NEW TRENDS IN SUBMERGED ARC FURNACE TECHNOLOGY

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ABSTRACT

During the last 100 years, the submerged arc furnace has been one of the most amazing diversified melting units. These furnaces have found their application in more than 20 different main industrial areas such as iron, ferro alloy, chemical industry, lead, zinc, copper, refractory, titanium oxide, recycling, phosphorus etc.

Such an evolution was only possible because of tremendous efforts in research and development and due to the large range of design solutions. The worldwide strong competition also forced the industry and plant suppliers to develop highly efficient, economically balanced units in optimized sizes and with long lifetimes, to adapt to the market conditions.

Regarding the environment, the plants improved significantly in terms of water treatment plants and off-gas treatments as well as on site recycling units.

This paper will give a short overview regarding the history of the furnace and the latest developments in today's main application fields: ferro alloys, non-ferrous, special application and recycling. In addition new activities in research and developments are briefly discussed.

1. THE HISTORY OF SUBMERGED ARC FURNACE TECHNOLOGY

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 deoxidation agents in steel making in the beginning of the 20th century led to the development of the first 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 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. The "evolution" and the major milestones of the unit will be described in more detail.

Development of large electrode systems, advanced transformer technology and new furnace construction principles allowed the design of large-capacity rectangular SAF with dimensions of up to 36 m in length and 17 meters in width [2]. Figure 1 shows an example of one of the first closed furnaces for pig iron production, which was installed in Germany.

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

New developments are recognized for processes applying increased slag bath operation in the construction of highly efficient units with a high power density [3]. The higher power density in the furnace causes higher heat fluxes through the sidewall which necessitates the application of new cooling concepts.

The first application of such a system had been successfully commissioned at the beginning of this century (see Figure 2).

The picture below shows the first industrial application of horizontally placed water-cooled copper elements in the side wall of a closed pig iron furnace with a round shell.

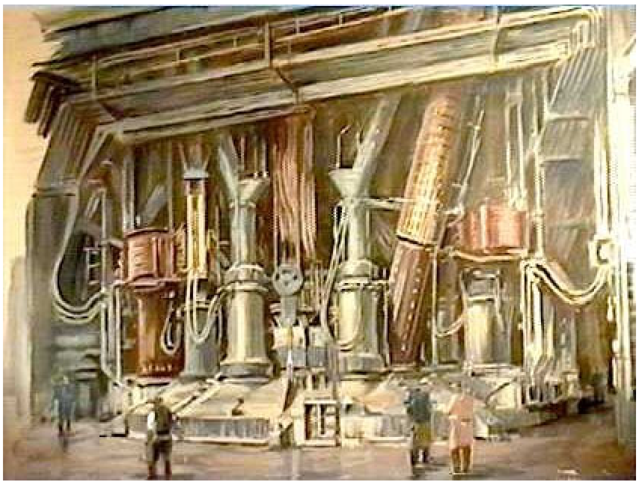


Figure 1. Pig iron furnace from the 1950s.

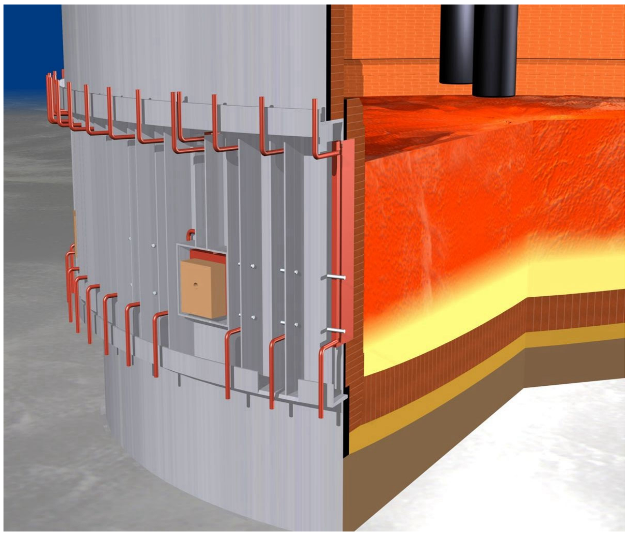


Figure 2. Modern pig iron furnace.

