

AC- AND DC- SMELTER TECHNOLOGY FOR FERROUS METAL PRODUCTION

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ABSTRACT

In 1906, the first submerged arc furnace had been supplied by SMS Siemag. Since then the unit is established in various industries such as ferro alloy, 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 been already started to implement this kind of technology. From the historical point of view there is no pyrometallurgical application for DC furnaces that has not been carried out by AC furnaces before. This paper will compare and evaluate SMS Siemag's view regarding the application areas such as FeCr-, FeNi-, FeMn- and TiO₂-slag-production as well as the potential for waste recycling. Furthermore, the technological highlights of AC and DC-smelters such as electrode system and furnace design will be described. In addition the latest technological trends in conventional smelter technology will be described on the basis of numerous plants, which are currently under execution or had been commissioned recently. SMS Siemag has started an unique long-term research and development project allowing a direct comparison of AC vs. DC technology in large scale in a recently installed 1 MVA test furnace at the IME at the University of Aachen/Germany.

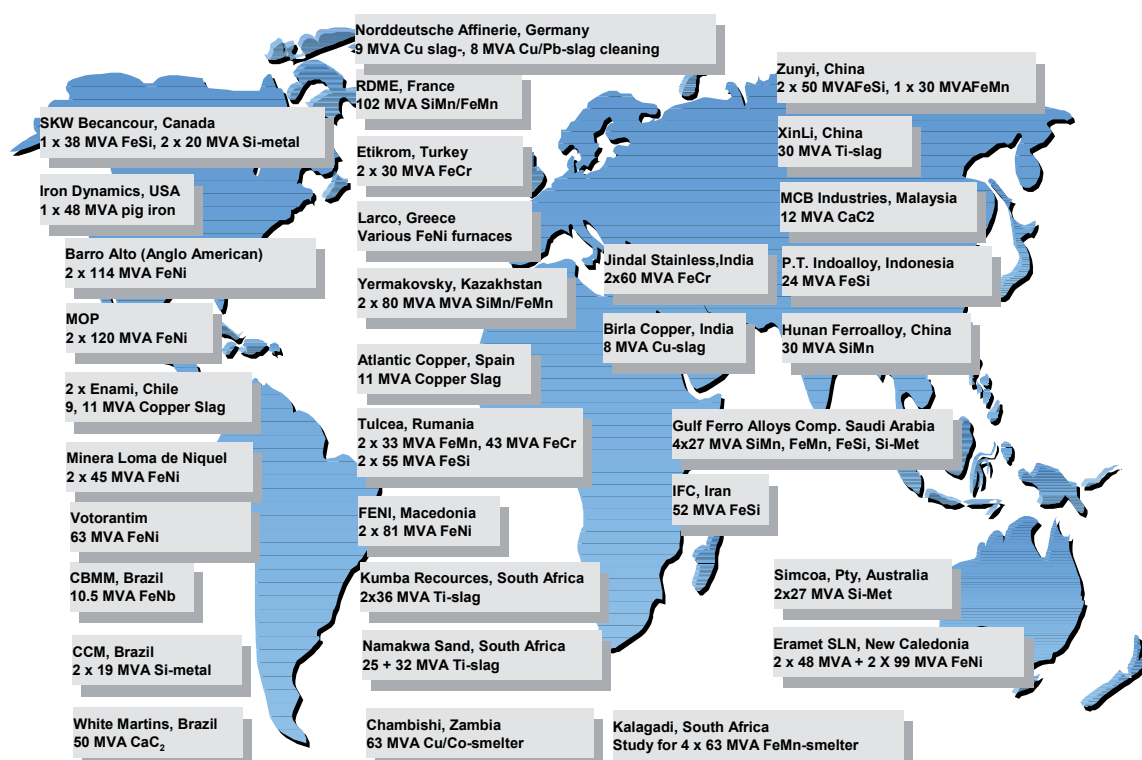
1 HISTORY, APPLICATIONS AND TRENDS

With the development of the dynamo machine by Werner von Siemens, one of the most recognizable developments started: the industrial utilization of electrical energy. The increasing demand for ferro alloy and desoxidation agents in steel making in 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 and was successfully commissioned in 1906. A second furnace was installed for the production of ferro alloys. The "evolution" and the major milestones of the electric smelting technology are shown in table 1:

Table 1: SMS Siemag milestones in AC and DC technology [2]

1906	First reduction furnace – DC-single electrode principle (1,5 MVA)
1911	First reduction furnace – AC-3-electrode principle
1913	6-electrode reduction furnace
1935	15 MVA furnace with round shell
1953	40 MVA large capacity furnace
1956	Compensated low-inductive high currency line
1958	Hydraulically controlled electrode column
1959	Large-capacity 60 MVA furnace
1966	Encapsulated electrode column
1969	Large-capacity ferro-, silico-chromium furnaces
1971	Large-capacity silicon metal furnace
1975	First large scale DC-furnace for steel production
1980	100 MVA rectangular furnace
1982	108 MVA circular closed type furnace
1992	First conductive hearth for ilmenite smelting
1992	Largest 102 MVA SiMn/FeMn furnace
2001	DC furnace for ilmenite smelting
2002	Continuous operating circular copper slag cleaning furnace
2003	Side wall copper cooling system for large capacity rectangular furnace
2004	Continuous operating rectangular copper slag cleaning furnace
2004	High capacity 120 MVA rectangular furnaces with thyristor + copper cooling system
2006	Pilot plant DC slag cleaning unit for precious metals (PGM, Cu, Co, etc.)
2009	Development of largest DC-furnace for FeCr (70 MW)

The following picture provides an overview installed AC- and DC- furnaces with the involvement of SMS Siemag.

**Figure 1:** SMS Siemag milestones in SAF technology

The track record demonstrates SMS Siemag's leading role for both technologies. SMS SIEMAG has been developing this technology for more than 100 years and has supplied a diverse market with about 700 smelting furnaces and major furnace components [3]. The major fraction of furnaces (> 99%) represents AC based concepts. Furthermore our steel making department supplied around 400 furnaces of which approx. 15 % are DC based EAF's. Numerous applications were 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 2**).

