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Passion for Metals

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Abstract – After a short summary of the SMS Metallurgy part of the SMS group, the paper will focus on Submerged Arc furnace technology. After general aspects of furnace design, the focus will shift to different applications and their specific furnace requirements. Finally, a state-of-the-art design tool as well as a new invention to improve slag-cleaning technology will be featured.

INTRODUCTION

The history of companies providing technology for the metallurgical industry goes back more than 250 years. While until the middle of the last century most of the companies were constantly growing, the past decade showed a significant decrease in the market. A number of companies disappeared from the landscape. In addition, smaller companies with niche products entered the market and are either being taken over by the big holdings or disappear due to weak financial conditions related to the project responsibilities. Despite the decreasing market, SMS managed a constant growth based on their innovative reliable technology and their long-term customer relationships. Today, SMS metallurgy is the largest system and equipment provider for the metallurgical industry. This paper will introduce SMS metallurgy and explain which companies have been merged and the product range available and supported.

Specifically we will then focus on the general design features of the Submerged Arc Furnace (SAF) technology of SMS Demag, with its 100 years of history. Since SAF designs depend on the metallurgical process, the paper will discuss specific applications for the ferrous and non-ferrous industries and the related furnace requirements for those processes. This also includes a brief description of the 3-D fluid-dynamic modelling system, recently developed by SMS Demag, which allows simulation of processes and therefore is a fundamental decision support to finalize the required furnace technology (especially for up-scaling).

Finally, the newly developed Intensive DC slag-cleaning unit will be presented, emphasizing the importance of R&D and the implementation of state-of-the-art technology to be competitive in today's global markets.

SMS METALLURGY

The SMS metallurgy originates from the merger between SMS Schloemann-Siemag AG and Mannesmann Demag AG in 1999. Looking back into the history of those two companies, we are talking of 187 years of experience serving the metallurgical market.

This does not consider the takeovers of companies or divisions with more than 250 years of historical background. Today, SMS metallurgy consists of eight independent companies: SMS Demag, SMS Meer, SMS Eumuco, SMS Elotherm, Concast, SMS Mevac, Hertwig Engineering, and Siemag.

Behind those names you will find the know-how of companies like: Messo, Vacmetal, Mannesmann Demag, MAN GHH, Krupp Industrietechnik, Sidernaval, Innse, *etc.*

With a turnover of approximately 2 billion Euro, and approximately 6 500 employees, SMS metallurgy has locations all over the world, including its SMS Demag office in Johannesburg. The product range goes from electric reduction furnaces to steelmaking equipment, continuous casting, hot rolling, cold rolling, strip processing, tubes, long products, pressing & forging, induction and electro heating up to metal logistic systems. With the continuous functional integration of process technology, mechatronic and product related services (all in house), SMS metallurgy stands for leading innovations and long-lasting customer-focused solutions.

SMS DEMAG SAF TECHNOLOGY

100 Years Submerged Arc Furnaces supplied by SMS Demag – an anniversary to celebrate!

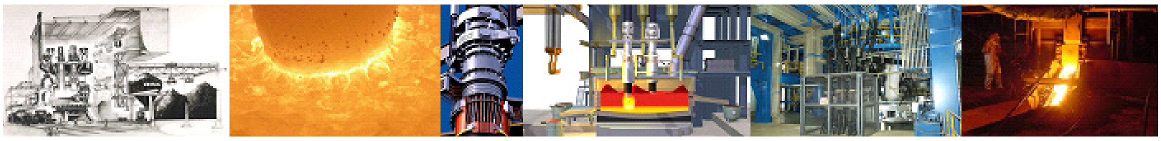


Figure 1: Submerged arc furnace (SAF) technology during the past decade

The submerged arc furnace (SAF) has been one of the most amazing metallurgically diversified melting units, which has found application in over 20 different industrial areas, including ferro-alloys, 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 100 years, and has supplied a diverse market with about 700 furnaces and major furnace components[2]. During this time, numerous applications were constantly developed serving various users[3,4].

User industries	Alloys / products
Iron & steel industry (main applications)	Ferro-Nickel, Ferro-Chrome, Ferrosilicon, Ferro-Manganese, Silico-Manganese, ……
Iron & steel industry (additional applications)	Ferro-Tungsten, Ferro-Tantalum, Ferro-Niob, Calcium-Silicon, Ferro-Vanadium, ……..
Non-ferrous metal industry	Copper, Lead, Antimon/Bismuth, Zinc, Nickel/Copper Matte, Platinum,…..
Refractory & grinding industry*	Corundum, Mullite, Fused Magnesite, Fused Oxides, Mineral Wool,……
Chemical & electronic industry	Calcium Carbide, Titanium Slag, Phosphorus, Silicon Metal,……

Figure 2: Various applications of SMS Demag furnaces[3]

Worldwide, strong competition has forced the metallurgical industry and its plant suppliers to develop highly efficient, economically balanced units in optimized sizes and with long lifetimes. Major efforts in research and development have resulted in a wide range of SAF design solutions.

