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Rectangular furnace design and revolutionary DC-slag cleaning technology for the PGM industry

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After a short summary of the historical milestones of the submerged arc furnace, the paper will highlight different applications and their specific smelting furnace requirements in the non-ferrous area. Additionally, aspects of rectangular furnace design and the features of the copper cooling system for the side wall will be emphasized. Finally a state-of-the-art design tool as well as a new invention to improve slag cleaning technology will be featured, which shows great potentials especially for the PGM and copper related industry.

Keywords: submerged arc furnaces, aerro alloys, non-ferrous, copper, slag cleaning, PGM, rectangular furnace, DC technology

History of the submerged arc furnace

For more than 100 years SMS Demag played a significant role in the development of the submerged arc furnace and electric smelter technology.

During the past century, the submerged arc furnace has been one of metallurgy's most amazing diversified melting units, which has found many applications in over 20 different industrial areas, including ferroalloys, iron, silicon metal, copper, lead, zinc, refractory, titanium oxide, calcium carbide, phosphorus and materials recycling, etc.[1]

SMS Demag has been developing this technology for more than 100 years and has supplied a diverse market with about 700 furnaces and major furnace components[2]. Numerous applications were constantly developed serving various users[3,4].

Such an evolution was possible only because of tremendous efforts in research and development and due to the large range of design solutions.

The increasing demand for ferroalloys and de-oxidation agents in steelmaking at the beginning of the 20th century led to the development of the first few furnaces.

Demag, for the last two centuries a major supplier for the iron and steel industry, started with the construction of the first submerged arc furnace in 1906. The 1.5 MVA unit was installed in Horst, Ruhr/Germany, for the production of calcium carbide and was successfully commissioned in 1906.

The 'evolution' and the major milestones of the technology are shown below:

- 1906: Reduction furnace (bottom + top electrode)
- 1913: 6-electrode rectangular reduction furnace
- 1935: 15 MVA furnace
- 1951: SAF with rotating gear for Si-metal production
- 1953: 40 MVA large capacity furnace
- 1956: Compensated low-inductive high currency line
- 1957: Copper slag cleaning furnace
- 1958: Hydraulically controlled electrode column
- 1959: Large-capacity 60 MVA furnace
- 1966: Encapsulated electrode column
- 1967: Large-capacity ferro-, silicon-chromium
- 1974: Large-capacity silicon metal furnace
- 1975: Hollow electrode charging system
- 1982: High capacity FeNi rectangular furnaces
- 1993: FeNb furnace
- 1995: Slag wool furnace
- 2001: DC furnace for ilmenite smelting
- 2004: Rectangular copper slag cleaning furnace
- 2004: High capacity FeNi rectangular SAF with thyristor + copper cooling system
- 2006: DC slag cleaning unit for precious metals (PGM, Cu, Co, etc.)

Figure 1 shows a typical submerged arc furnace from the 1950s, as it was promoted at that time. It should be pointed out that the principles of the furnace technology have not changed significantly.

The development of large electrode systems, advanced transformer and thyristor technology and new furnace construction principles nowadays allows the design of large-capacity rectangular SAFs with dimensions of up to 40 m in length and 18 m in width and circular furnaces of 22 m in diameter.

From a design point of view even bigger units are possible but their technological and economical feasibility has to be carefully checked.

The furnace control systems also underwent a significant evolution during the past decades. The first few furnaces were completely manually controlled. Since the end of the 1950s, SMS Demag SAFs have been equipped with electrode controllers. Today's advanced submerged arc furnaces make use of modern software controllers.

SMS Demag's key competence is the mid size and large-scale rectangular furnaces. An example of a two rectangular furnace in-line layout is illustrated in Figure 2.

The unit shown illustrates a two-in-line submerged arc furnace configuration, which had been sold to a Brazilian client for the production of FeNi. With a power rating of 120 MVA and a hearth dimension of 36.4 m x 13.4 m, the smelters represents the world largest submerged arc furnaces ever built. It is planned to commission the plant in 2008.