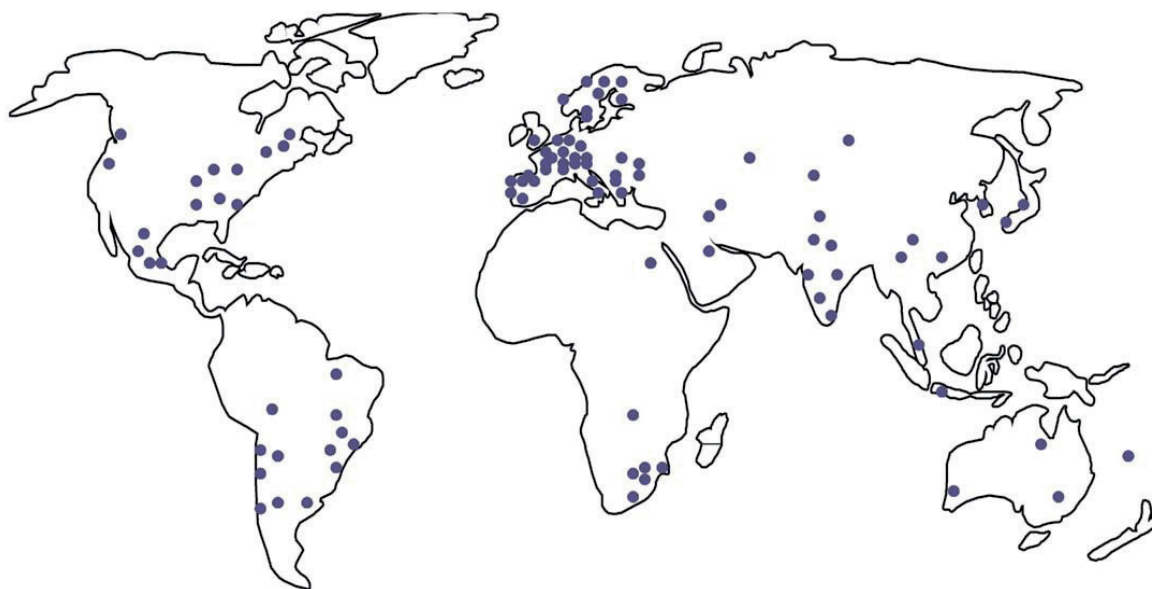


Figure 2: Customer distribution worldwide [4]

2 TECHNOLOGICAL FEATURES OF AC AND DC FURNACES

The process mainly determines the technological design features of a smelter. The following summary describes the various types of furnace features with regards to power characteristics, process, roof, charging system, shell and electrode system. The combination of such basic features allows the design of tailor made furnaces to suit the specific process requirements.

Basic system

- AC based rectangular (3 or 6 electrodes in-line)
- AC based circular furnaces
- DC based circular furnaces (single or twin electrode)

Process type

- Open design
- Semi-closed design
- Closed design

Furnace roof types

- Water cooled multi-sectional roofs
- Water cooled roof (spray cooling)
- Suspended brick roof/cast roof
- Flat/arched shape

Charging systems

- Hot/cold charging
- Hollow electrode charging system (HES)
- Liquid charging (launder system)
- Choke/batch feeding principle
- Automatic/manual feeding

Furnace shell types

- Flat/dished bottom
- Cylindrical/conical
- Stationary/rotating
- Changeable/tiltable
- Various sidewall cooling systems

Pre-baked/graphite electrodes

- Self baking electrodes
- Extrusion electrodes
- Hollow electrode system for pre-baked or self-baking electrodes
- Suspended/supported E-column design
- Prebaked electrode

3 CONVENTIONAL AC FURNACES

The principle of a conventional submerged arc furnace is electric resistance heating. Electric energy is converted into heat and reduction energy by using the resistance R of the burden or the molten slag, sometimes, e.g. in the case of FeNi production, reinforced by the electrical resistance of an arc between the slag and electrode. The energy is transmitted to the furnace hearth by carbon electrodes [5]. The power of the furnace is the product of the hearth resistance and the square of the electrode current. Therefore, a limited increasing electrode current may result in a relatively large increasing load. A typical furnace with slag operation comprises a circular or rectangular shaped furnace shell with separated tap holes for slag and metal. For some processes the slag and metal is tapped through one tap hole and separated downstream via cascade casting or skimmers. The furnace shell is refractory lined and – if additional shell cooling is required by the process – water-cooled by a special sidewall cooling system. The shell bottom is usually cooled by forced air ventilation. The electrode is consumed by the furnace bath. The self-baking electrodes with casings or prebaked electrodes are periodically extended by new pieces [6]. The electrode is semi-automatically slipped into the bath with the furnace at full electric load and with no interruptions of the furnace operation. The electrode column assemblies contain all facilities to hold, slip, and regulate the penetration into the bath. All electrode operations are performed hydraulically. A cross section of a typical AC smelter is illustrated in **Figure 3**.

The electric power is normally supplied from the furnace transformer via high current lines, water-cooled flexibles, bus tubes at the electrodes and the contact clamps to the electrodes. If the process generates off-gas which contains a certain amount of CO, the furnace can be designed as a closed furnace type and the CO can be utilized for further applications such as power generation, heating, pumping, steam generation, etc.

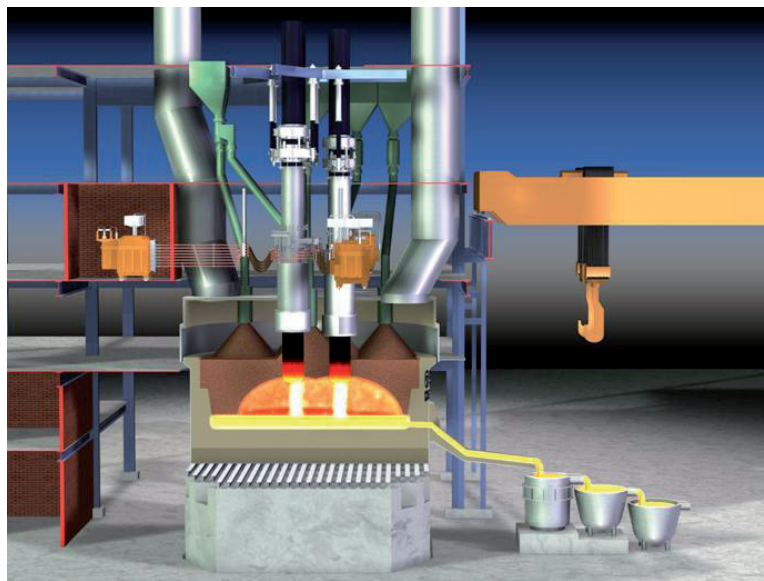


Figure 3: Cross section of a conventional SAF

The major features of SMS Siemag's AC-based furnaces are:

- Patented, low maintenance electrode columns for various electrode types
- fail-safe, robust designed electrode holding and slipping device
- Robust vessel design does not allow bulging/movement
- Proven hollow electrode charging system
- Gas tight water cooled roof design provides high quality CO-rich gas
- Application of energy recovery system possible

The choice of the raw material according to the customer's aspects has the biggest impact on the process. On the one hand it affects the slag composition and on the other hand the smelting pattern inside the furnace (based on the physical properties and the amount of energy input [7].