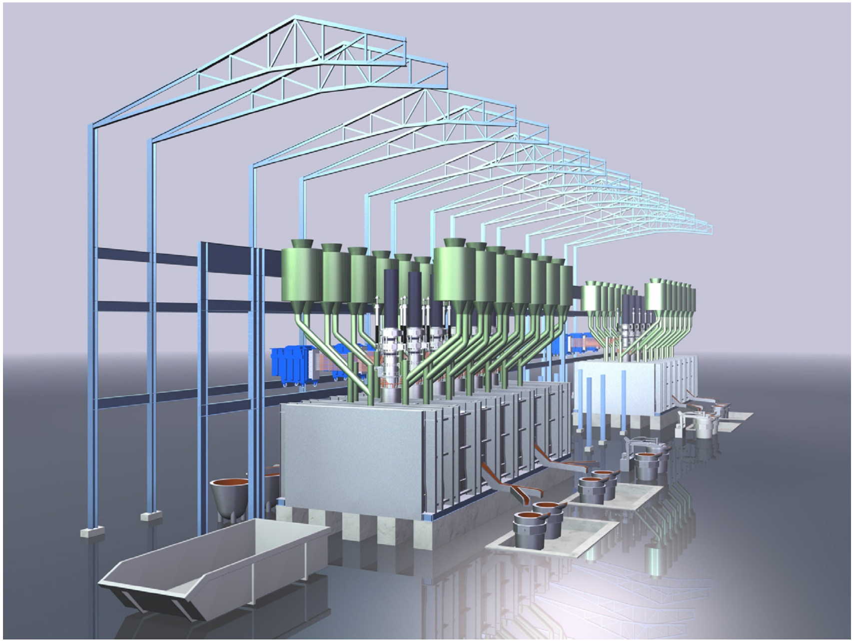


Figure 3: SMS Demag six-in-line furnace

It was the increasing demand for ferro-alloys and de-oxidation agents for steelmaking at the beginning of the 20th century which led to the development of submerged arc furnaces [5]. Demag started constructing the first SAF in 1905.

A 1.5 MVA unit was installed in Essen Horst Ruhr in Germany for the production of calcium carbide and was successfully commissioned in 1906.

Over the past century, the size of furnaces increased tremendously – furnaces with power ratings 100 times larger (up to 150 MVA) are feasible today. This up-scaling is possible mainly due to the development of large electrode systems, advanced transformer and thyristor technology, and new furnace construction principles. Today, large-capacity furnaces can be built 40 metres long and 18 metres wide (for a rectangular design), or 20 metres in diameter (round type). Even larger plants are currently under discussion, especially for the ferro-alloys application.

Principle of a submerged arc furnace

The principle of a submerged arc furnace is simple. The SAF works with electrical energy, which is generated mainly using the electrical resistance of the burden or molten slag. The electrodes are immersed in the melt, which provides the required energy transfer area between the electrodes and melt. The melt is the transfer medium that supplies the energy required for melting and chemical reactions of the charge[1]. The submerged arc furnace comprises the following major equipment parts (see Figure 4):

- Furnace charging system
- Furnace shell with tapping system
- Furnace roof
- Gas off-takes and stacks
- Electrode columns
- High-current supply system
- Tapping equipment
- Furnace transformer

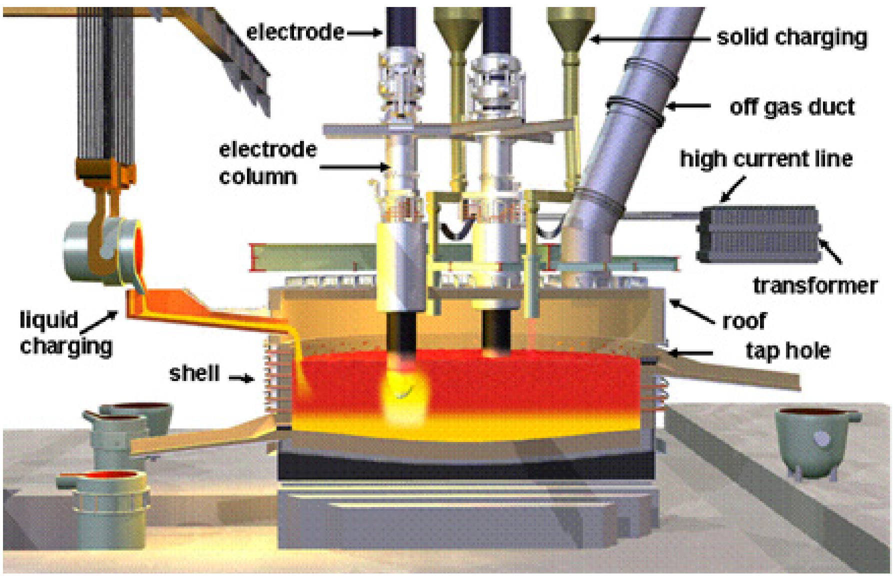


Figure 4: Main components of a submerged arc furnace[1]

A typical furnace with slag operation comprises a round or rectangular furnace shell with tap holes for slag, matte, or metal. The furnace shell is refractory lined and – if additional shell cooling is required by the process – water-cooled.