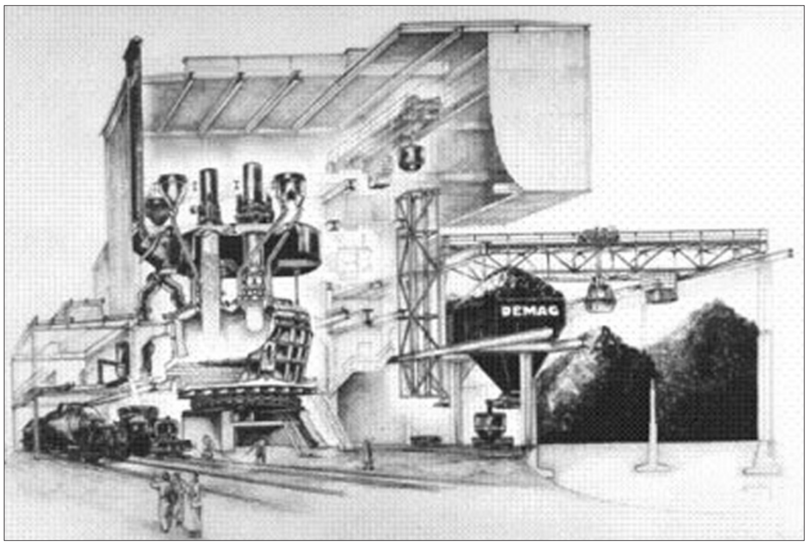

Figure 1. SAF for ferroalloy production from the 1950s

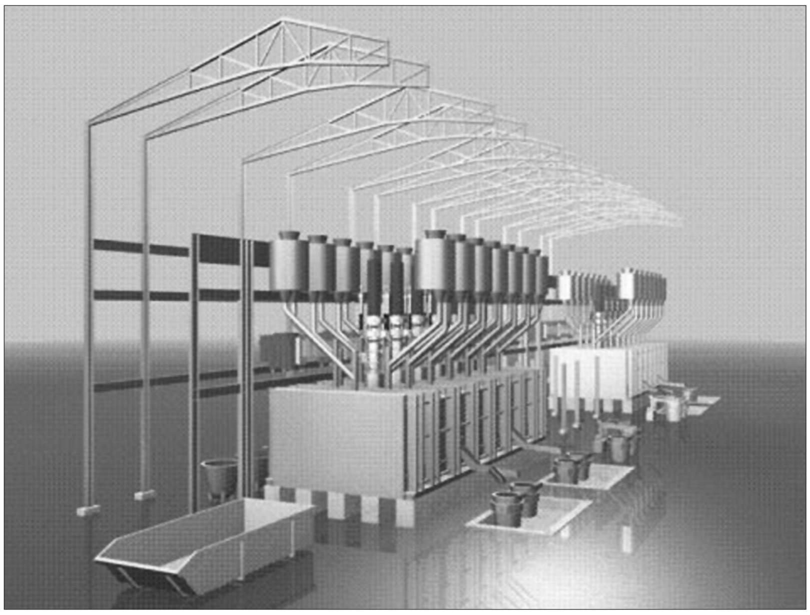

Figure 2. SMS Demag's six-in-line furnace

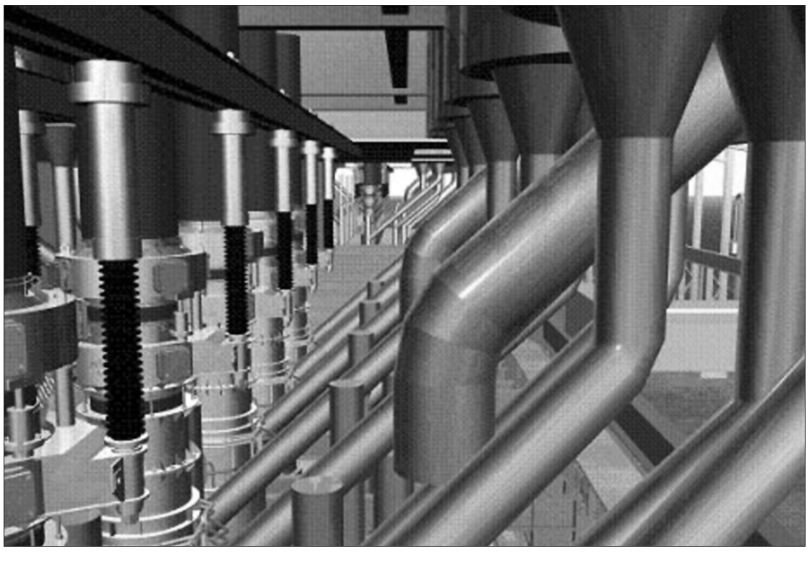

Figure 3. Electrode arrangement of a rectangular furnace

The design of high-power smelting units for ferronickel also led to the development of various sidewall cooling concepts as well as to the development of AC thyristor controls, which allow better operational control, higher and more efficient power input and less overall maintenance.

Sidewall cooling and a thyristor control system are currently successfully in operation at a newly installed smelter for Eramet in New Caledonia. The furnace is designed as a 6-electrode rectangular SAF with a transformer rating of 99 MVA and an operating load of 75 MW.

The furnace has been placed on the original foundations in an existing building. With the modifications, the target to double the power input/capacity while keeping the original dimensions has been exceeded. Figure 4 shows the sidewall cooling system of this furnace.

The advantages of large-capacity rectangular furnaces of SMS Demag vs. other suppliers can be summarized as follows:

- Moderate electrode sizing for higher availability and easier operation
- Easier charging/tapping arrangement and charging/tapping philosophy
- Simple and mechanically robust shell and roof design (no expensive down-holding system required)
- Higher possible production rate by even power and burden distribution
- Safe efficient sidewall cooling system
- Less complex building construction due to less span
- Proven technology in large scale
- Extremely short commissioning period
- Satisfied customers.

Technological highlights of rectangular furnaces

The use of higher power densities causes higher heat transfer through the sidewalls, which necessitates the application of new cooling concepts[6,7].

New sidewall concepts have been developed. An illustration of the stripe cooling concept is shown in Figure 5.

To ensure the best available solution and to compare theoretically calculated data with practical results, SMS Demag has built a full-size test facility located in their workshop in Germany.