The physical properties determine whether the smelter can run in

- conventional resistance mode using the electrical resistance of slag,
- shielded arc mode using the electrical resistance of the slag AND arc or using the electrical resistance of the feeding mix.

4 CONVENTIONAL DC FURNACES

The DC furnaces are generally of circular type and the electric energy is converted into heat 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 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 almost all projects. A typical furnace with open slag bath operation comprises usually 1 – 3 slag tap holes and 1 – 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 side wall area. The refractory concept has to be designed carefully to adopt this more aggressive conditions. The electrode is consumed by the furnace process. The prebaked electrodes are periodically extended by new pieces [8]. Conventional concepts apply electrode arm to regulate the electrode. SMS Siemag developed an innovative E-column specially designed for DC-furnaces. The mechanical functions and the electrical power transfer principles are similar to the conventional AC based electrode columns. **Figure 4** shows the roof section of a DC smelter.

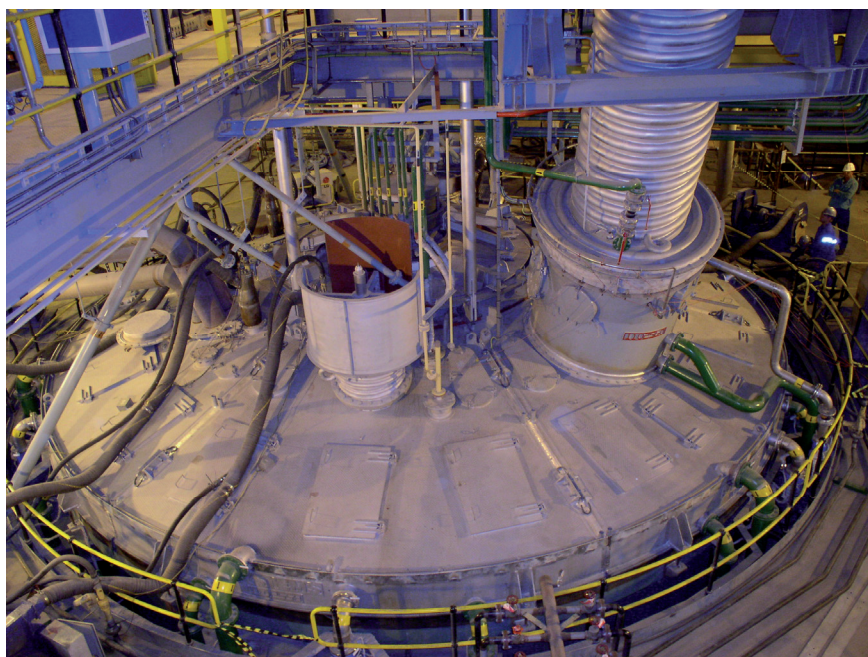


Figure 4: Roof section of a DC smelter

Also DC furnaces can be designed as a closed furnace type and the CO can be collected. Our strength for DC-technology can be summarized as follows [14]:

- Unique in-house knowledge to minimize 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 nipping under full power (providing maximized power-on time)

- Quick changeable centre piece device essential for maximum operating time
- Intelligent feeding arrangement to maximize throughput and refractory lifetime
- Robust shell design
- Proven hollow electrode charging system
- Large product portfolio of roof and sidewall cooling systems for sufficient protection at moderate energy consumption level
- Leading supplier for DC furnaces in the metals industry