Various sidewall-cooling systems are available depending on the specification of the process: rinse cooling, spray cooling, chamber cooling, channel cooling, or Cu-strip cooling. The shell bottom is cooled, if cooling is necessary, by forced air ventilation. In special applications, water-cooling might be required. Furnace roofs, either brick type or water-cooled type, comprise all required glands, openings, and sealings for the electrode columns, charging pipes, and off-gas ducts.

The electrical energy is transferred into the furnace via self-baking carbon electrodes or pre-baked graphite electrodes. The electrode arrangements depend on the process and the installed power. In the case of a circular furnace, the electrodes are arranged either centrally (single electrode) or as a triangle (three electrodes). In the case of a rectangular furnace, they are arranged either as 3 or 6 electrodes along the centre-line, as 2 lines with 3 electrodes each.

The electrode is consumed in the furnace bath (see Figure 5). Self-baking electrodes with casings, pre-baked, or graphite electrodes are periodically extended by new pieces. The electrode is semi-automatically slipped into the bath, carried out under full electrical furnace load with no interruptions to furnace operation.

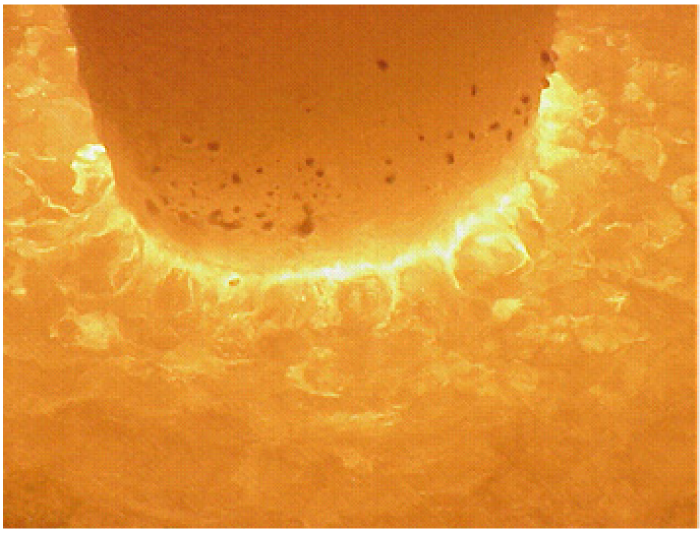


Figure 5: Electrode submerged in the bath

The electrode column assemblies contain all facilities to hold, slip, backslip, and regulate the penetration into the bath. All operations on the electrodes are executed hydraulically.

The electrical power is normally transferred from the furnace transformers via high-current lines, water-cooled flexibles, bus tubes at the electrodes and the contact clamps into the electrodes.

Today, operational control and supervision is effected by a PLC and visualisation system. A back-up for manual operation is foreseen and is located in the control room.

Metal or matte, and slag, are tapped periodically by means of a drilling machine and the taphole is closed either with a manually placed plug or a mud gun. Metal is tapped into ladles; slag and matte are either tapped into slag pots, dry pits, or granulation systems.

The process gas created from the chemical reactions leaves the furnace at the gas stack connection in the furnace roof. Depending on the plant design, the process gas is combusted either inside the furnace, or outside the furnace by the balanced addition of combustion and cooling air and sent to the filter system. If the process generates off-gas that contains a certain amount of CO (or other hazardous substance) in the process gas, the furnace is designed as a closed furnace type.

The furnace type described above is considered to be a typical design. Various other layout and design options can be tailored to meet the individual requirements of specific processes.

Technological highlights

New developments have incorporated increased slag bath operation alongside the use of highly efficient units with high power densities. The use of greater power densities causes higher energy transfer through the sidewalls, which necessitates the application of new cooling concepts[6,7]. New side-wall concepts for round and rectangular furnaces have been developed. An illustration of the stripe-cooling concept is shown in Figure 6.

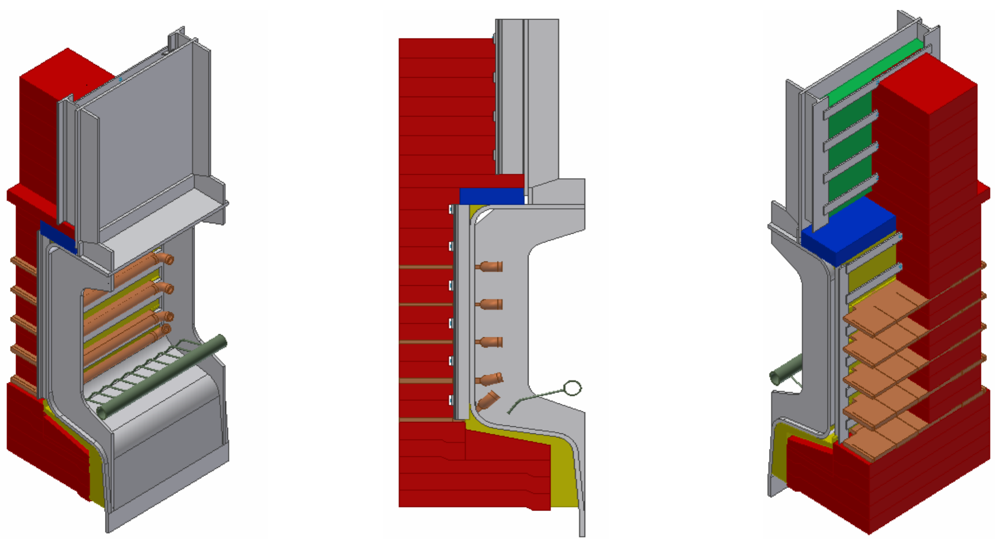


Figure 6: Side-wall copper stripe cooling

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

To ensure the best available solution, and to compare theoretically calculated data with practical results, we built a full-size scale test facility, located in our workshop in Germany. This stand is used for testing several cooling options. For the Eramet project, a section of the furnace was successfully tested. During the development of new cooling systems we reflected the refractory concepts[8].

