HISTORY AND NEW MILESTONES IN SUBMERGED ARC FURNACE TECHNOLOGY FOR FERRO ALLOY AND SILICON PRODUCTION

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As far back as in 1906, the SMS group delivered the first submerged arc furnaces. Meanwhile - over the last 100 years – SMS supplied more than 750 submerged arc furnaces and major components to our customers worldwide, which operate plants for the production of ferroalloys, Si-metal, non-ferrous metals and other applications. The smelter departments of the SMS group in Düsseldorf, Germany and Johannesburg, South Africa worked out numerous solutions to ensure the profitability of the operating industry in the ferroalloy business. Many highly interesting and challenging furnace projects are being implemented, including the world's largest FeNi furnace for POSCO SNNC, South Korea, the FeCr production line based on DC-technology working with an electrode column for JSC Kazchrome, the first FeMn/SiMn-plant equipped with hybrid gas cleaning system (scrubber system – wet ESP combination) for Sakura/Malaysia, modern calcium carbide furnaces for two clients in China, one modern smelter for a FeNb production line and innovative smelter for fused magnesia production. The paper will present the status of these projects. Furthermore, new solutions regarding energy recovery and other auxiliary equipment as well as innovation and future concepts will be presented.

SMS GROUP, BENEFITS FOR THE WORLD MARKET

Usually, most of the ferroalloys and special slags are produced in electric smelters/submerged arc furnaces. The SMS group has a market share of more than 50% of the western world. During the last 100 years, the SMS group developed the furnaces to such extent that it is today utilized for more than 20 different main industrial areas such as iron, ferroalloy, chemical industry, lead, zinc, copper, refractory, titanium oxide, recycling, phosphorus etc. [1, 2]. Such an evolution was only possible due to tremendous efforts in research and development, a large range of design solutions and finally the initiatives and visions of our clients resulting in joint trendsetting developments. The worldwide strong competition also forced the industry and technology suppliers to improve the efficiency and economy adapting to the market conditions. Regarding the environment, the plants improved significantly in terms of gas cleaning and energy efficiency [3].

THE HISTORY OF SUBMERGED ARC FURNACE TECHNOLOGY

The increasing demand for ferroalloys and desoxidation agents in steelmaking at the beginning of the 20th century led to the development of the first industrial electric smelters. SMS which has been a major supplier for the iron and steel industry for the last 100 years started with the construction of the first submerged arc furnace in 1905. The 1,5 MVA unit was installed in Horst Ruhr/Germany for the production of calcium carbide and was successfully commissioned in 1906. Development of large electrode systems, advanced transformer technology and new furnace construction principles allowed the design of large-capacity rectangular SAF's with current dimensions of up to 40 m in length. Over 99 % of the furnaces are AC based, either with three or six inline electrode systems for rectangular furnaces, or with three electrodes for circular furnaces [1, 2]. This will remain the dominant smelting technology over the coming decades. Well-known benefits of AC furnaces are their reliable and efficient operation. DC technology is normally used in certain niche areas (such as FeCr fines, TiO_2 slag production) [4, 5]. Over the recent years, SMS has developed a next generation DC-smelter which aims at holding its position as the leading supplier in this field.

FENI-APPLICATION:

Ferro-nickel is mainly produced in submerged-arc furnaces by the reduction of nickel ores/calcine. The aim is to transfer most of the nickel into the metal phase. Good carbon distribution and specific slag metallurgy are important for a high yield. First, pre-heated and pre-reduced ores are hot-charged (at temperatures of up to 900 °C) into the furnace. Then, final nickel reduction takes place in the submerged-arc furnace. Ferro-nickel furnaces are semi-open stationary-type furnaces. Usually, round furnaces are used for smaller and medium quantities, whereas large capacities are produced in rectangular furnaces [6].