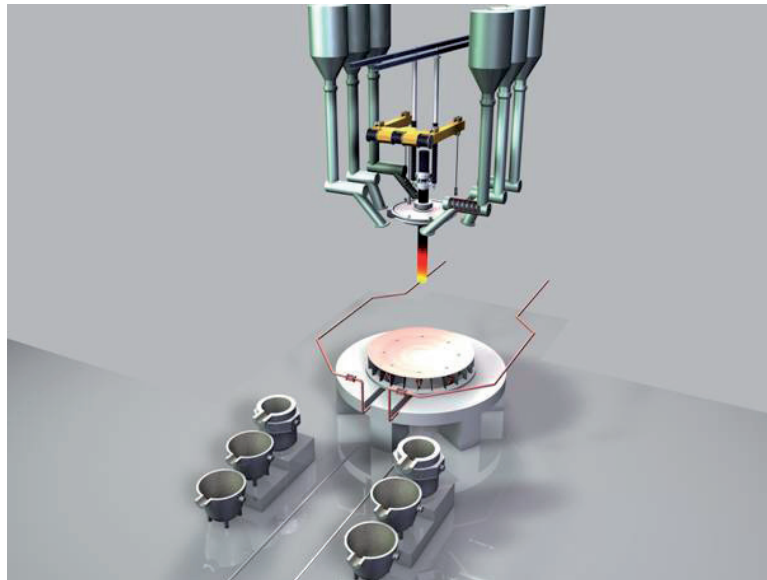


Figure 5: Electrode system of a modern DC-smelter

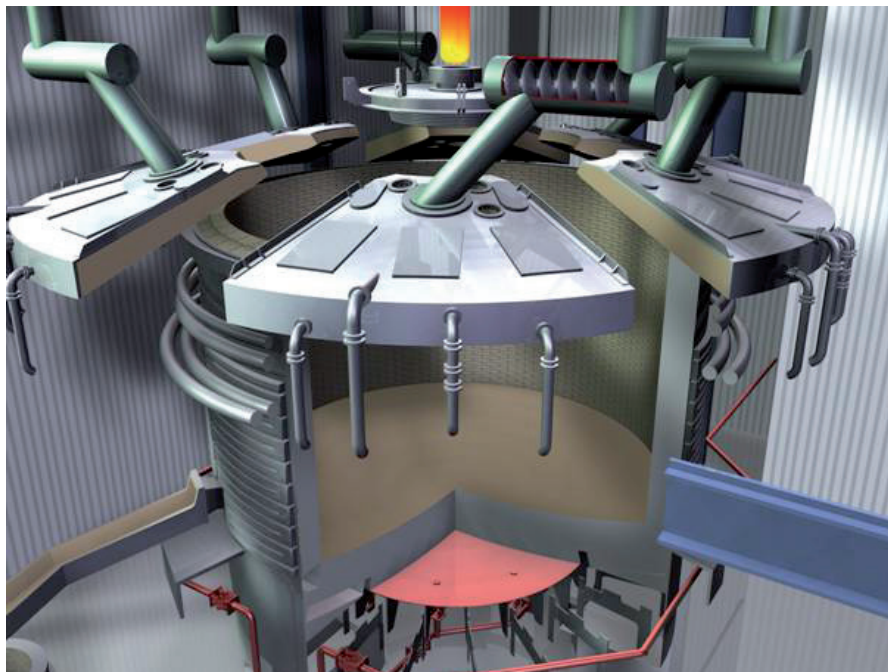


Figure 6: Illustration of a modern DC-smelter with conductive hearth

Illustrations of a DC unit are illustrated in **Figure 5 + 6**. The DC furnace is usually operating 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 are showing 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 side wall 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 side wall 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 the DC technology is the direct use of fine material, eliminating the necessity of investment intensive agglomeration steps placed upstream the furnace. The lower price level of fine material is beneficial for the overall operating costs.

5 GENERAL ASPECTS APPLICATION

Today more than 99% of today's ferro alloy and TiO_2 -production is carried out in AC furnaces. There is no application in the pyrometallurgy for DC furnaces that has not been carried out in AC furnaces before. A partial substitution of AC furnaces by DC furnaces was considered only by few customers (mainly for the application FeCr, FeNi, TiO_2 , PGM) as it will be further described in the following chapters.

6 FERRO CHROME

Ferro-chrome production is carried out in either a DC or AC-based SAF. Until today almost all FeCr is produced in conventional AC furnaces which are charging cold lumpy material to the furnace.

At the beginning of 2008, SMS Siemag received the order from ETI- Krom in Elazığ, Eastern Turkey, for the revamp of two AC-based FeCr furnaces. The engineering work has commenced, and the customer plans to commission the new furnaces within 2009. The furnace power of 30 MVA will remain unchanged, as well as major parts of the feeding system [10].

A common proven technology for the use of fines is to charge cold-bonded briquettes into a conventional AC-based SAF. SMS Siemag has successfully commissioned two 60-MVA units in India. After attaining the required physical briquette properties, the furnaces are operating above their nominal capacity. **Figure 7** shows a picture of this plant.



Figure 7: Tapping area of the AC-based FeCr furnaces of Jindal in India

One option for saving operating costs is to pre-heat the ore, which can be done in a rotary kilns, a rotary hearth or a pre-heating shaft. The use of a preheated step (especially shaft furnaces) has proven to be beneficial for achieving low electrical energy consumption in an AC submerged arc furnace. It is mainly used in South Africa. Major draw back of such technologies is the higher investment cost as well as lower overall plant availability for the overall process line.

The increasing proportion of fine ore drove some ferrochrome producers to 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, 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 developing 4 x 70 MW furnaces for Kazchrome in Kazakhstan. The units will produce approx. 440,000 annual tons of liquid ferro chrome. The plant will also include a converter shop with a capacity of 50,000 tpy of M.C. ferro chrome. A preliminary layout of the plant is shown in **figure 8**.

In the past a common way of charging fines into the SAF was via a hollow electrode system (HES) in a single electrode DC furnace. Recent investigations have shown that a conventional feeding of chrome ore in the vicinity of the electrode via charging tubes will stabilize the process.