In certain applications, such as pig iron and several ferro alloy 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 capital importance. The resistance against chemical attack or infiltration is only of secondary 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 in a wide range and thus be adapted to all reasonable energy-removal loads to be expected; the cost - optimized solution for each application can be selected this way
- Cooling elements are easy and cheap to fabricate
- Thickness of plates allows for thermal expansion of the lining
- Bricks are ensured to remain in full contact with the copper elements

Several industries are also evaluating the potential of applying DC technology. Submerged arc furnace DC technology shows a slightly increasing market share world-wide in niche areas, especially in certain ferro-alloys, slag cleaning, and titanium dioxide production.

SMS Demag has also recognised the potential within slag cleaning for the recovery of precious metals in a separate compact unit.

It should be noted that SMS Demag holds the patents of all DC bottom anode systems *i.e.* conductive hearth (Concast), billet type (Demag), and pin type (GHH). This automatically involves the company in most planned projects at an early stage. Nevertheless, the majority of conventional submerged arc furnaces are, and will remain, AC technology-based.

One of the key components of the furnace is the electrode column. The SMS Demag design (Figure 7) has been continuously improved over the years and is acknowledged for its reliable and good performance in all SAF applications. In normal operating conditions, availabilities of almost 100% are achievable. One of our clients in Finland even achieved three years' operation without any interruption or maintenance.

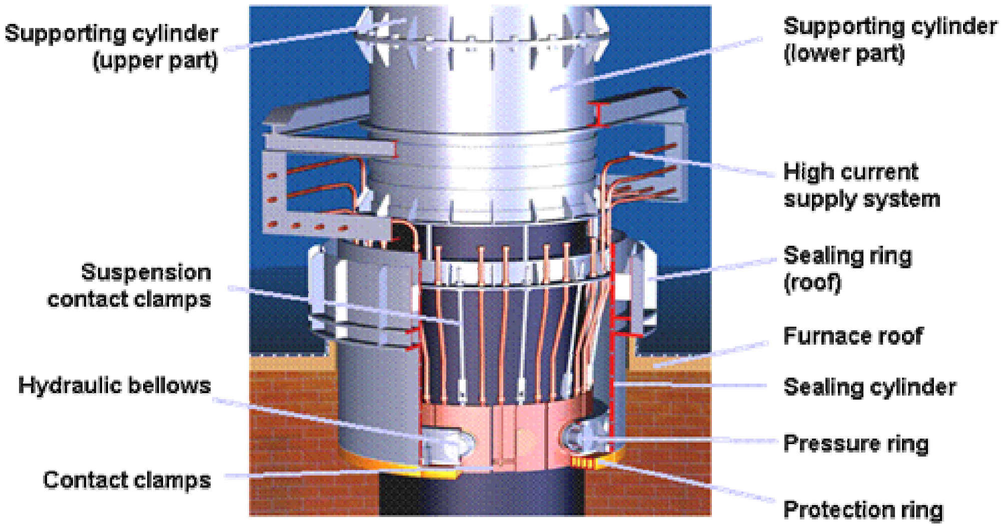


Figure 7: SMS Demag electrode system

Ferro-alloy production

The demand for bulk ferro-alloys is expected to increase steadily in relationship to the growth of the iron and steel industry, which indicates a solid base for good future market developments.

The majority of ferro-alloys are produced by pyrometallurgical smelting in submerged arc furnaces. The hydrometallurgical production of ferro-alloys such as high-pressure acid leaching processes for nickel production have so far not shown the predicted economic and technical benefits.

The strong competitiveness of submerged arc furnaces for ferro-alloys has been achieved mainly by the installation of advanced high-power smelting units. Examples in various sectors are given below.

Ferro-nickel: Today, a modern ferro-nickel SAF is characterised by high efficiency. In general, these may be, depending on the requested capacity, round- or rectangular-shaped furnaces[9].

The choice is based mainly on the anticipated power input. SMS Demag has determined that if more than a 60-70 MW nominal furnace input is required, a rectangular furnace is the best solution from a technical and operational point of view.

Efficient furnace operation can only be achieved with a correctly designed SAF, highly efficient energy transfer with partial arcing mode (shielded arc), correct ore blending, controlled calcination of the furnace feed, sufficient dust recycling, and a modern furnace operation with skilled personnel, allowing precise slag and temperature control.