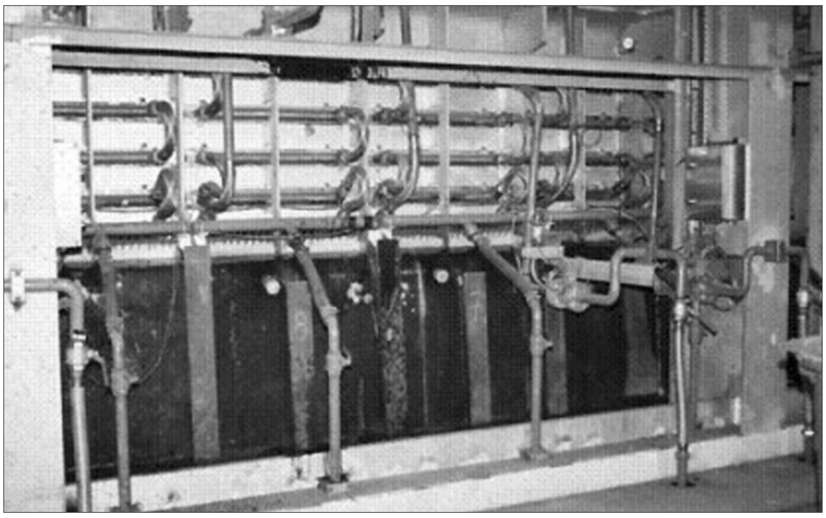

Figure 4. Sidewall copper cooling system of rectangular furnace

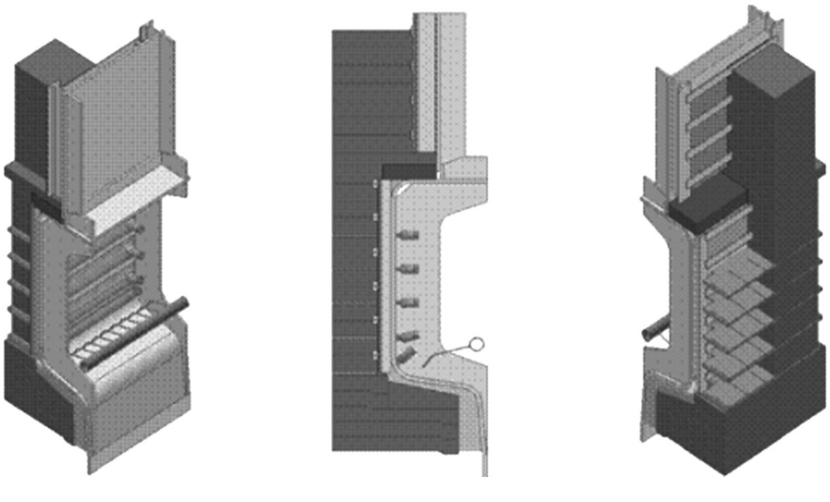

Figure 5. Sidewall copper stripe cooling

This stand is used for testing several cooling options. For the Eramet project, where SMS Demag supplied a rectangular FeNi-furnace, a section of the furnace was successfully tested. During the development of new cooling systems SMS Demag reflected the refractory concepts[8]. The customer has announced that a second furnace is to be installed next year with the same sidewall cooling concept.

For safety reasons the water cooling channels remain outside the furnace shell.

In certain applications such as PGM, pig iron and several ferroalloys and non ferrous processes, a sufficient energy removal rate will create a layer of frozen slag, the so-called freeze line, which protects the remaining sidewall lining. In this case a high thermal conductivity of the lining is of great importance.

The main features of the cooling concept are:

- Safe system with water passages outside the shell
- Mechanically stable, embedded in furnace design
- Uniform—not point-wise—cooling of the slag zone
- Formation of 'freeze line' guaranteed all over the refractory wall in the slag zone—chemical and mechanical attack of slag is safely avoided
- Cooling of slag and hot metal level possible
- Spacing of the copper stripes and their thickness can be varied over a wide range and thus be adapted to all heat loads to be expected; this way the cost-optimized solution for each application can be selected
- Cooling elements are easy and cheap to fabricate
- Thickness of plates allows thermal expansion of the lining
- Bricks are ensured to remain in full contact with the copper elements.

Furthermore, the two world largest rectangular furnace of Onca Puma will be equipped with the same cooling concept.

Non-ferrous applications

Submerged arc furnaces are frequently applied in the non-ferrous industry and other special operations, as described below.

Slag cleaning

SMS Demag has supplied more than 25 slag cleaning units in the past 40 years. Depending on the process, the slag is either liquid charged via launders into the furnace or cold-charged in solid form via conventional feeding systems. The application range is very wide and units are operating in copper, nickel, cobalt, lead, tin, zinc and precious metals (platinum/palladium) production[10].

Copper

Slag cleaning furnaces are commonly connected to copper smelting units such as Teniente and Noranda converters and Outokumpu flash smelters. The main function of the furnace is the reduction of the copper level in the slag[11]. SMS Demag's furnaces are designed for a reduction of the copper level from 1–8 % down to 0.6– 0.9%.

There is a trend towards semi-continuous operating practice of the primary smelters (such as ISASMELT or Ausmelt) as well as of the slag cleaning furnaces[12]. The rectangular SAF is more suitable for this task due to better geometrical conditions (see Figure 6). The rectangular shape of the furnace combined with the 3 in-line electrode arrangement provides a larger active reaction zone due to less dead zone in the smelter.