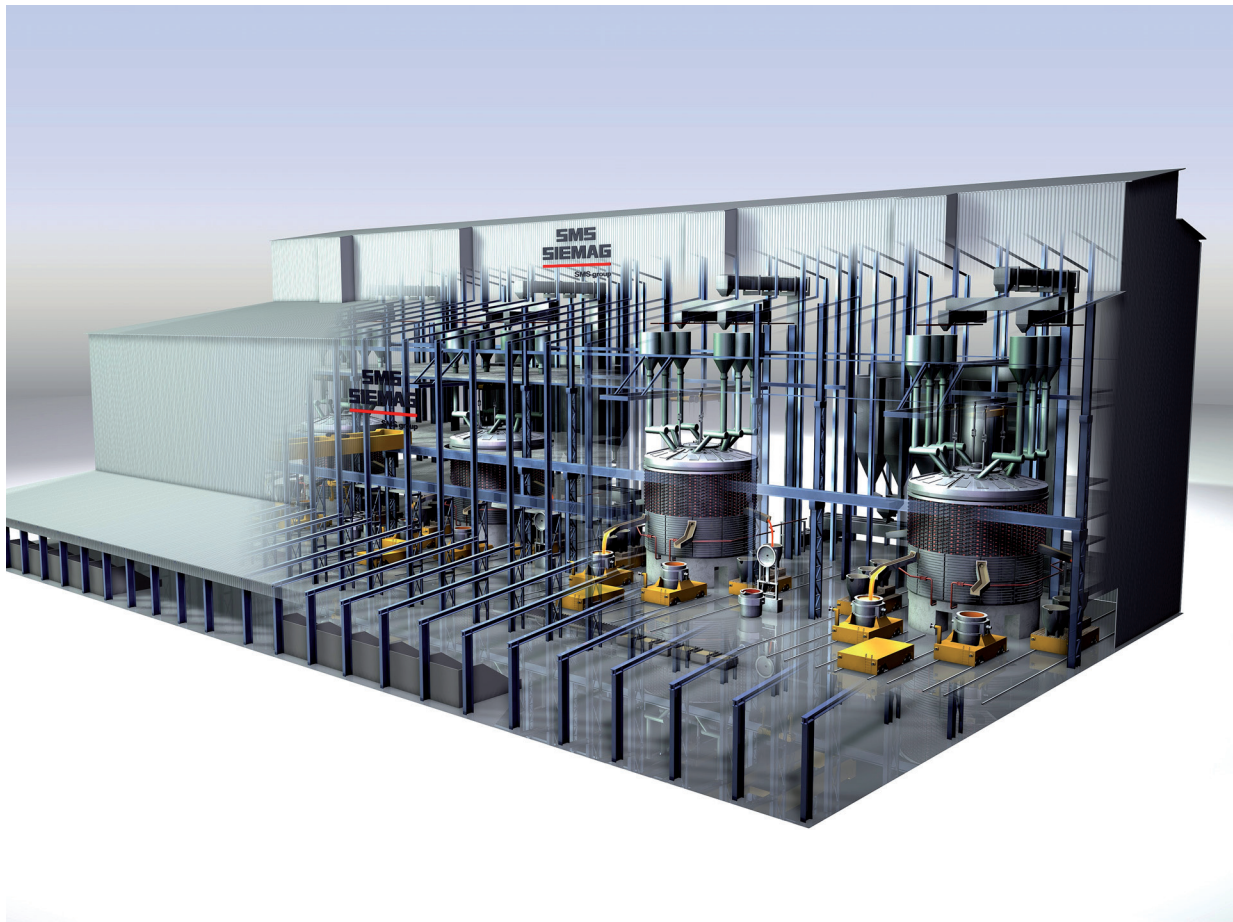


Figure 8: 3D Illustration of a modern DC-based FeCr plant

7 FERRO NICKEL

Until today all of the pyrometallurgical FeNi is produced in conventional AC based submerged arc furnaces [8]. The strong competitiveness of submerged arc furnaces for ferroalloys has been mainly achieved by the installation of advanced high-power smelting units. During the last decade numerous improvements have been developed providing efficient and safe operation with large scale FeNi-furnaces. Today, modern ferro-nickel SAF's are characterized by high efficiency. In general, depending on the requested capacity, these may be round or rectangular-shaped furnaces (see **Figure 9**) [11]. The choice is mainly based on the anticipated power input. SMS SIEMAG has found that where more than 60-70 MW nominal furnace load is required, a rectangular furnace is the best solution from the technical, economical and operational point of view. Below this capacity the circular furnaces are the preferred solution [12,13].

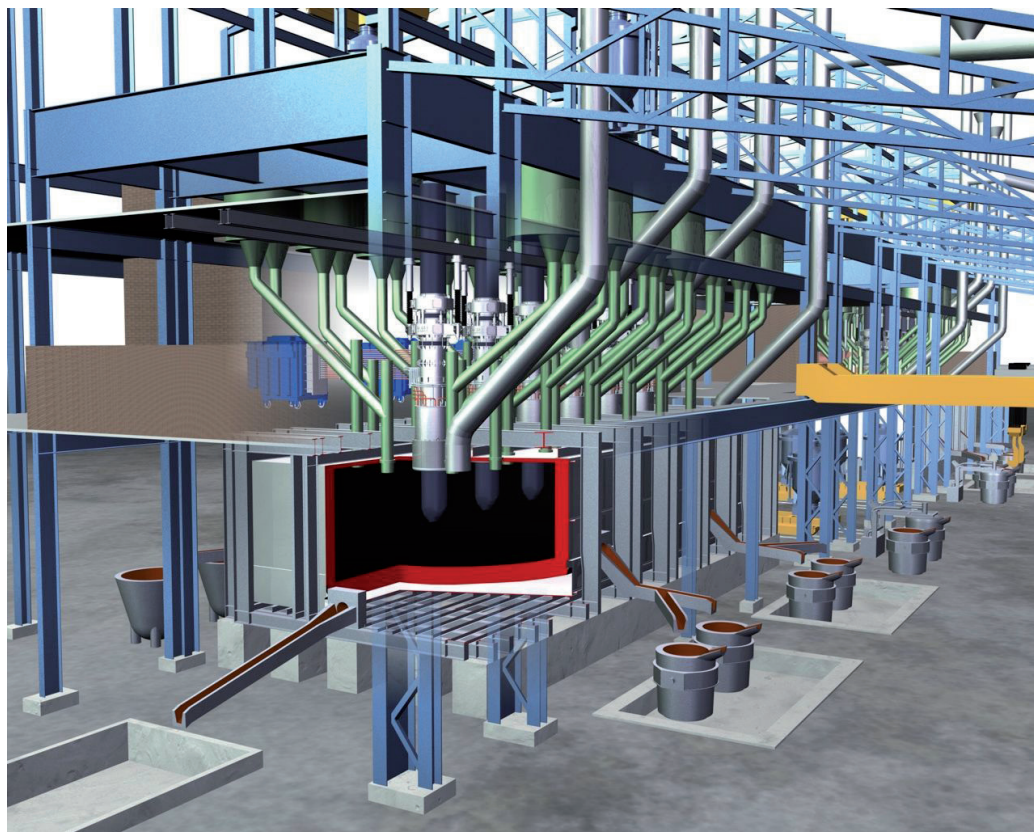


Figure 9: 3D Illustration of a modern rectangular FeNi plant

This new demand 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 and are under construction for Anglo American and Vale in Brazil.

Several industries are also evaluating the potential for applying DC technology in the production of ferro nickel. One project in New Caledonia has caused attention by using various sequences of fluidized beds in combination with a twin DC smelter. SMS SIEMAG does not see any benefit in comparison with the conventional approach. The majority of submerged arc furnaces for FeNi production is and will continue to be AC technology based.

SMS Siemag follows this technological approach critically. The DC process combines a calcination and smelting step, which are not proven in industrial scale. Furthermore, SMS Siemag is concerned regarding the higher energy consumption due to lower thermal efficiency and lower life time of such a technological approach. The start up and ramp up of such technology will be another challenging effort. Other companies are following up the development of twin-DC furnaces for the FeNi-smelting. This technology will put additional challenges in terms of roof integrity and process control. It will be interesting to follow up this technology, when entering the commissioning stage.

8 FERRO MANGANESE

Over recent decades, SMS Siemag has designed and supplied several ferromanganese/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 into the furnace, which is nearly 20 meters in diameter and has 102 MVA transformer capacity [14]. An illustration of a typical FeMn furnace is shown in **Figure 10**.