The control systems also went through a significant evolution during the last decades (see Table 1).

Evolution of controlling systems for SAF

1906	Manually controlled
1955	Electr. balanced beam controller
1960	Moving-coil controller
1965	AEG transductor controller
1975	AEG transistor controller
1978	Siemens transistor controller
1985	H&B controller
1995	Software controller

Since the end of the 1950s SMS Demag SAF's have been equipped with electrode controllers. Today's advanced submerged arc furnaces make use of software controllers.

The DC application for submerged arc furnace technology shows world-wide an increasing market share in niche areas especially in some ferro-alloys, slag cleaning and TiO_2 production units. Nevertheless, the majority of submerged arc furnaces are and will remain AC-technology-based.

The next chapter will emphasize current developments and recent projects in the area of ferro alloys, non-ferrous and special applications.

2. DEVELOPMENTS AND PROJECTS FOR FERRO ALLOY APPLICATION

The ferro alloy industry is directly linked to the steel industry.

It is predicted that the total crude steel production will reach an annual rate of almost 800 million ton of crude steel per year by the end of 2010 (see Figure 3). An increase in EAF share of steel making, whereas LD steel making will remain stagnant [4].

The stainless steel production is predicted to increase at an annual rate of 5%.

The demand for ferro alloys as a bulk alloy is expected to increase steadily which indicates a solid base for good future market developments.

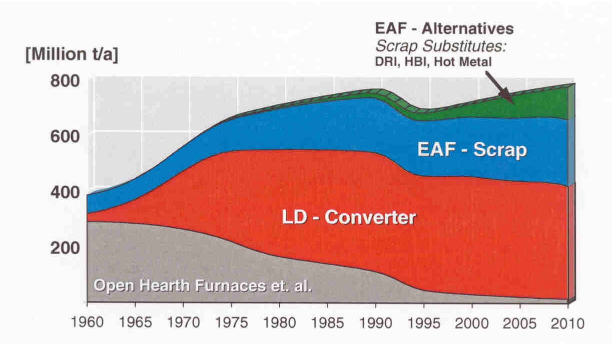


Figure 3. World steel production developments by process route.

Figure 4. Metal tap at Minera Loma de Niquel in Venezuela.

Originally, the alloying metals required for upgrading steel were exclusively produced in special blast furnaces which results in a pig iron consisting of small to medium contents of silicon, chromium and manganese. Type of the melting and metallurgical equilibrium determined the carbon content of these alloys.

The submerged arc furnace is a much better qualified unit to produce ferro alloys with regard to temperature control and adjustment to different reduction potentials. Over the time an independent ferro alloy industry established which meets today's permanently increasing demands of the steel industry.

The majority of ferro alloys is produced by pyrometallurgical smelting taking place in submerged arc furnaces.

Other attempts regarding the hydrometallurgical production of ferro alloys such as high pressurized acid leaching processes for nickel production do so far not show the predicted economical and technical benefits.

The strong competitiveness of submerged arc furnaces in this sector was mainly achieved by the installation of advanced high power smelting units.

2.1 FeNi-application

Today, a modern FeNi-furnaces is characterized by its high efficiency. In general we offer, depending on the requested capacity, round furnace designs or rectangular shaped furnaces.

Efficient furnace operation can only be achieved with:

- correctly designed SAF
- highly efficient energy transfer with arcing mode
- proper mining management
- controlled calcinations of the SAF feed
- sufficient dust recycling
- modern furnace operation with skilled personnel, allowing precise slag and temperature control [5]

A good example for those conditions is practiced at the plant at Minera Loma de Niquel in Venezuela.

The mine is located only 3 km from the site. The ore contains 15-30% moisture, 1.5-1.8% nickel, 15-17% iron and the SiO_2/MgO ratio is approx. 1.3.

After the ore is processed in a drying and raw material preparation step it is charged for calcination to 2 rotary kilns. The generated calcine is then charged into the 2 45 MVA submerged arc furnaces (see Figure 4).

The design of high power smelting units in the ferro nickel application led also to the development of various suitable side wall cooling concepts.