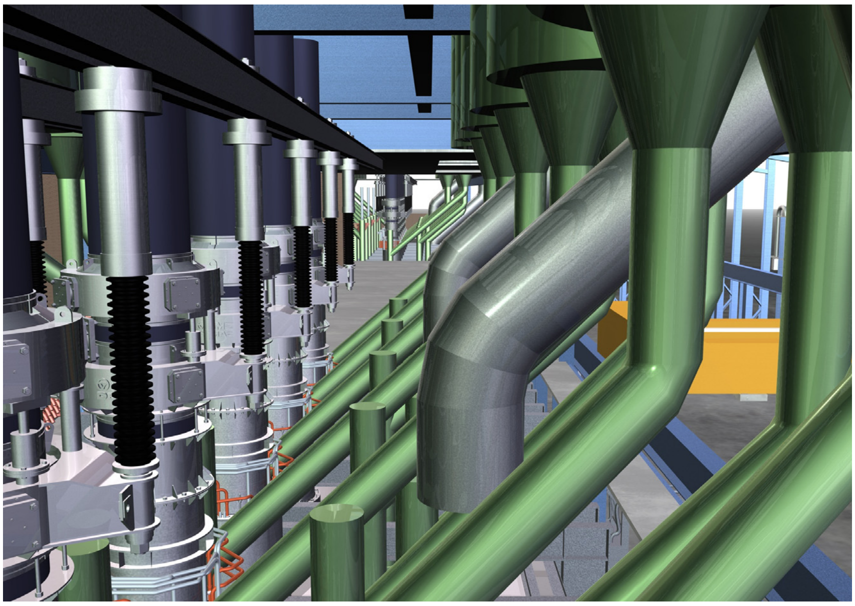


Figure 8: Electrode arrangement of a rectangular furnace

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

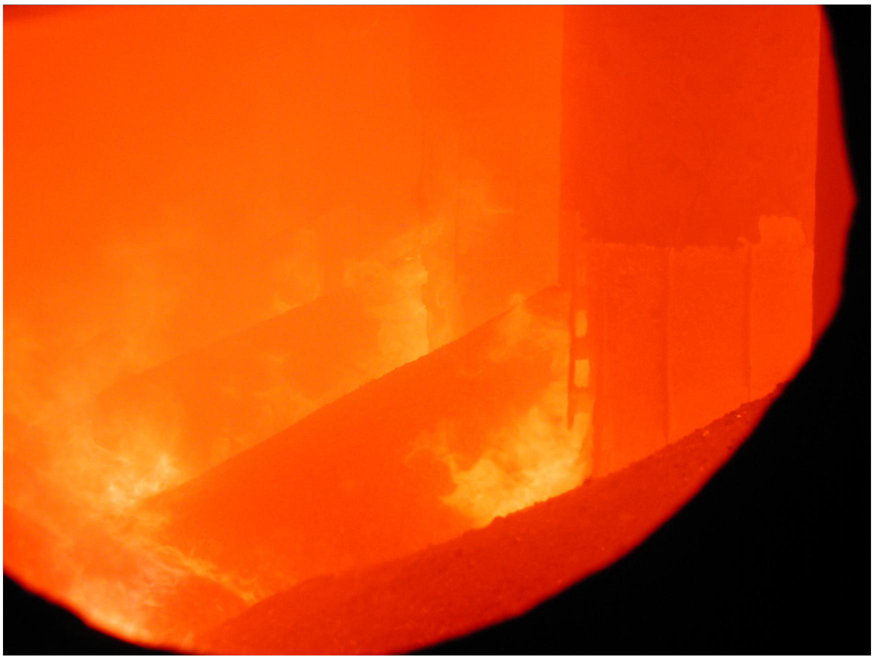


Figure 9: Shielded arc operation in a FeNi rectangular furnace

Side-wall cooling and a thyristor control system are currently successfully in operation at a newly installed smelter for Eramet in New Caledonia.

The furnace is a 6-electrode rectangular SAF with a transformer rating of 99 MVA and an operating load of 75 MW. It represents one of the most modern furnaces ever built for ferro-nickel production.

The furnace had been placed on the original foundations in an existing building. With the modified furnace, the goal to double the power input and capacity while keeping the original dimensions had been exceeded. Figure 10 shows the sidewall cooling system of this furnace.

Figure 10: Side-wall cooling system of FeNi rectangular 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 tapping arrangement and tapping philosophy
- Simple and mechanically robust shell and roof design (no expensive downholding system required)
- Higher possible production rate, by even distribution of power and burden
- Intelligent refractory and side-wall cooling system
- Less complex building construction due to less span
- Proven technology in large scale
- Extremely short commissioning period

=> Satisfied customers

Ferro-chrome: Ferro-chrome production is carried out in either a DC- or AC-based SAF, although almost all FeCr furnaces are based on AC technology. One option for saving operating costs is to pre-heat the ore, which can be done in rotary kiln, rotary hearth, or pre-heating shaft. The use of a preheated furnace has been shown to be beneficial for achieving low electrical energy consumption in an AC submerged arc furnace.