SMS Siemag finished a study for Kalagadi for the conceptual engineering of a large FeMn complex, which is planned to be constructed in South Africa. The nominal plant capacity is calculated for 320,000 annual tons of H.C. FeMn which will be produced with four 65 MVA closed type furnaces.

Today's Fe-alloy furnaces are designed with a compact high-current supply system, which minimizes the reactance of the furnace and maximizes the electrical efficiency.

The application of DC technology for the FeMn production is from the economical point of view not recommendable. The Mn-recovery of such process is due to an excessive Mn-vaporization pretty poor.

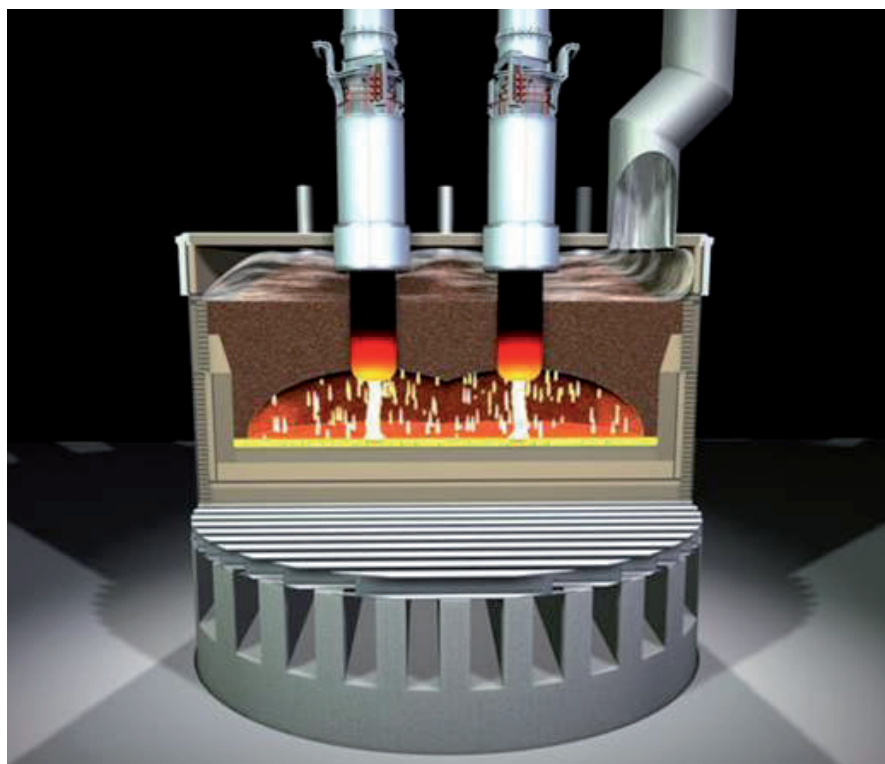


Figure 10: Cross section of an AC-based closed type FeMn furnaces

9 SILICON METAL AND FeSi

SMS Siemag has supplied the majority of large-scale submerged arc furnaces for silicon production, which typically operate at 12-22 MW. The demand for high-grade silicon is growing, mainly due to increasing demand from aluminum, silicon and other industries. A large-scale modern Si-metal plant is shown in **Figure 11**.

The process requires an energy input of about 12 MWh per ton of silicon with high quality raw materials, such as high-quality quartz and low ash reductants. It is sometimes economically feasible to install energy recovery systems. The specially designed furnace hood allows an off-gas temperature of approx. 800°C. Additionally, the patented fume exhaust gas is injected in the hood which eliminates the necessity for a bag house for the secondary dedusting system in this area [15].

The company RWS in Bavaria, southern Germany, has awarded a contract to SMSD to revamp its old # 4 furnace. The furnace # 4 (former DEMAG furnace) was commissioned in 1955 and is still in operation. SMS Siemag supplied three electrode columns of its latest design and a new water-cooled gas hood.

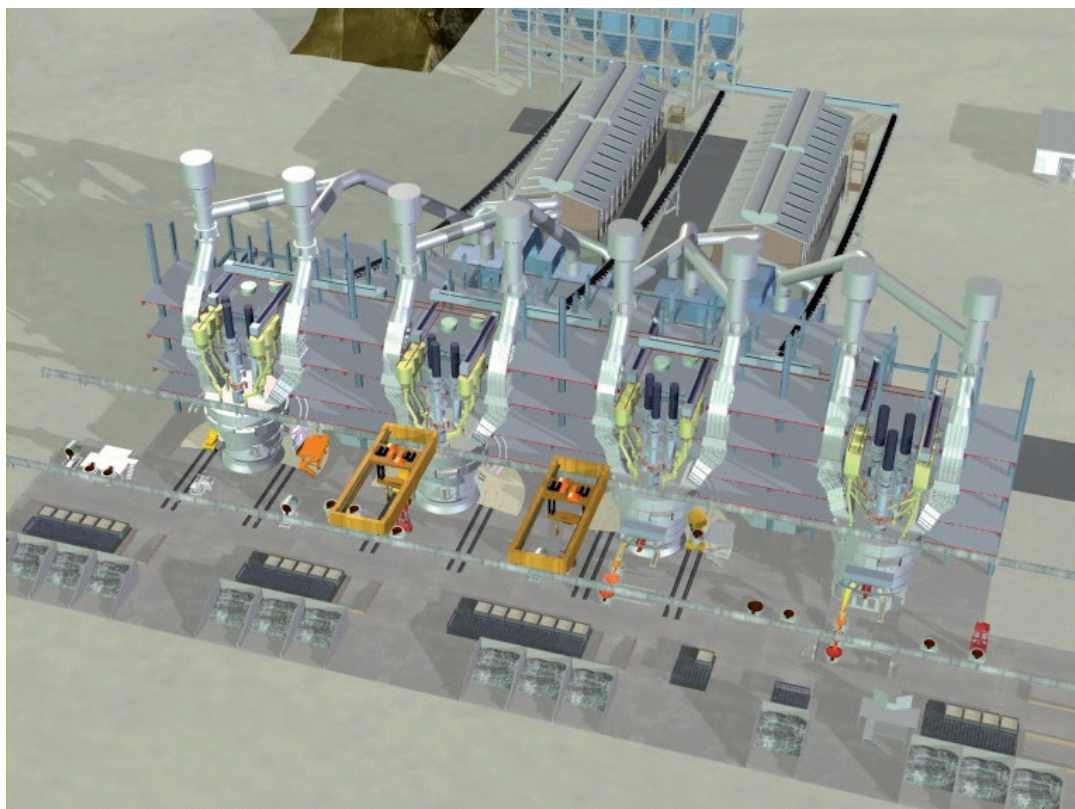


Figure 11: 3D illustration of a modern Si-metal plant

SMS Siemag is at present supplying two furnaces for Si-metal production of 30 MVA transformer capacity each. The scheduled annual production capacity is 24,000 tpa of Si-metal.