A new milestone in terms of cooling was achieved with the development of copper cooling elements for round and rectangular submerged arc furnaces. The concepts will be explained in more detail in the chapter design criteria on the following pages.

Such a cooling system is currently being installed at a furnace for Eramet in New Caledonia. It is planned to restart the modified furnace by the beginning of 2004. The principles of this cooling concept had been developed during the last decade and were tested in a 1:1 model. The furnace at Eramet is a 6-electrode rectangular SAF with a transformer rating of 99 MVA and an operating load of 75 MW.

This is the largest ferro nickel furnace installed by SMS Demag. The advanced furnace design and the development of a 2100 mm long self-baking electrode will allow even bigger production units.

2.2 FeCr-application

FeCr production is carried out either in DC or AC based SAF. The increasing share of fine ores in the mine bodies of newly explored mines might force the ferro chrome producer 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), which had first been successfully utilized in the fifties. Since 1993 such a system operates successfully.

It is also possible to agglomerate the fine ores by a mini sinter plant or by a cold briquetting unit before charging to a conventional AC-based submerged arc furnace.

SMS Demag received the order for two 60 MVA FeCr furnaces in India.

The plant combines a cold briquetting line with the submerged arc furnaces and will have a nominal annual production of approx. 150 000 t high carbon ferro chrome.

A picture of a mini sinter plant is shown in Figure 5.

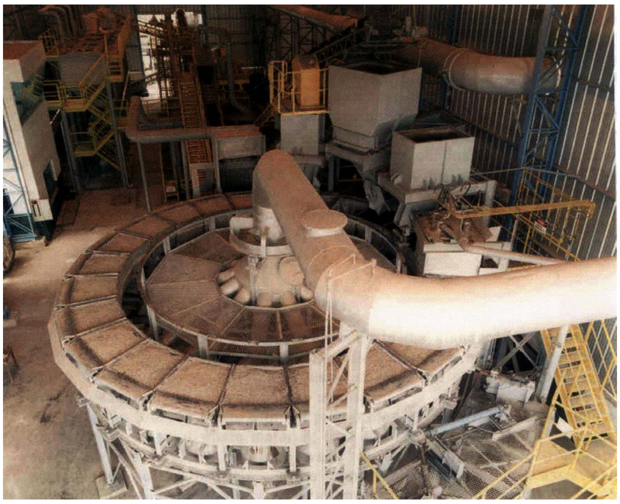


Figure 5. Mini sinter plant.

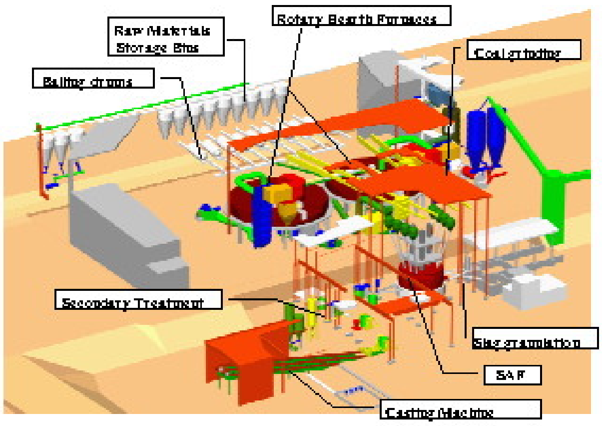


Figure 6. Rotary hearth furnace/submerged arc furnace combination [7].

Other investigations check the heating and pre-reduction of material to higher metallization levels of the chromium and iron in the material prior to the submerged arc furnace.

This technological approach is comparable to several FeNi-processes [6].

A future pre-treatment of the fine ore is currently under investigation in our research laboratory in Italy [7]. The results look promising. Past industrial scale tests at Inmetco and pilot scale tests investigated the option of achieving an acceptable range of pre-heating with pre-reduction of the iron and the chrome fraction in a rotary hearth furnace. Such a unit in combination with an SAF is shown in Figure 6.

In principle, ore fines are pelletized together with coal and then heated up in the RHF, where the pre-reduction is carried out. Hot pre-reduced pellets can then be charged with approx. 1000°C via a hot feeding system to the SAF.