We expect that for continuous operation, the recovery rate of a rectangular furnace can be (depending on the specific parameters) 0.1–0.4 % higher in comparison to the conventional round type SAFs. This persuaded a customer in Zambia to install a SMS Demag rectangular slag cleaning furnace downstream from a continuously operating ISASMELT furnace. The plant is currently under construction and incorporates latest mechanical design aspects[13].

It is intended by the client to commission the furnace in the third quarter of 2006.

For batch operating practice, state-of-the-art round type furnaces are still the preferable choice.

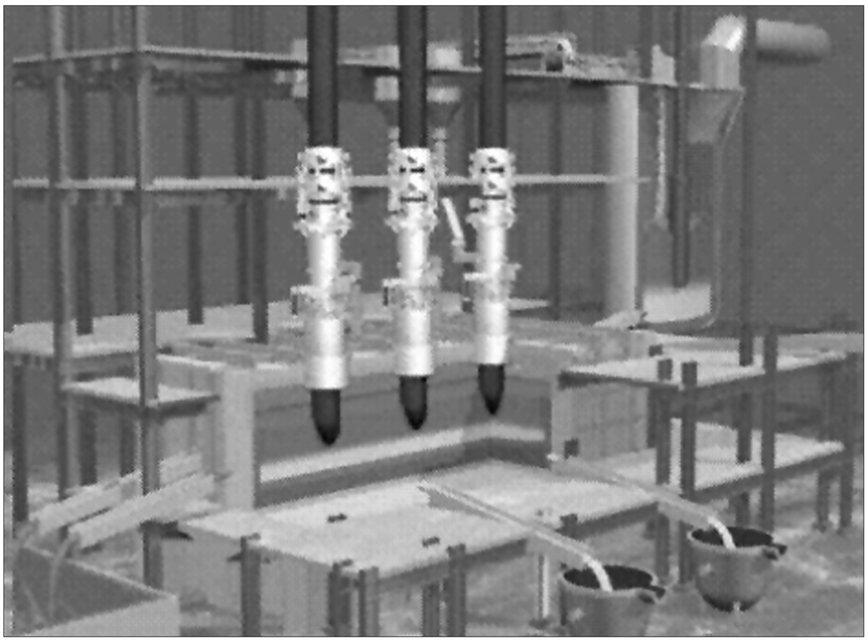

Figure 6. 3D Illustration of a rectangular copper slag cleaning furnace

PGM

Platinum group metals (PGM) are mainly produced from sulphide nickel and copper minerals. After flotation and concentrate drying, raw material is smelted in large SAFs for separating the gangue and generating a base-metal-matte phase as a collector for noble metals. The matte is further treated in converting steps.

PGM smelting can be compared to the smelting of nickel matte by SAF, with SMS Demag's rectangular furnace being well suited to this technology.

The rectangular layout leads to a uniform bath and allows a good separation of the matte from the slag phase. For increasing the specific power input, sidewall cooling systems and thyristor control systems are required for such furnaces.

Optimized charging systems for concentrate and fluxes can be individually developed by SMS Demag's 3-D fluid-dynamic modelling (see below).

3-D fluid-dynamic modelling

With the application of SMS Demag modelling tools, the understanding of up-scaled new processes is becoming more transparent. One example is the 3-D-modelling of large-scale submerged arc furnaces. This model was first successfully applied to two large-scale submerged arc furnaces in Chile[14]. The modelling provides important data for proper furnace sizing and correct dimensioning for the cooling system. Furthermore, it gives a realistic indication of operational conditions.

Major factors that are considered in the model:

- Joule's heat generation in ohmic resistors: slag, metal, arc and electrodes
- heat consumption in the bank and bank/slag interfaces due to endothermic reactions of reduction and melting
- heat transfer by conduction and convection in the slag and metal/matte
- heat transfer by conduction in refractory, shell and electrodes

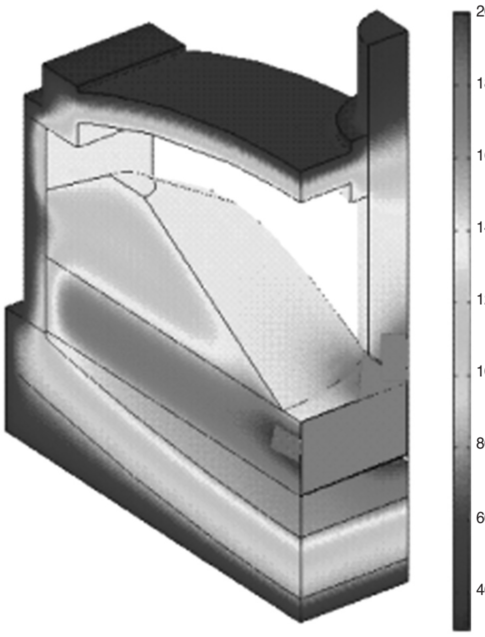

Figure 7. Example of temperature distribution in a rectangular furnace

- heat transfer by convection through furnace shell/water, shell/air interfaces
- heat transfer by convection and radiation at slag/gas, bank/gas, electrodes/gas and refractory/gas interfaces
- slag and metal/matte motion induced by buoyancy forces (natural convection).