Besides the furnaces themselves, the entire plant engineering from raw material handling to packing of the final product (four different grain sizes Si-metal) falls under SMS Siemag's scope. The contractual partner of SMS Siemag is ThyssenKrupp Mannex (TKM), the end customer is BASCO COMPANY with its subsidiary TOO "SILICIUM KAZAKHSTAN", Almaty, Kazakhstan, which has been newly established to operate the plant.

In April 2008 SMS Siemag received an order from Bluestar for the supply of two 30 MVA Si-metal furnaces. The capacity is comparable to the Basco project.

The DC technology is not applicable for the production of raw silicon metal. A Scandinavian company is considering using DC furnaces for the refining of the Si-metal to high grade solar Si-metal.

10 TiO_2

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 also implemented DC technology to eliminate the agglomeration step.

SMS Siemag was strongly involved in the introduction of the 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 Sand (1 x 27 MVA and 1 x 34 MVA) and Ticor (2 x 36 MVA) in South Africa. Namakwas Sand was commissioned in 1999 and Ticor in 2003. The reason for the DC application is also driven by the available sources of TiO_2 fines.

In this process, pre-treated Ilmenite ore is smelted in a submerged arc furnace to form TiO_2 -rich slag and hot metal (pig iron) (see **Figure 12**).



Figure 12 Slag and metal tapping area of a DC-based TiO₂-smelter

SMS Siemag has recently supplied two SAF's for Ilmenite to South Africa. Furthermore, key equipment of SMS Siemag is used in the two furnaces of Namakwa Sands.

11 STAINLESS STEEL DUST AND WASTE TREATMENT

The recycling of stainless steel mill fines can be carried out with both technologies. **Figure 13** illustrates the flow chart of a single AC furnace recycling concept. The waste can be charged as fines or being briquetted prior being charged into the furnace. The design of the furnace, especially the right choice of furnace cooling and refractory concept has to be done with great care due to the aggressive nature of the slag as well as the furnaces gas (Cl, F, Alkalies, Pb, Zn, etc.).

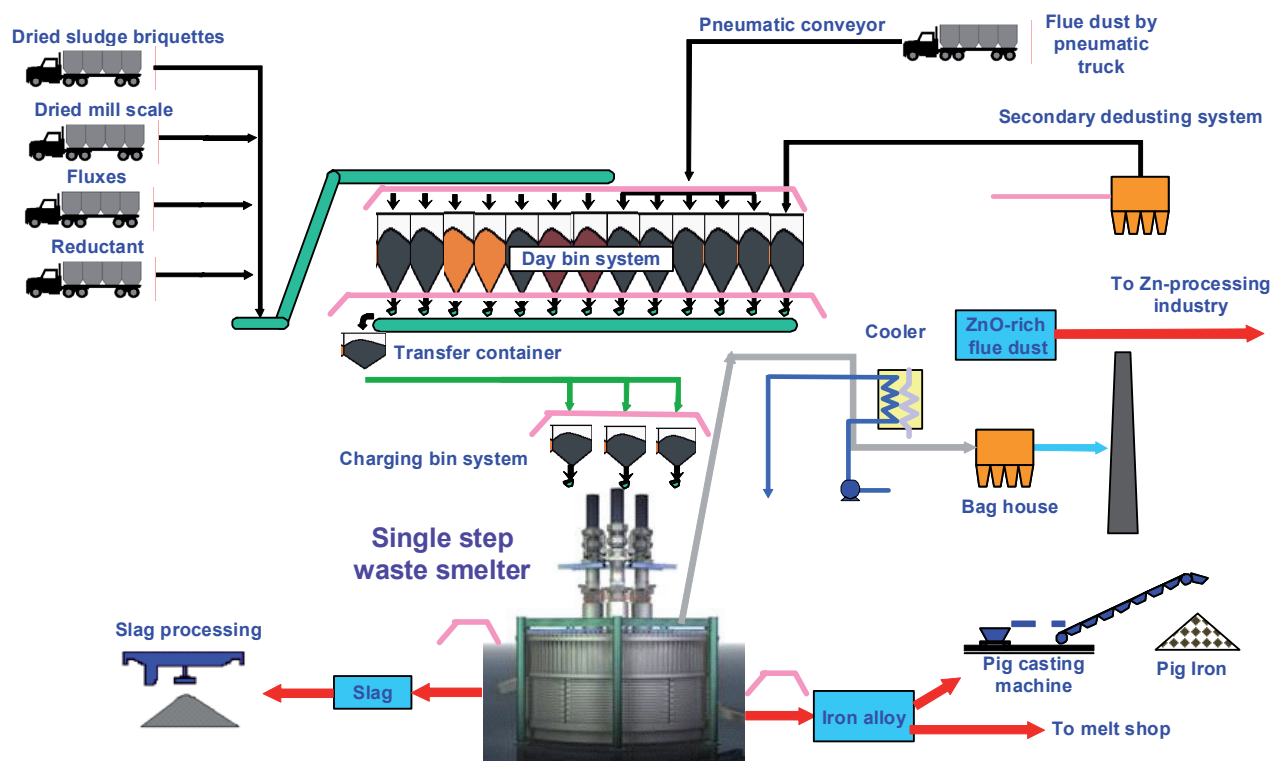


Figure 13: Flow sheet of SMS Siemag's waste recycling concept

In recent years, submerged arc furnace technology has become the focus for the recycling of various waste materials accumulating in the ferroalloys, iron/steel and non-ferrous industries (such as dusts, slag, slurries), as well as for waste from used hybrid batteries and spent catalysts from the automotive and chemical industries. The SAF-based solutions are not only environmentally balanced, but also economically feasible [8].

SMS Siemag can offer several one-step processes for the recycling of hazardous waste materials, the principles being similar to those of ferrochrome production. Usually the process generates no waste materials apart from molten iron, slag and crude zinc oxide.