2.3 FeMn-application

During the last decades we design and supply several FeMn/SiMn furnaces worldwide. The technology is in a good development stage. Some highlights regarding some process innovations are: At SEAS the largest FeMn-SiMn furnace is operating very successfully. The furnace processes Al_2O_3-rich Carajas ore from Brazil. Partially the ore is charged as sinter to the furnace.

SMS Demag is currently carrying out studies about optimizing of furnace dimensioning, in particular regarding: geometry, high level slag bath and energy transfer. A 3-dimensional view of an advanced Fe-alloy unit is shown in Figure 7.

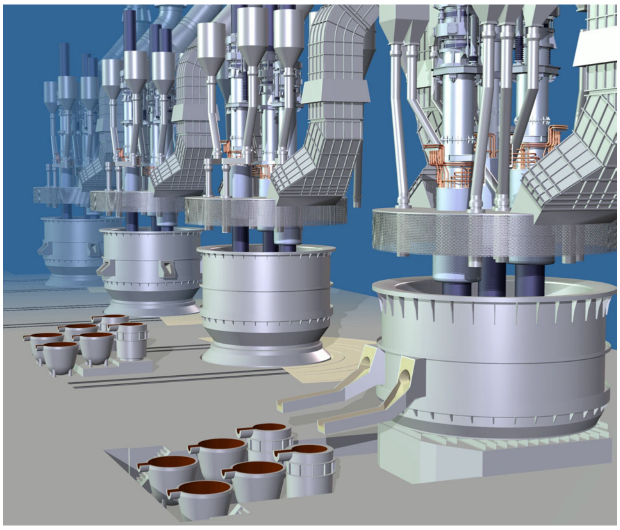


Figure 7. 3-D illustration of Fe-alloy plant.

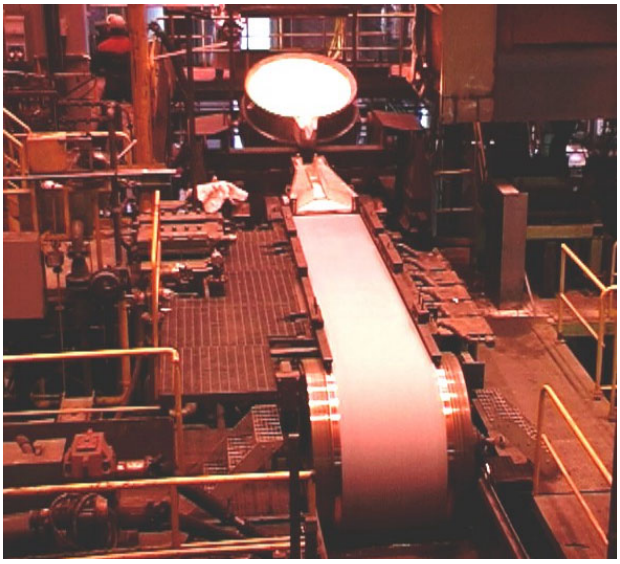


Figure 8. Belt casting plant [9.].

SMS Demag is currently working on studies in North America regarding the revamping of an existing FeMn plant.

2.4 Si-metal application

In the last decades we supplied the majority of the submerged arc furnaces for Si-metal production and have a world market share above 95% [8]. The demand for high-grade Si-metal shows still increasing tendency mainly due to the still growing market in aluminum, silicone, glue, elastomer, plastics, etc.

Currently a former Elkem furnace is revamped in China and will be equipped with the latest available technology in this field. Commissioning of the furnace is planned at the beginning of 2004.

The process requires a high energy level of approx. 12 000 kWh/t of silicon. It is in some occasions economically feasible to install energy recovery systems:

Basically two systems are applicable and offered by SMS Demag:

- energy recovery with turbine and generators to generate electricity
- energy recovery with a boiler system for steam production and direct use of steam

Operating plants and internal studies shows a generation of 10-12 MW electricity, when 2 x 27 MVA furnaces are connected to a turbine. Especially in countries with high energy prices such as Scandinavia this might be an interesting option. SMS Demag installed such a system for a Si metal plant in Norway 1978.

Downstream the SAF we are currently investigating the option of solidifying the Si-metal on a casting-belt-machine. Such a system is shown in Figure 8 and is an interesting solution for the Si-metal industry. The final product is Si-metal strip.