Fig. 1: Sidewall cooling concepts based on stripe cooling

Related developments followed, such as various sidewall cooling methods as well as AC thyristor controls for better operation, higher and more efficient power input, and less overall maintenance. Smelters are charged with either lateritic-based calcine as applied, for example, for POSCO SNNC/Korea, Eramet/New Caledonia, Barro Alto/Brazil, or MOP/Brazil, or with limonitic-based calcine as, for example, at Feni Industries in Macedonia and Larco in Greece. The groundwork for the new generation rectangular type furnaces was done together with SLN Eramet in 2006. SMS commissioned the first 99-MVA FeNi furnace for SLN Eramet in New Caledonia (Furnace No. 10), followed later by a second 99-MVA FeNi furnace. Owing to the success of this revamp, Eramet decided to modify Furnace No. 9 in the same way. Modernization of the furnace – originally installed by SMS in 1971 –more than doubled its capacity. This remarkable increase is due to a special sidewall cooling system and a higher transformer rating.

Eramet was the first customer to benefit from implementation of the plate copper cooling principle. The side wall cooling system does not feature any water passages inside the lining, so it is considered considerably safer than other systems available on the market [6].Based on comparable furnace principles, SMS was awarded by Vale (two 120 MVA furnaces) and Anglo American (two 114 MVA furnaces) to supply rectangular furnaces with 6 in-line electrodes. A special feature of the furnaces is the application of thyristors. These improve the shielded arc operation in order to enhance the production rate. To cope with the high silica rates contained in the slag, the furnace cooling system comprises SMS copper plate cooling sidewall system in the slag zone (see Figure 1), similar to the one used at Eramet in New Caledonia.

Figure 2: Illustration of the 135 MVA FeNi smelter of POSCO SNNC

It is also possible to monitor each individual feeding pile in order to optimize the melting conditions and increase the melting capacity. In December 2012 SMS received the order from POSCO SNNC for the supply of the world's largest submerged-arc furnace. The company seeks to boost its annual capacity to approx. 54,000 tons of Ni. The power rating of the rectangular FeNi smelter is 135 MVA resulting in a total nominal power input of approx. 100 MW. To provide this significant capacity, the furnace requires dimensions of approx. 40 x 15 m (see Fig. 2 and 3). The refractory binding system allows a controlled expansion of the furnace lining. The furnace has been commissioned in November 2014.

POSCO SNNC executed the project at a highly professional level according to their targeted ambitious time schedule of 20 months and on budget which is a considerable achievement in the FeNi industry. Until now the start-up is smooth and it is POSCO SNNC's goal to reach 100% capacity by the 2nd half of 2015. According to POSCO SNNC, especially the thyristor control system supports the operation especially during the ramp-up period greatly.

Figure 3: Slag tapping at POSCO SNNC FeNi-furnace

FECR-APPLICATION:

High-carbon ferrochrome with carbon contents of 4 - 8 % is usually used in AOD converters for the production of alloy steel grades. Mainly due to environmental reasons, ferrochrome is commonly produced in closed stationary furnaces. Medium-carbon chrome alloys (0.5 - 2 %C) and low-carbon FeCr (<0.5 %C) are produced in combined process stages. Both products require special slag metallurgy to attain high chrome yields. FeCr production is carried out either in DC or AC based SAF. The increasing share of fine ores of newly explored mines might force the ferrochrome producer either to agglomerate the ore or to process it directly as fines. Basically the production of charge FeCr/HC FeCr can be carried out in various ways.

AC-based solutions:

- AC-smelter for lumpy Cr-ore
- Briquetting plant –AC-smelter for Cr-ore fines
- Sinter plant – pre-heater –AC-smelter for Cr-ore fines
- Pre-heater –AC-smelter for lumpy Cr-ore
- Rotary hearth furnace (for the pre-reduction of Cr-ore fines) – AC-smelter
- Rotary kiln – AC-smelter for Cr-ore fines

DC-based solutions

- DC-furnace for the direct charge of fines
- Kiln-based pre-heater combined with circular DC-furnace

