of copper and magnetite contents in the discard slag, which was the first proof of the workability of the general process principle[15].

Encouraged by the good results, SMS Siemag decided together with the Universidade de Chile and Anglo American to install a 1–2 t/h demonstration plant at the Chagres plant of Anglo American in Chile. The layout was based on the results of the lab-scale tests and supported by CFD modelling. The construction of the mobile equipment was finished in 2006 and five test series have been carried out between 2006 and 2007.

The slag was charged to the test unit by manual tiltable ladles. The flow rate of the charge was measured by a load cell. During the test series, only 1 to 2 ladles were charged into the unit. In all five test series it was observed that the unit is easy to control and to handle. The noise and dust/fume emissions of the test plant were very low.

The quick analysis via microprobe already gave an indication that the copper content could be reduced significantly. The chemical analysis confirmed that the initial copper content of 1.6% in the slag was reduced to below 0.7%. In addition, the magnetite content decreased from 14% to 8%.

The test results obtained exceeded the expectations of SMS Siemag despite the fact that the transformer capacity of the unit was too low and the equipment used was not reliable, leading to several unfavourable test conditions. The slag temperature level of all test series was much too low, resulting in a high slag viscosity as well as in build-ups in the reactor. The consequence was too small a reaction volume, causing a short residence time. More astonishing is the already achieved ‘slag cleaning level’. This clearly shows that the full potential of the technology is still unknown[15].

New test plant in Europe

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

In addition, the unit has several more features (more flexible and powerful magnets, two electrodes, injection options), allowing a reliable test phase with the possibility

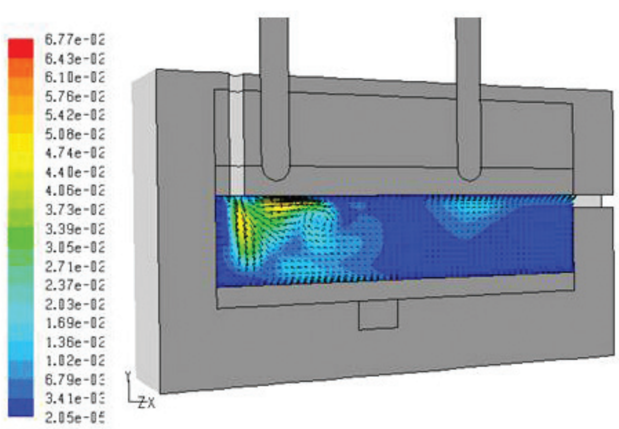

Figure 10. Flow velocity (m/s)

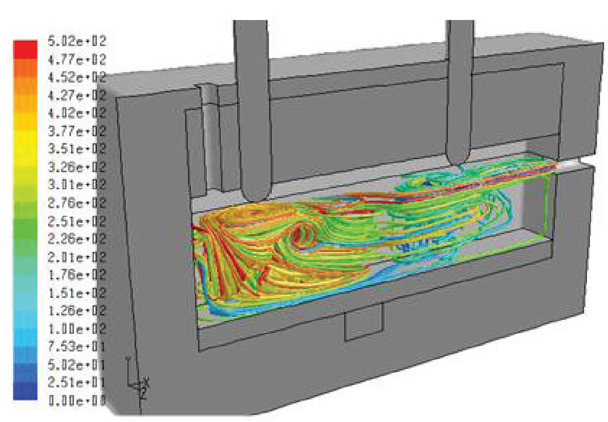

Figure 11. Flow topology

of investigating the influence of various parameters in order to evaluate the full potential of this process principle (see Figures 12–14).

During the first campaign, approx. 120 tons of slag was processed in the reactor within four days. The major focus of the tests was to stabilize the reactor. The unit is easy to control and demonstrates a good handling. The first metallurgical indications already indicate show a positive trend in the reduction of metal in the slag phase. It is planned to carry out further tests over the next year in order to optimize the parameters of the unit.

Aspects of industrial set-up

SMS Siemag is also in the planning phase for implementing this technology on an industrial scale. Capacities of up to 100 tph are possible (see Figure 15). The upscaling risks should be moderate for such a new technology, for the following reasons:

- Larger units minimize the energy losses and prevent build-ups/accretion in the unit
- Charging and tapping is easier
- Ladle handling is easier
- Industrial standard components are easier to integrate into the system.

Potential critical aspects are the unknown refractory wear in the stirring zone of the reactor as well as the determination of the right stirring pattern.

Additionally, the lower copper content in the final slag might also allow the material to be sold to the iron and steel industry.