Originally the units were developed for the production of hot strip for the steel industry. The same technology was also successfully tested for FeMn.

3. DEVELOPMENTS AND PROJECTS FOR SPECIAL APPLICATION

The submerged arc furnace technology shows its variety of design features especially in the special application area. Numerous processes have been developed for the production of special alloys, CaC_2/CaSi, TiO_2, phosphorus, refractory materials and minerals and many more.

3.1 Special alloys

The production of special alloys is an unique niche product line. With our units, products such as Fe-tungsten, Fe-vanadium, Fe-tantalum and Fe-niobium are produced in a few units in the world. Figure 9 illustrates a dephosphorization furnace for the ferro niobium industry which is operating in Brazil.

Figure 9. Dephosphorization furnace for the ferro niobium industry.

Figure 10. Ilmenite smelting plant under construction.

3.2 TiO_2-smelting

The market for TiO_2 products shows a strong demand. Usually the product is utilized in the paint, coating, alloying, cosmetic and space industry.

Numerous large scale projects are currently under discussion mainly in South Africa, Australia, Middle East and North America.

Basically pre-treated ilmenite ore is smelted in a submerged arc furnace to TiO_2-rich slag and hot metal.

The smelting can be carried out in a DC- or AC- furnace, which depends in particular on the specific know-how of the producer.

SMS Demag supplied 2 submerged arc furnaces for Kumba Resources in Empangeni/South Africa. The first furnace had been commissioned successfully and is continuing to ramp-up production ahead schedule.

The second furnace will start by the third quarter of 2003. Figure 10 shows the plant during the construction phase.
The furnace utilizes a newly designed billet type bottom electrode as shown in Figure 11.

The design features should show certain advantages in comparison to conductive hearth or pin type anodes:
- Mechanically stable system
- Minimized arc deflection
- Controlled optimal furnace operation
- Controlled non-interrupted current flow
- Minimized electrical losses
- Maximizing lifetime of bottom anode
- and furnace bottom
- Easy start up procedure
- More flexible choice of standard refractory material
- Mechanically tight hearth design without gaps.

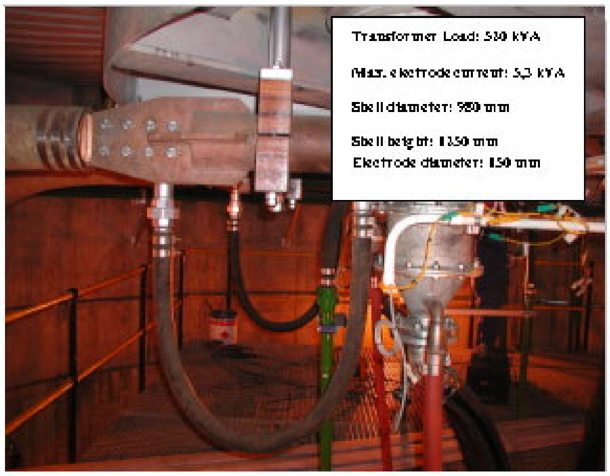


Figure 11. Billet type anode for DC-SAF.

Figure 12. 520 kVA test furnace in Aachen/Germany.

The furnace is equipped with a specially designed HES charging system with an electrode arm which allows easy maintenance in case the electrode is plugged. The electrode can be completely lifted out of the furnace.

In general the slag temperature in Ilmenite smelters is in the higher range (approx. 1680-1720°C). The application of side wall copper cooling should be carefully considered.

3.3 Calcium carbide/Calcium silicon
No significant developments are recognizable in the production of calcium carbide and calcium silicon. The market can be described as being stagnant [10].

4. SPECIAL TEST AND PILOT FURNACES

Numerous studies had been carried out and test or pilot furnaces designed and supplied to test new application areas and to reduce the up-scaling risks of industrially sized plants. We supplied furnaces in the range between 150 kVA and 3 MVA.

Recent unsuccessful industrial projects underline the necessity of tests and pilot plants.

A typical example of a smaller sized test furnace is a unit which had been supplied for the Technical University of Aachen/Germany.