The same principle can also be applied for the recycling of dusts/wastes accumulated in the nickel, chrome and manganese industry.

12 TEST FURNACE AT THE IME IN AACHEN/GERMANY

SMS Siemag 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.

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 (see **Figure 14**). This will provide important comparative results between the two basic process principles.

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

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

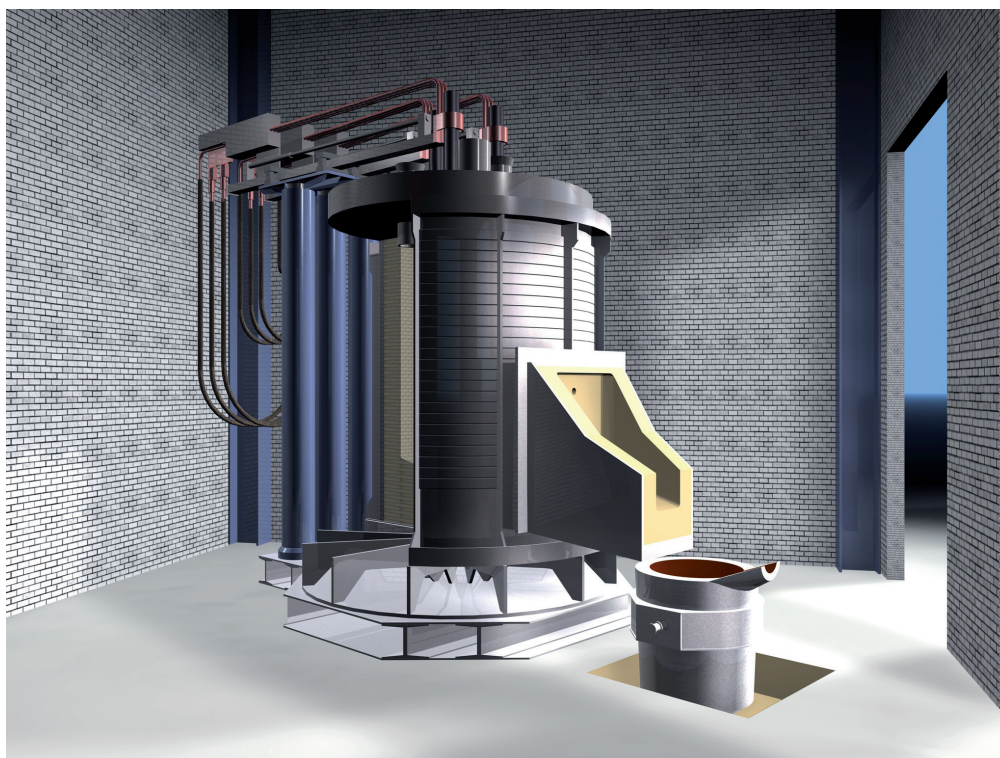


Figure 14 New AC/DC-based 1 MVA test furnace at the IME in Aachen/Germany

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 side wall cooling systems such as spray cooling, channel cooling and intensive copper cooling. The size of the furnace provides important information for upgrading of new processes. SMS Siemag expects the furnace to be commissioned by the beginning of 2010.

13 CONCLUSION

The first SAF 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 – for AC based furnaces as well as for DC-based furnaces. Today especially the potentials of DC-based smelters raises worldwide attention and some projects had been already started to implement this kind of technology. From the historical point of view there is no pyrometallurgical application for DC furnaces that has not been carried out by AC furnaces before. Depending on the local conditions, SMS Siemag sees good potentials of the DC-technology especially in the FeCr and TiO₂-slag area. DC application potentials for the production of other ferro alloy products are due to technological and economical reasons limited. 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 conclusions just from a traditional view, SMS Siemag has started a longer-term research and development project. The investigation regarding the comparison AC vs. DC is jointly carried out with the Technical University in Aachen/Germany.

14 REFERENCES

- [1] Degel, R.; Kunze, J.: History, current status of submerged arc furnace technology for ferroalloy metals, Steel Grips 1 (2003), No.3
- [2] N.N.: SMS Siemag brochure: References Submerged Arc Furnaces 2009
- [3] N.N.: SMS Siemag Newsletter 2009
- [4] Degel, R.; Kleinschmidt, G.; Becker, M.: Modern technologies for iron and steel making and casting, Metalex Conference 2004, November 18 – 19 in Bangkok/Thailand
- [5] Degel, R.; Kunze, J.: New trends in submerged arc furnace technology, 10th international ferroalloy congress – INFACON X, 1 – 4 February 2004, Capetown, South Africa
- [6] Degel, R.; Rath, G.; Kunze, J.: Status report on pyrometallurgical ferronickel production, 8th INFACON conference, September 2001, Quebec, Canada
- [7] Degel, R.; 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. , Degel, R.: Pyrometallurgical ferronickel production and experiences at Minera Loma de Niquel in Venezuela; proceeding EMC conference Friedrichshafen 2001
- [9] Degel, R.; Borgwardt, D.: Efficient recycling with SAF technology for the iron and steel, ferroalloy and non-ferrous industry, Steel Grips 2 (2004), No.1
- [10] Kempken, J.; Degel, R.: 100 Years SAF technology by SMS Demag, Pyrometallurgical conference 2006 in Johannesburg, Proceedings
- [11] Oterdoom, H., Hecker, E., Degel, R.: 2006, "Innovation and new trends in SAF technology", 100 years SAF technology symposium, May 11 – 13 2006 in Duesseldorf
- [12] Degel, R.*; Kempken, J.; Kunze, J.; König, R.: Design of modern large capacity FeNi-smelting plants, INFACON IX, 18. - 21. Feb. 2007 in Delhi
- [13] Kempken, J.; Degel, R.*: 100 Years SAF technology by SMS Demag, Pyrometallurgical conference 2006 at the cradle of the human kinds, Johannesburg, Proceedings
- [14] Degel, R.; Schreiter, T.*: SAF technology: Innovative solutions for South Afrika, Minerals engineering conference, Capetown, 13 – 14 November 2005
- [15] Degel, R.*; Lembgen, H.-E.; Schmieden, H.: SAF technology: Leadership with advanced solutions, 2nd Ferro Alloy Conference, Sept. 2005, Delhi/India