Transfer of the results to other applications

Besides the processing of slag from conventional slag cleaning furnaces, investigations are being carried out 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 platinum and palladium-producing industry, particularly above all in Africa. SMS Siemag sees great potential for this technology in this field. A recovery of > 50% 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[19].

SMS Siemag also envisages good potential for the new technology in existing platinum 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

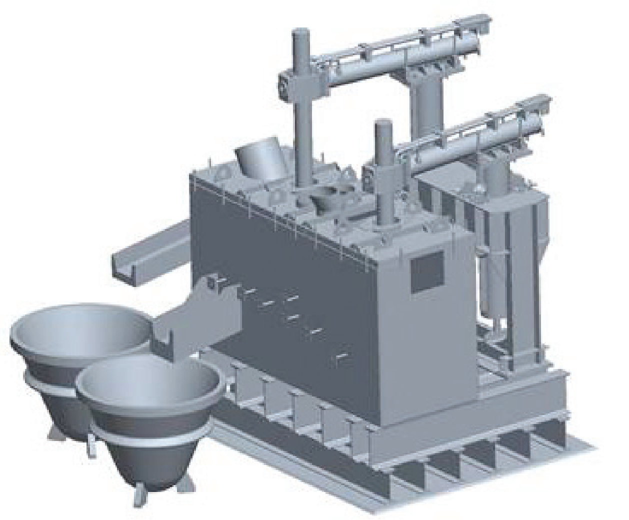

Figure 12. 3-D Illustration of 4 t/h intensive slag-stirring reactor

Figure 14. Top of the slag-stirring reactor

Figure 13. Pilot plant—front view

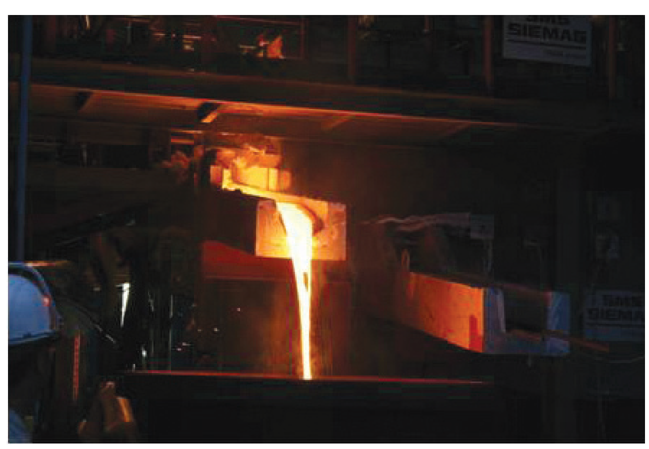

Figure 15. Overflow of the intensive slag-stirring reactor

principles are the same and good additional recovery rates are expected.

Conclusions and outlook

The first submerged arc furnace was commissioned more than 100 years ago in Germany. Since then, the remarkable development of this smelting tool has been recognized all over the world, and submerged arc furnaces are now operating in at least 20 different main industrial fields. SMS Siemag looks back proudly on the significant role of the company in the history of this unique and highly efficient unit. Today, especially the potential of DC-based smelters raises worldwide attention and some projects have already started to implement this kind of technology. Depending on the local conditions, SMS Siemag sees good potential for DC technology especially in the FeCr, PGM and TiO_2-slag area. The 4 × 72 MW DC furnaces for FeCr production, which are currently installed by SMS Siemag for Kazchrome in Kazakhstan, represent the most modern furnaces and will be commissioned in 2011. SMS Siemag is responsible for two large R&D projects focusing on DC application: a new milestone has been achieved in the upscaling of a new slag-cleaning furnace principle, allowing the reduction of the noble/base metal level in the discard slag to the lowest possible level. Test results for the first campaign (processing 120 t of slag) in a 4 t/h pilot plant in Europe show very promising results. Furthermore, SMS Siemag has started a unique long-term research and development project allowing a direct comparison of AC vs. DC technology on a large scale in a recently installed 1 MVA test furnace at the IME at the University of Aachen/Germany. With ongoing innovation and adaptation to customer and market requests, we are convinced that the units will also be successful in the future.

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Rolf Degel

SMS Demag AG

1995 – Graduated of RWTH / Aachen / Germany as process engineer
1996 – Phd in alternative iron-making processes
1996 – Head of R&D and GM of DRI – plant for NSM in Thailand
1998 – Senior sales manager of iron-making division for SMS Demag in USA
Since 2002 GM submerged furnaces for SMS Demag in Germany.