The furnace allows the smelting with AC or DC mode and hollow electrode charging is applicable. It is equipped with a dry and wet cleaning system which allows also the analysis of the off-gas and dust.

Figure 12 shows a photo and the main features of the test furnace.

During the last years numerous tests have been carried out regarding ferro alloy and slag cleaning.

At the moment, the furnace is used to check the feasibility of smelting hybrid based batteries.

5. DEVELOPMENTS IN RECYCLING

The submerged arc furnace is not only environmentally balanced, but also a flexible unit for the recycling of waste accumulated in the ferro alloy, iron and steel and non-ferrous industry.

Depending on the plant and process, accumulated dust can be directly sent back to one of the process steps.

If metallurgically feasible, non-treated material can be either cold briquetted and sent to the submerged arc furnace directly or charged via hollow electrode systems.

For the recycling of steel mill waste, especially waste from the stainless steel production we suggest the application of the so-called RedSmelt technology. The process principle is shown in Figure 13.

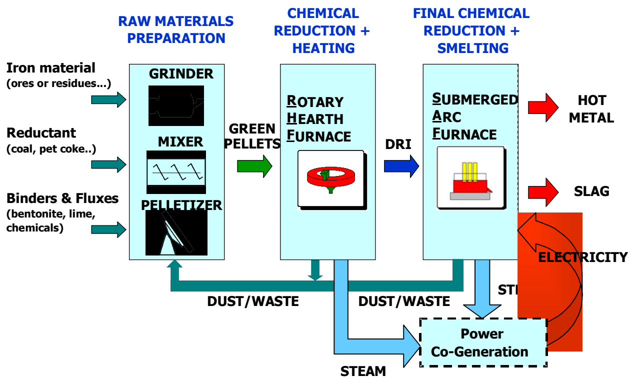


Figure 13. RedSmelt flow sheet [11].

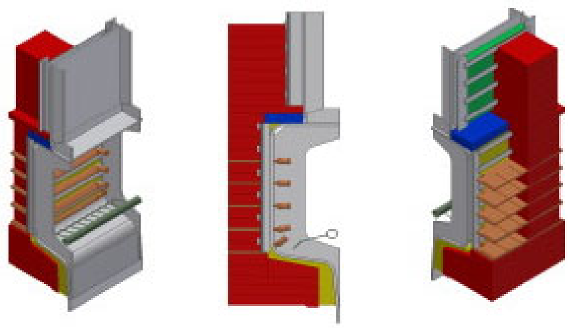


Figure 14. Side wall copper stripe cooling.

Basically the waste is (if necessary) ground, pelletized together with a solid reductant (such as coal) and sent to the rotary hearth furnace (RHF).

The doughnut shaped furnace produces direct reduced iron with an iron metallization of up to 92% which is then smelted in a closed submerged arc furnace.

The process generates besides molten iron, slag and crude zinc oxide no waste material.

Due to future more stringent environmental restrictions regarding dumping of waste, other interesting projects are currently under intensive discussion regarding the smelting of dried sewage sludge from water treatment plants and the conversion of leachable flue ashes from coal-based power plants to non-leachable slag.

6. ADDITIONAL SAF DESIGN HIGHLIGHTS

During the last century we steadily improved our furnace design, components and key-equipment.

Especially advanced computer supported software allows several improvements in certain areas. In this chapter we would like to highlight some of the major recent developments.

6.1 Side wall cooling concepts

New sidewall concepts for round and rectangular furnaces have been developed. An illustration of the stripe cooling concept is shown in Figure 15.

The copper stripes can remove up to 60 kW/m^2 of heat. 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 test facility located in our workshop in Hilchenbach/Germany in full size scale.

This stand is used for testing several cooling options. A section of the Eramet furnace was successfully tested.

6.2 Refractory

During the development of new cooling systems we reflected the refractory concepts.

In certain processes such as pig iron a sufficient heat 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. In some applications our customers achieved refractory lifetime of more than 15 years in their submerged arc furnaces.