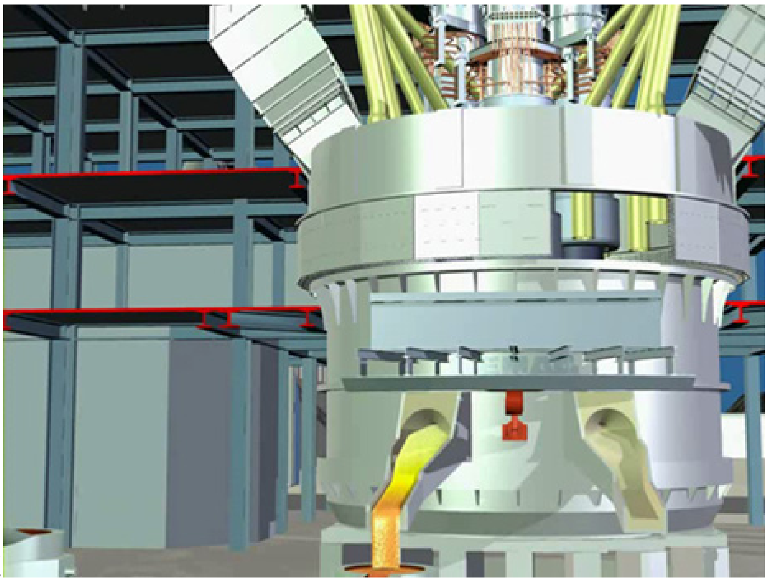
Error!

Figure 11: 3D Illustration - FeCr furnace

The increasing proportion of ore fines in the ore bodies of newly explored mines will force some ferro-chrome producers either to agglomerate the ore or to process it directly as fines. A common way of charging fines to the SAF is via a hollow electrode system (HES) in a single DC furnace, or feeding the material in between the hot spots of a twin DC furnace. SMS Demag is currently investigating options for processing UG2 fines (chrome-rich residue material from the PGM industry).

A common proven technology for the use of fines is to charge cold-bonded briquettes to a conventional AC-based SAF. SMS Demag successfully commissioned one such 60 MVA unit in India, with a second identical furnace being in the start-up phase.

Ferro-manganese: Over recent decades, SMS Demag has designed and supplied several ferro-manganese/silico-manganese SAFs around the world. In France, the world's largest FeMn-SiMn furnace is operating very successfully, processing alumina-rich Carajas ore from Brazil. The major part of the ore is charged as sinter to the furnace, which is nearly 20 metres in diameter and has a transformer capacity of 102 MVA.

Special Ferro-alloys: Special products such as ferro-tungsten, ferro-vanadium, ferro-tantalum, and ferro-niobium are produced in a few SAF units around the world. Furnace design is tailor-made to process requirements, developed in close cooperation with the customer. In the together sector, in particular, several developments have been introduced in together with the Brazilian producer CBMM. In 2005, SMS Demag successfully commissioned a third furnace.

Silicon metal: SMS Demag has supplied the majority (about 95%) of industry-scale submerged arc furnaces for pure silicon production, which typically operate at 15-22 MW. The demand for high-grade silicon is growing, mainly due to increasing demand from aluminium, silicones, and other industries. A large-scale modern Si-metal plant (as built) is illustrated in Figure 12.

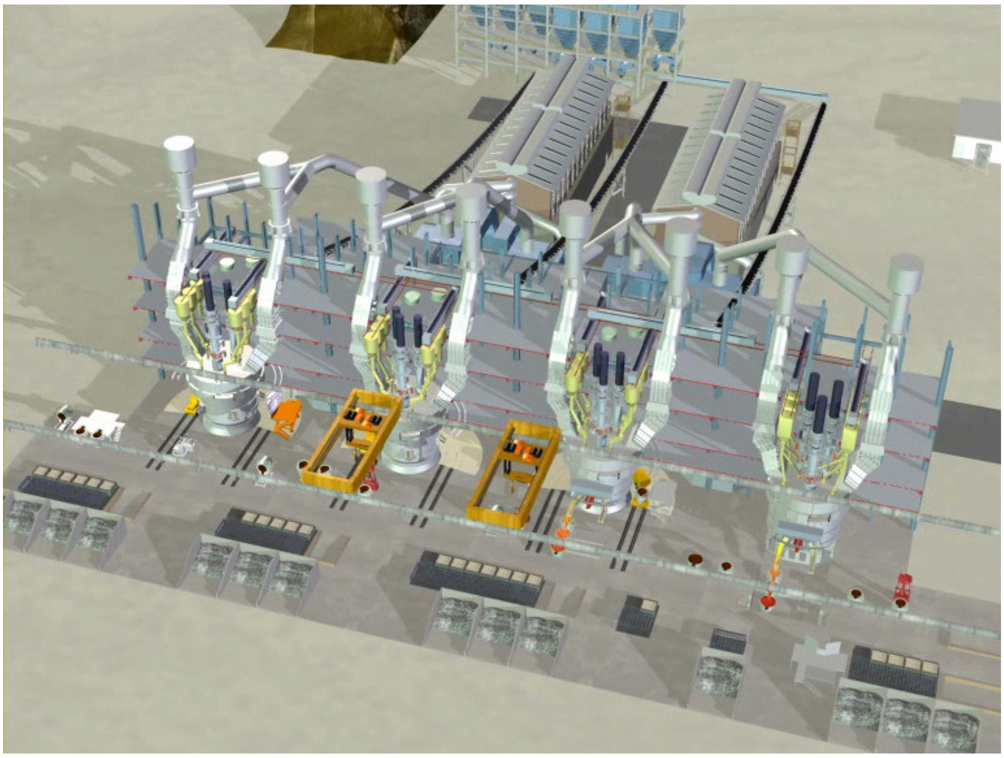


Figure 12: 3D Illustration of a modern Si-metal plant

The process requires an energy input of about 12 MWh / t of silicon with a good raw material such as high-quality quartz. It is sometimes economically feasible to install energy recovery systems.