The advanced modelling tool of SMS Demag therefore contributes:

- to get a better understanding of new process approaches
- to have more orientation points for furnace design
- to match long-term experiences with new advanced modelling tools
- to support customers and suppliers in their decisions for new process procedures
- to get a better understanding for sidewall cooling concepts
- to considerably lower up-scaling risks.

Secondary DC-based intensive slag cleaning step ('washing machine')

SMS Demag offers an innovative intensive slag cleaning step which is arranged downstream of conventional slag cleaning furnaces[11]. This new development overcomes the hitherto unsolved problem of fine dispersed smaller precious metal droplets not gravitationally settling into the matte/metal phase of the furnace (see Figure 8).

This has always led to a significant portion of precious metals remaining in the slag zone.

The new invention is a very interesting solution especially for the copper and PGM industry.

In the case of copper slag cleaning, the copper content of the slag can be further reduced by 0.2–0.5 percentage points.

The recovery of copper inclusion had been demonstrated successfully. Currently numerous talks are held with the platinum and palladium producing industry, especially in Southern Africa. SMS Demag sees great potential this technology in this field. A recovery of 50% of the lost PGM containing matte as inclusions at a unitary electric energy consumption of 50 –70 kWh/t of slag is, according to the test work, feasible.

The principles of the channel type furnace are simple. The small channel-type unit has a permanent DC electric field in combination with a magnetic field.

In the first zone of the furnace the slag is electro-magnetically stirred, which leads to a partial coagulation of the smaller metal droplets.

In the second zone, the droplets are forced by capillary motion phenomenon towards the metal/matte phase and additional electrolytic effects increase the metal recovery rate. The unit/process is patented for all metals.

The principles of the new slag cleaning step were jointly developed by SMS Demag and the University of Chile in Santiago/Chile (UDC). In the initial stage numerous fundamental tests have been carried out.

Due to the ability to further reduce the precious metal content, the unit has internally the nick name 'washing machine'.

During the comprehensive test programme, numerous slags from various applications of SAF technology had been investigated such as:

- Copper slag
- Lead and zinc slag
- Waste material

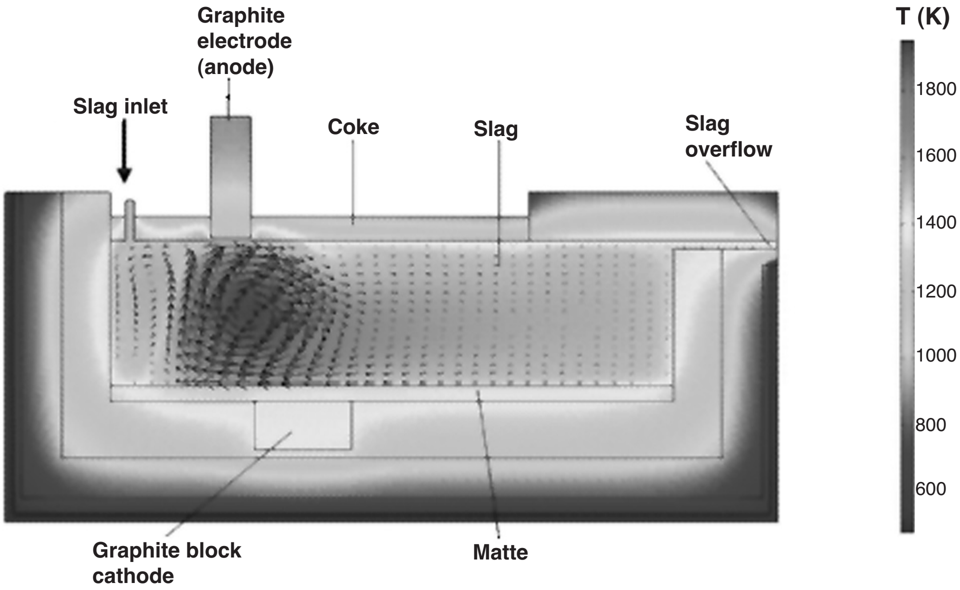

Figure 8. Principles of the new slag cleaning unit for the recovery of precious metals