South Africa is one of the largest ferrochrome producers in the world. Metix as part of the SMS group with currently the largest market in the southern African region share has modified numerous furnaces over the past decade [7]. One of the first major projects for SMS group consisted of supplying the overall EPCM services for HFC's F4PS2 project. The project involved a 350 000 tpa sinter plant and a 78 MVA closed FeCr furnace with preheating. Work was completed in 2005, simultaneously marking the launch of Metix equipment onto the SAF market with the supply of full electrodes (1750 mm diameter) to the biggest FeCr furnace in South Africa. SMS group also modified two existing open FeCr furnaces into closed furnaces by supplying new electrode columns, busbar systems, and closed roofs with copper roof deltas. A new gas cleaning plant and water treatment was also part of the supply and service package. The plant was recommissioned in 2010. The SMS group was the EPCM contractor for Tata Steel's FeCr plant in Richards Bay, with a 300,000 tpa briquetting plant and two 37 MVA furnaces commissioned in 2006. The sinter technology was developed in cooperation with Outotec.

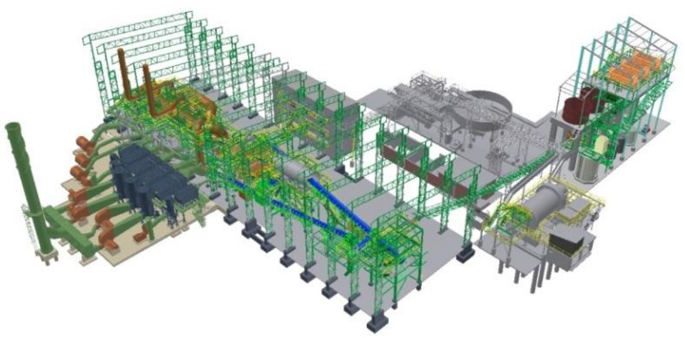

Figure 4: Sinter plant as installed for Tata Steel

A significant plant based on DC-furnaces is now being commissioned for the client JSC Kazchrome. The SMS group is responsible for the engineering and supply of a FeCr to the plant. The complex was constructed at the existing FeCr plant in Aktobe, Kazakhstan. SMS supplied four DC-based smelters with a power input of 72 MW for each furnace (Figures 5 and 6). The annual plate production of the plant (melt shop No. 4) is approx. 440,000 t of H.C. ferrochrome [4]. The benefits of DC furnaces include:

- Unique in-house know-how to minimize arc deflection (busbar routing and electrode column)
- Optimized energy consumption due to combined electrode movement regulator with thyristor ignition controller and high electrode speed
- Patented reliable long-life electrode column system that allows slipping and nipping under power (providing maximized power-on time)
- Quick-change centerpiece device essential for maximum operating time
- Intelligent feeding arrangement to maximize throughput

Figure 5: Illustration of the DC-furnace

The first metal tap was achieved in November 2014. Currently furnace No. 2 and 3 are in the commissioning period. It is planned that all the furnaces will be put into operation within 2015. To improve the operation, the DC-electrode column is applied and it shows satisfactory results. One challenge is the control of the typical high metal and slag temperature levels as a result of the process that puts significant stress on the lining and the tap holes.

Figure 6: First metal tap in November 2014 at the Kazchrome plant

For ETI KROM in Elazig, Turkey SMS revamped two existing FeCr furnaces (Figure 7). The furnaces were connected to a 30 MVA-transformer each. The smelters were commissioned in 2011 and demonstrate reliable operation. SMS group is currently installing an energy recovery system connecting the two recently installed furnaces and the two refurbished furnaces [8]. The commissioning is scheduled for the 2nd half of 2015. As a prime example of green technology, the energy recovery system utilizes the sensible energy of the off-gas and converts it into super-heated steam. This steam then drives a power generator. SMS calculates that approx. 5 MW will be recovered as electrical power.