Non-Ferrous

Submerged arc furnaces are successful in a range of other non-ferrous and other special operations, as described below.

Slag cleaning: SMS Demag has supplied more than 20 slag cleaning units in the past 40 years. Depending on the process, the slag is either liquid-charged via launders into the furnace or is cold-charged in solid form via conventional feeding systems. The application range is very wide and is operating in copper, nickel, cobalt, lead, tin and precious metals (platinum / palladium) production[10].

Copper: Slag cleaning furnaces are commonly connected to copper smelting units such as El Teniente and Noranda converters, Outokumpu flash smelters, and reverberatory furnaces. The main function of the furnace is the reduction of the copper level in the slag[11]. Our furnaces are designed for a reduction of the copper level from 1 - 4% down to 0.7 – 0.9%.

The trend goes to continuous operation practice of the primary smelters as well as for the slag cleaning furnaces[12]. The rectangular SAF is more suitable for this task due to better geometrical conditions (see Figure 13).

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 fact caused a customer in Zambia to decide to install a SMS Demag rectangular slag-cleaning furnace downstream of a continuous operating ISASMELT furnace. The plant is currently under construction, and incorporates latest mechanical design aspects[13].

For batch operation practice, a state-of-the-art round type furnace is still the preferable choice.

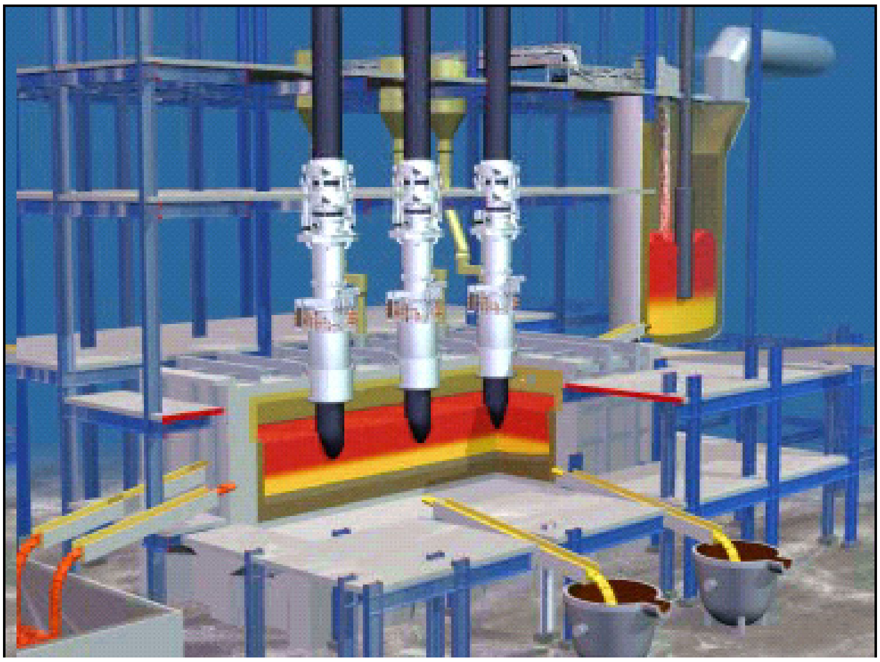


Figure 13: 3D Illustration of a rectangular copper slag-cleaning furnace

Due to the highly aggressive slag (higher Cu_2O content due to the charging of discarded slag), it should be considered in some applications to add copper side-wall cooling in the areas of premature wear.

PGMs: Platinum Group Metals (PGMs) are produced mainly from sulphidic 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 a converting step.

PGM smelting can be considered as very similar to the smelting of nickel matte by a SAF whereby SMS Demag's rectangular furnace is the ideal equipment for 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 side-wall cooling system and thyristor control system are required for such furnaces.

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

Lead/zinc: The SAF is commonly applied also in lead production, whether used for slag cleaning of upstream primary smelting (such as the lead blast furnace, Outokumpu, Kivcet, QSL, TBRC, BBU, or Mezica processes), or as an independent unit for the re-melting of secondary material or scrap[14]. During slag cleaning, lead levels can usually be reduced from 2-4% down to 0.5-0.7% and zinc levels from 8-12% down to 3-4%.

It is assumed that DC furnaces will show a better zinc fume-off rate and better slag cleaning in comparison with conventional AC technology, but this is under further investigation.

Calcium carbide: Owing to high oil and gas prices, several companies involved with special gases (*e.g.* acetylene) and plastics (*e.g.* PVC) are now seriously considering producing their raw materials from calcium carbide. The surprising potential revival for this material is being followed in various projects at SMS Demag. Based on our previous references and still-available in-house knowledge, we currently claim to be the only supplier of large capacity calcium carbide furnace technology.