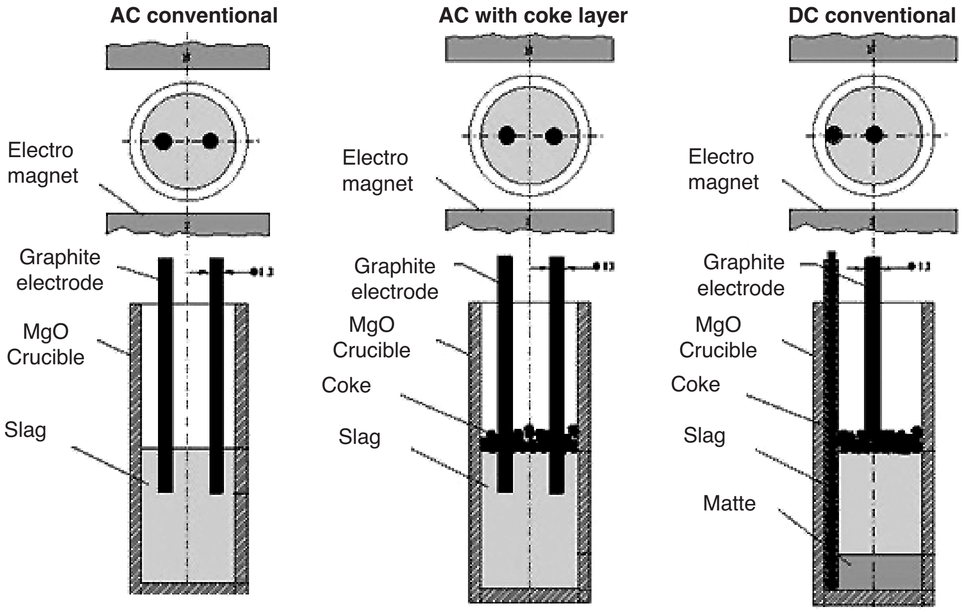

Figure 9. Laboratory test AC-DC comparison

- PGM slag
- FeCr slag
- FeMn slag
- FeNi slag
- others.

Figure 9 illustrates a cross-section of three possible test setups for the laboratory tests. The small test rig allowed to run the process in conventional AC-, conventional AC with coke layer and in DC-mode.

Especially for all the copper slags, results looked very promising. UDC carried out numerous fundamental tests in the field of settling phenomenon of copper slags.

The test demonstrated that (especially for copper slags) settling conditions could be significantly enhanced. Looking at the graphical trends for copper slag in Figure 10, it is obvious that the slag cleaning effect was more progressive with applying a DC-field. Besides other effects the acceleration of copper slag cleaning could be explained by the so-called electro capillarity motion phenomena, which is in principle shown in the next picture as well as overlapping electrolytic effects (see Figure 11).

When the liquid metal droplet is exposed to an electrical DC field, it starts to develop a certain internal 'flow pattern' as shown in Figure 11. The droplet movement at the exterior area, in combination with the friction between droplet and the slag, forces the droplet to move. The drop 'eats' itself through the slag (in the shown case, downwards).

It is well known that coagulation of the copper droplets will also promote settling conditions in a slag cleaning furnace. Additional stirring/agitation of the slag enhances the chance that matte droplets hit each other. The liquid drops will coagulate to larger droplets, which have better descending conditions.

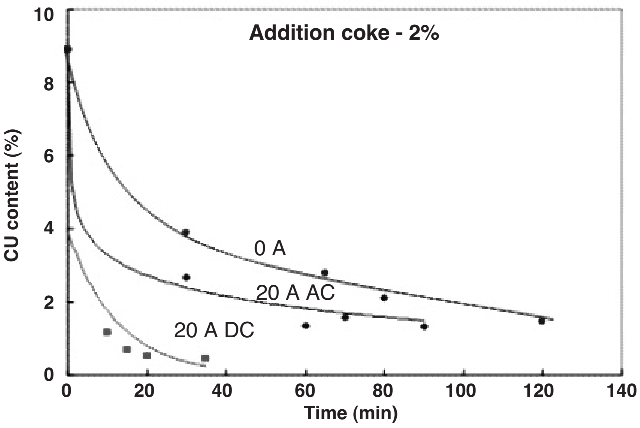

Figure 10. Copper content over time under AC and DC conditions

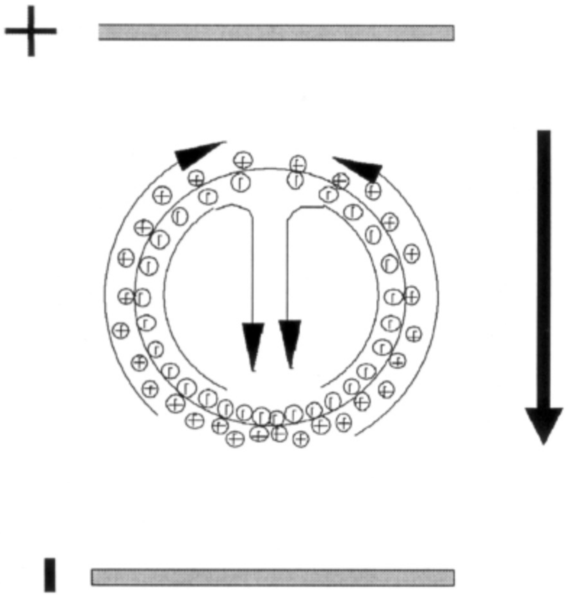

Figure 11. Principles of electro capillarity motion phenomena

Figure 12. Photograph of the initial pilot plant during operation

The new slag cleaning channel-type furnace incorporated both principles of enhancing coagulation and enforcement of matte setting into the matte phase. A picture of the pilot plant is shown in Figure 12.

The first pilot set up at UDC had a capacity of 0.5 t/h of slag processing. In a first furnace, slag was melted in a chamber by means of a natural gas burner. Then the slag was tapped continuously into the DC channel type slag cleaning unit.

The first results exceeded SMS Demag's and UDC expectations. Occasionally the copper content in the slag could be reduced down to < 0.4% (depending on the original slag copper content).

It was demonstrated that a significant fraction of the remaining copper droplets could be transferred in the matte phase. Looking at the cross-section of the slag before and after the slag cleaning step, it can be seen that the further cleaned slag is almost free of copper droplets (see Figure 13).

The first pilot set-up was especially designed for testing slags from the copper producing industry. In order to test a larger variety of different slags with a higher melting point, it had been decided to install a new pilot plant at UDC. The primary gas fired slag melting furnace was replaced with an electrically powered smelter (see Figure 14).