Figurer 7: Energy recovery system under construction for Etikrom

FEMN-APPLICATION:

Ferro-manganese is usually available on the market as high-carbon (6 - 8 % C), medium-carbon (1 - 4 % C), and low-carbon (< 0.4 % C) ferro-manganese products. Alloys with high Si contents (15 - 20 %) are known as silico-manganese. High-carbon ferro-manganese and silico-manganese are produced in open or closed furnaces. Recent installations are Mogale Alloys in Krugersdorp, where the SMS group was responsible for the upgrading of two SiMn furnaces with new electrode columns, air-cooled roofs, gasoff takes, bus tubes and flexible cables. For Yunnan Metallurgical Group Co Ltd in China the SMS group supplied the core equipment for a closed 67.5 MVA SiMn furnace, the largest in China, as well as the engineering of the plant.

Figure 8: Water cooled roof during manufacturing for Rainbow Minerals

The plant has been started up in 2011. SMS was awarded by Rainbow Minerals/South Africa for the installation of a FeMn/SiMn-plant in the Sarawak area in Malaysia (the so-called „Sakura-Project"). The major goal targeted the 100% utilization of local Mn-ore and to minimize the specific power consumption through the use of modern technology. This will be achieved by installing an optimized bus bar system and to use of copper pressure rings for the lower part of the electrode. The two furnaces will have 81 MVA and will produce 550,000 tons of FeMn/SiMn annually. SMS handles the order as an EPC contractor. It is planned to commission the plants in 2015.

The plant will be equipped with a new scrubber system, comprising a double venture system combined with a wet type ESP (Figure 9). This technology ensures a stable operation of the furnace and is less cost-intensive compared to the disintegrator solution. This unit can reach dust contents < 10mg in the clean gas [8].

Figure 9: Wet gas cleaning plant for closed submerged arc furnaces

FESI/SILICON APPLICATION:

The ferrosilicon grades produced in a submerged arc furnace feature Si contents of 15 - 96 %. Grades with more than 96 % Si are known as silicon. Due to the high energy concentration and the process gas formation involved, these applications make extreme demands on the design and material. The furnaces are characterized by encapsulated electrode columns with hydraulic control, contact clamp tightening operation, and short and low inductive electrical feeders. Silicon production units generally utilize prebaked electrodes. SMS group also offers special composite type electrode systems for silicon production to reduce operating costs and to increase the overall furnace capacity (Figure 10). Silicon and FeSi: SMS group has supplied the majority of large-scale submerged arc furnaces for silicon production, which typically operate at 12-24 MW. The demand for large-scale modern silicon plant is growing and today units up to 40 MW are economically and technically feasible [9].

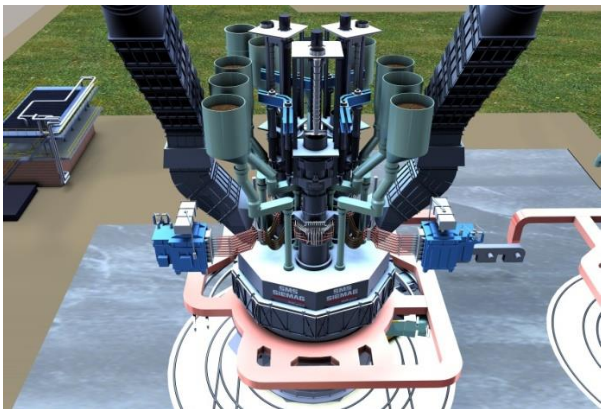

Figure 10: 3D illustration of a modern silicon smelter

The process requires an energy input of about 10-12,5 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 fume exhaust gas is injected in the hood which eliminates the necessity for a bag house for the tapping fume dedusting system in this area.

POSCO awarded SMS with the supply of two FeSi-furnaces with a power rating of 21 MW. The furnaces were commissioned in 2013/2014 (Figure 11).

Figure 11: FeSi furnace of POSCO during operation

In 2010, the SILIKAZ COMPANY commissioned the two-furnace plant installed in Kazakhstan. Besides the furnaces themselves, the entire plant engineering from raw material handling to packing of the final product was done by SMS. At the moment several projects for FeSi and silicon plants are being executed. The clients Mississippi Silicon, the USA and PCC, Germany will build a two-furnace-based silicon plant. The technical data for both plants and the related furnaces are similar. Each furnaces has a power rating of about 24 MW and the plants will produce > 30,000 annual tons of silicon.