Titanium dioxide: The market for titanium dioxide-based products shows strong demand. Numerous large-scale projects are currently under discussion, mainly in South Africa, Australia, and China. In this process, pre-treated ilmenite ore is smelted in a submerged arc furnace to form a TiO_2-rich slag and hot metal (pig iron).

The smelting can be carried out in a DC or AC furnace, depending mainly on the experience of the producer. SMS Demag recently supplied two SAFs for ilmenite to South Africa that are running successfully.

Recycling: In recent years, the submerged arc furnace has become the focus for the recycling of various waste materials that accumulate in the ferro-alloys, iron / steel, and non-ferrous industry (such as dust, slag, slurries), as well as for waste from used hybrid batteries and spent catalysts from the automotive and chemical industries[15]. The SAF-based solutions are not only environmentally balanced, but also economically feasible.

SMS Demag can offer several one-step processes for the recycling of critical waste materials, the principles being similar to those of ferro-chrome production. The process generates no waste materials apart from molten iron, slag, and crude zinc oxide.

3-D fluid-dynamic modelling

With the modelling tool of SMS Demag, the understanding of up-scaled new processes is more transparent. The model was firstly successfully applied to a large-scale submerged arc furnace application in Chile[14]. The modelling provides important data for proper furnace sizing and correct dimensioning for the cooling system. Furthermore it gives good indications of operational conditions.

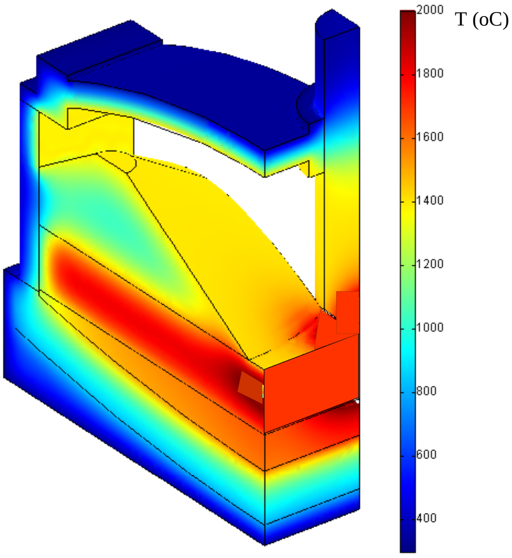


Figure 14: Example of temperature distribution in a rectangular furnace

Major factors which are considered in the model:

- Joule's energy generation in ohmic resistors: slag, metal, arc, and electrodes;
- energy 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;
- heat transfer by conduction in refractory, shell and electrodes;
- heat transfer by convection through furnace shell/water, shell/air interfaces;
- heat transfer by convection and radiations at slag/gas, bank/gas, electrodes/gas and refractory/gas interfaces;
- slag and metal 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 of an orientation point for furnace design

- to match long-term experiences with new advanced modelling tools
- to support the client's and supplier's decision for new process procedures
- to get a better understanding for side wall cooling concepts
- to considerably lower up-scaling risks

Secondary intensive slag cleaning

SMS Demag can now offer an innovative secondary intensive slag-cleaning step, which is placed downstream of conventional slag cleaning furnaces[14]. 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. This has always led to a significant portion of precious metals remaining in the slag zone.

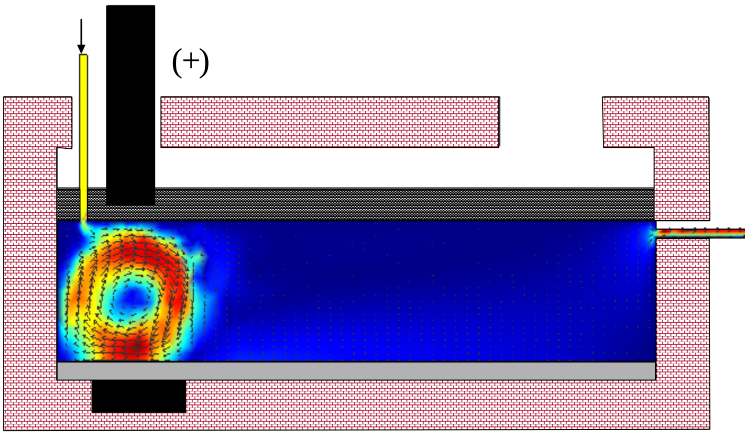


Figure 15: DC-Intensive slag cleaning unit[14]

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 electromagnetically stirred, which leads to a partial coagulation of the smaller metal droplets. In the second zone, the droplets are forced by capillary motion towards the metal/matte phase and additional electrolytic effects increase the metal recovery rate.

In the case of copper slag cleaning, the copper content of the slag can be further reduced by 0.2-0.5 percentage points. With a small investment for the compact unit, amortisation periods of less than one year seem to be possible.

CONCLUSIONS

The first SAF was commissioned almost exactly 100 years ago. Since then a tremendous development of this smelting tool was recognized and it is now operating in at least 20 different main industrial fields.

We proudly look back at the significant role we played in the history of this unique and highly efficient unit. With ongoing innovation, and adapting to the customers and market requests we hope that the units will be also successful in the next 100 years.

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