This modification of the pilot plant was done jointly with Europe's leading copper producer. The first test results are highly promising, showing a copper reduction in the slag from 0.9% down to 0.4%.

One major drawback of both pilot test facilities is the limitation in melting capacity. In addition. the pilot plant does not 100% reflect the identical slag characteristics as tapped on an industrial site, because. the fact that it needs to be remelted.

For this reason SMS Demag is currently designing a mobile test facility. The unit will have a capacity of approximately 1–2 tph slag treatment. The necessary instrumentation for receiving immediate results of the tests is included in the test rig.

SMS Demag is planning to carry out tests especially in the southern countries of Africa, Europe and in Chile. The mobile DC slag cleaning step pilot facility will give our clients the immediate evidence that the slag cleaning principles will also work for their specific process. First tests on sites are planned for 2007.

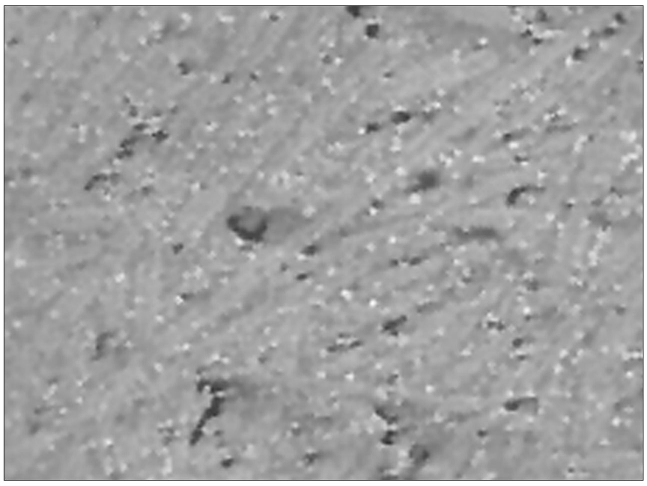

Figure 13. Cross-section of cleaned slag after passing the DC slag cleaning step

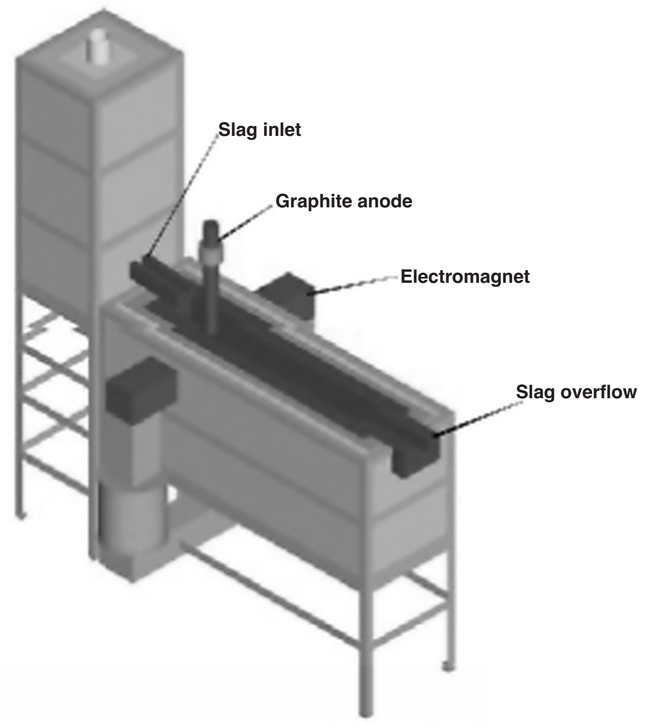

Figure 14. New pilot plant for testing various slags

The economics of this unit are for some applications outstanding. Taking the example of conventional plant utilizing submerged arc furnace for copper slag cleaning and taking the current copper price of approx. 8000 USD per ton of copper and a copper production of approx. 200000 tpy, such a unit will have an amortization period of less than 6 months.

Additionally SMS Demag is in talks with numerous other companies in the copper and PGM industry to install the first industrial-scale plant. The payback period of less than half a year is so promising for some companies that they are considering an immediate installation of the unit. Figure 15 shows the cross-section of a 75 tph unit.

The advantages of the unit are obvious:

- High recovery of precious metals
- Extremely low investment due to simple principle
- No control of the electrode necessary => easy operation
- Minimum of graphite anode consumption due to coke layer principle
- Possibility of bypass option will not effect daily operation and minimizes project risks
- Small compact unit will fit in almost all downstream location of primary smelting unit
- Amortization of less than half a year is possible.

Conclusions and outlook

The first SAF was commissioned 100 years ago in Germany. Since then a tremendous development of this smelting tool was recognized all over the world and submerged arc furnaces are now operating in at least 20 different main industrial fields.

SMS Demag as a leader in large-scale electrical smelters proudly looks back at the significant role of the company in the history of this unique and highly efficient unit.

Especially in the field of rectangular furnace technology, SMS Demag could enhance its market position. The last orders in rectangular furnaces demonstrate our clients trust in our intelligent solution (such as sidewall cooling system, furnace integrity).

Our recent innovations also focus on the additional recovery of precious metals out of liquid slag. The developed ‘washing machine’ will become a very attractive solution, especially for the PGM and copper industry in Africa.