TIO$_2$-SMELTING:

Titanium slag furnaces produce TiO_2-rich slag and pig iron as a valuable “by-product”. The ilmentite ore can be processed either in DC or AC furnaces. It is not necessary to pre-treat the ore before directly smelting ore fines in DC furnaces. Usually the specific electrical power consumption is higher due to the lower thermal efficiency of the furnace. In South Africa, most smelters are DC-based. Other companies produce TiO_2 slag in AC-based smelting units, using either circular or rectangular furnaces. 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 ilmentite ore is smelted in a submerged arc furnace to TiO_2-rich slag and hot metal. The SMS group supplied 2 submerged arc furnaces for Kumba Resources in Empangeni, South Africa and to Xiling, China.

CALCIUM CARBIDE:

Calcium carbide (CaC_2) is used as the starting material in the production of acetylene and calcium cyanamid. Initially, acetylene was produced for lightning purposes. In organic and plastics chemistry, calcium carbide is in strong competition with the various processes for the production of acetylene from hydrocarbons and it is used as a desulfurization agent in the steel industry.

Figure 12: Calcium carbide – example: Guodian Younglight and Junzheng Energy

In 2010 and 2011, SMS group was contracted by 2 major CaC_2 producers in China for the engineering and supply of the China's largest CaC_2 furnaces. Featuring a power rating of 81 MVA, they achieve an annual production of >120,000 t each. The 6 furnaces ordered by Guodian Ningxia Younglight are located in Ningxia province while the 4 furnaces of Junzheng Energy operate in the province of Inner Mongolia. All furnaces are equipped with a hollow electrode system (HES) which are unique in China. This system enables operators to charge also fine material (see Figure 12).

FUSED MAGNESIA SMELTING FURNACES:

The electric smelter is also used for the production of minerals. One example is the production of fused magnesia or fused alumina, being further processed in the refractory industry. The Magnezit Group, which is based in Satka, Russia, awarded SMS a contract for the engineering and supply of 10 smelting furnaces for the production of fused magnesia. The plant in Satka will receive 5 furnaces and 5 more are intended for the plant in Rasdolinsk. Each furnace has a transformer capacity of 8.8 MVA and produces approx. 10.000 t/y of fused MgO. SMS is supplying the engineering and the complete furnaces as well as the electrics and automation (see Figure 13).

Figure 13: Magnesiafurnaces for Magnezit

METAL REFINING

Refining options for ferroalloys: The SMS group also supplies technology for ferroalloy refining, mainly FeNi. References for FeNi refining are Pacific Metals, Falconbridge Dominicana, Cerro Matoso, and Koniambo. These are all ladle furnace solutions with auxiliary equipment (slag rake, oxygen blowing). Refining technology for FeCr and FeMn SMS has a long history of converter technology. Reference lists specify more than 200 converters supplied over the last 60 years. SMS constantly improves the process and the technology. Today, state-of-the-art design by SMS covers converters with fluid flow models optimized by CFD (computational fluid dynamics), as well as detailed parameter. The product portfolio includes chemical heating stations, slag rakes, ladle furnaces and ladle cars with electromagnetic stirring. Another option is refining the FeNi in a conventional converter like the one SMS supplied to Larco in Greece. Our range of converters includes conventional BOF converters for FeNi, AOD converters for the production of MC FeMn and MCFeCr and AOD vacuum converters /10/. Most recently, SMS developed and proved in industrial-scale application of CO_2-blowing technology in an AOD vacuum converter for MC FeCr< 1.0 % C (see Figure 14). This technology significantly cuts operation costs and the need for expensive cooling materials. The Cr yield achieved is above 95.5 %.