6.3 Tap hole

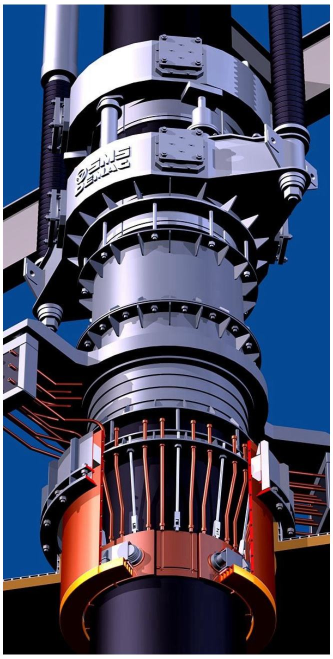
For highly stressed tap holes we recently designed a new tap hole, surrounded by water-cooled copper plates. The next photo (Figure 15) shows a typical arrangement of such a system.

Figure 15. Water cooled tap hole.

The installation demonstrated significant improvements in tap-hole lifetime and maintenance.

6.4 Electrode column

One of the major key items of our furnace still remains the electrode column (see Figure 16).



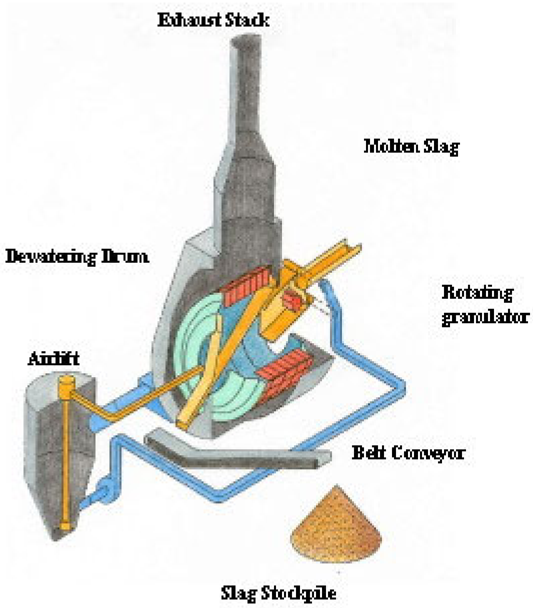


Figure 16. New generation electrode column.

Figure 17. Compact slag granulation system.

In general the SMS Demag design has been known and appreciated by our clients for decades for its reliable and good performance in all submerged arc furnace applications.

Several recent improvements have been incorporated in the design:

- failsafe hydraulically actuated electrode
- holding and slipping device
- reliable insulation up to 1500 volt operating voltage
- durable forged contact clamps with
- maximized
- energy transfer to electrode
- advanced electrode sealing
- little maintenance and easy to handle
- compact units with minimized space and load
- requirements
- wear resistance ensures long life
- up to 5% energy saving achieved with minimized magnetic losses due to special design

The newly developed electrodes were recently installed in the last references and demonstrate an excellent performance.

6.5 Energy transfer optimization

FEM calculations are carried out to minimize electrical losses due to magnetic fields. In some cases up to 5% energy could be saved with the use of non-magnetic materials in certain areas.

6.6 Slag granulation for ferro alloy

Beside the conventional slag granulation technology we improved the design of a compact slag granulation system.

This system is characterized by low operating and investment costs and might be an interesting reasonable solution especially for the ferro alloy industry. Figure 17 shows the basic principle of this granulation technology.

Several reference plants are successfully operating in Asia and CIS.

7. CURRENT RESEARCH AND DEVELOPMENT ACTIVITIES

We are in close contact with well known universities and institutes all over the world such as:

- IME Aachen/Germany
- IFM Aachen/Germany
- Technical University Dortmund/Germany
- University Duisburg/Germany
- Slag institute Rheinhausen/Germany
- Institute of ore beneficiation/Germany
- University de Santiago/Chile
- University in Delft/Netherlands

Major current activities are focused on the comparison of DC and AC application. We carry out theoretical evaluations and practical tests on lab scale. Furthermore we also improve all software programs which allow us precise sizing of the furnaces.

Furthermore a process simulator is in the test phase, which will allow the dynamical simulation of various SAF processes.

FEM calculations are used for energy and cooling optimization and also for finding best constructive solutions regarding furnace parts.

8. CONCLUSIONS

The first SAF was commissioned almost 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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