References

1. DEGEL, R. and KUNZE, J. History, current status of submerged arc furnace technology for ferroalloy metals, *Steel Grips,* vol. 1, no. 3, 2003).
2. KEMPKEN, J. and DEGEL, R. A hot technology, *Metal bulletin monthly*, Nov. 2005, ferroalloys supplement, pp. 23–26

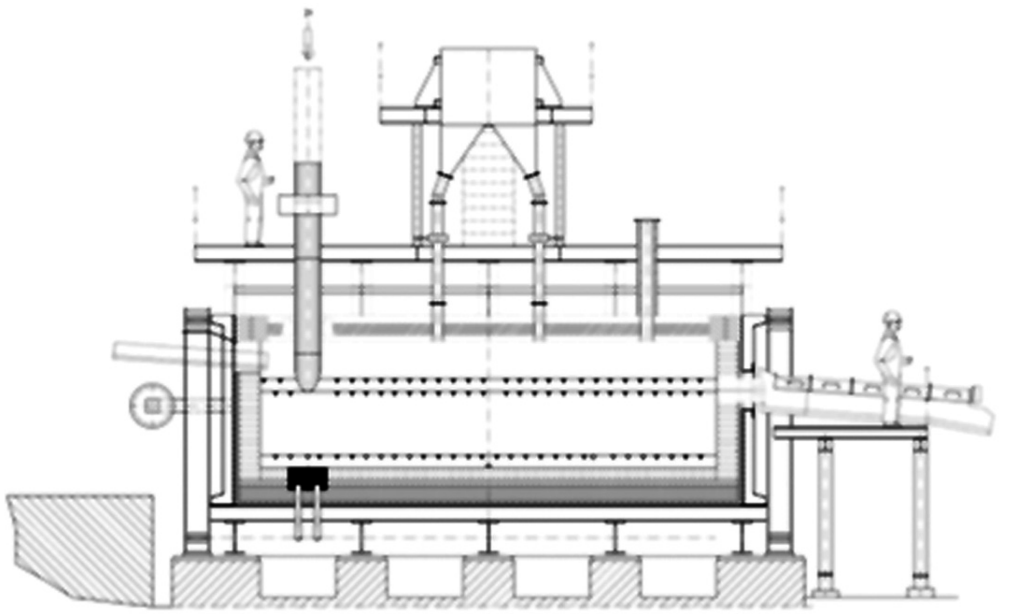

Figure 15. Large-scale 75 tph DC-based slag cleaning step

3. N.N.: Demag brochure: Elektro-Reduktionsöfen Referenzliste 1970.
4. N.N.: SMS Demag brochure: References Submerged Arc Furnaces 2006.
5. DEGEL, R. and KUNZE, J. New trends in submerged arc furnace technology, *10th international ferroalloy congress—INFACON X*, 1–4 February 2004, Cape Town, South Africa.
6. DEGEL, R., RATH, G., and KUNZE, J. Status report on pyrometallurgical ferro nickel production, *8th INFACON Conference*, September 2001, Quebec, Canada
7. DEGEL, R. and BORGWARDT, D. New trends in submerged arc furnace technology, Technical seminars at 100 years SMS in China, October 2004, Beijing/China.
8. LEMBGEN, H.-E., KUNZE, J., and DEGEL, R. Pyrometallurgical ferronickel production and experiences at Minera Loma de Niquel in Venezuela; *Proceedings EMC Conference*, Friedrichshafen, 2001.
9. DEGEL, R. and KUNZE, J. Advanced submerged arc furnace technology for non-ferrous metal industry, *1st International conference on plant and process Technologies for Non Ferrous Metals*, June 16–21, 2003, Düsseldorf, Germany.
10. DEGEL, R., KUNZE, J., and WARCZOK, A. Current status and trends in the copper slag cleaning, *5th International Conference Copper 2003* in Santiago/Chile, 30 November, 3–December 2003.
11. DEGEL, R. and KUNZE, J. Innovative submerged arc furnace technology for non-ferrous industries, *World of Metallurgy—ERZMETALL* vol. 57, no. 3, 2004, pp. 129–136.
12. DEGEL. R. and KUNZE. J. Submerged arc furnace technology in non-ferrous application, *EMC 2003 conference* Hannover.
13. RATH, G., VLAJICIC, T., and METELMANN, O. Lead smelting in a submerged arc furnace: *JOM*, vol. 42, no. 6, June 1990 EMC in Dresden.
14. DEGEL, R. and BORGWARDT, D. Efficient recycling with SAF technology for the iron and steel, ferro alloy and non-ferrous industry, *Steel Grips,* vol. 2, no. 1, 2004.
15. KEMPKEN, J. and DEGEL, R. 100 Years SAF technology by SMS Demag, Proceedings, *Pyrometallurgical Conference 2006*, Johannesburg, SAIMM.
16. DEGEL, R., KUMMER, K.-H., and KUNZE, J. New trends in SAF technology, June 2005, *Proceedings EMC*, Dresden, .
17. DEGEL, R. and OTERDOOM, H. R+D of SMS Demag in SAF technology, May 2006, *Proceedings International Symposium 100 Years SAF Technology*, Düsseldorf/Germany,.