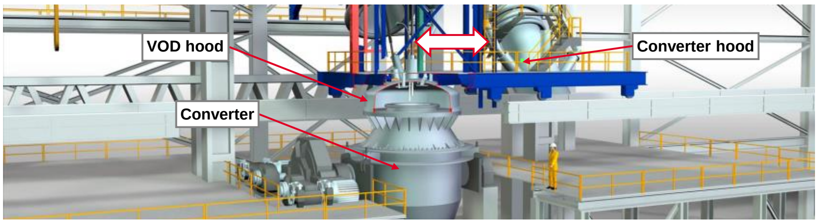

Figure 14: Vacuum AOD for the production of MC FeMn and FeCr

APPLICATION OF ENERGY RECOVERY SYSTEMS

Semi-open type furnaces: In Semi-open type electric smelters, the combustible components which are generated during the process are fully burned in the freeboard area. The furnaces are either equipped with doors or openings in the roof that allows the control of the off-gas temperature. Depending on the process the off-gas temperatures are between 550 to 750°C [11]. Internal calculation shows that more than 20% of the input electric power can be recovered. Due to environmental and ecological reasons, a larger portion of electric smelters are closed-type furnaces, which produce certain quantities of CO-rich gas that can be utilized in various up-and downstream processes. SMS developed a “dirty-boiler-system”, which can take the hot dirty combustible gas and transform the chemical and sensible heat into steam.

The process gas can also be used after treatment (e.g. Disintegrator Scrubber) in a Process Gas Boiler (see picture 15) to generate superheated steam. A part of the sensible heat can be used to heat up e.g. feed water. But the superheated steam enables the generation of electrical energy or process steam for different applications.

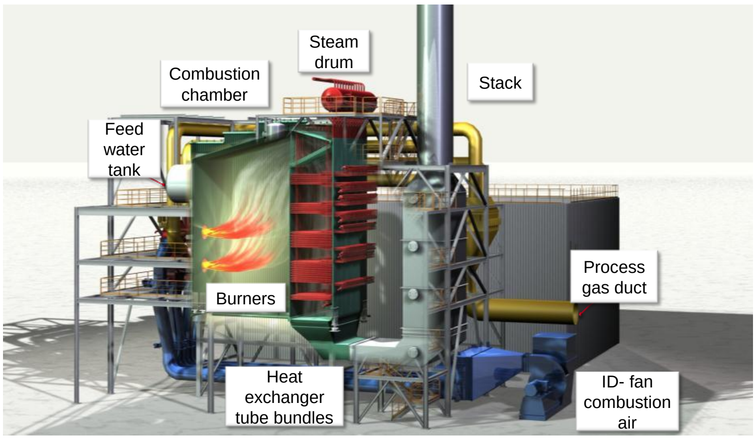

Figure 15: “Process Gas Boiler” for recovery of energy of process gas

AUXILARY EQUIPMENT

The SMS group covers the full range of necessary auxiliary equipment required for the smelters such as water treatment and cooling units, primary and secondary gas cleaning systems, metal and slag treatment pig casting and slag granulation, raw material/product handling units as well as other auxiliaries such as stoking machines and tap hole mud gun as well as drilling machines [13].

From the technical point of view, it is most challenging, recovering the sensible heat out of liquid slag. Especially for a process, generating large amounts of slag (such as for FeNi-smelter plants), such a system could decrease the overall energy consumption significantly. Paul Wurth as part of SMS developed a system, which was firstly tested in 2013 at one of the leading steel producers in Germany. The dry slag granulation system injects steel ball into the liquid slag and the conductivity of the “slag cake” is improved; it is possible that the sensible heat is transferred to a heat exchanger. The cooled down solidified slag is later crushed, the steel balls are screened out and send back into the energy recovery unit. When the results are positive and the plant demonstrates its feasibility, such system will be a very attractive solution for the ferroalloy and non-ferrous industry.

Figure 16: Slag energy recovery system

INNOVATION FOR THE FURNACES OF TOMORROW

A key factor in the global leadership of SMS in electric smelters is the creative spirit of our engineers [13]. Their inspired thinking enables them to develop new application areas for smelters and optimize existing designs. SMS team cooperates with its customers as well as reputed institutes and universities to develop groundbreaking innovations. Constant interaction with third parties gives us new impulses and new insights. Major current activities are focused on the comparison of DC and AC application. SMS carried out theoretical evaluations and practical tests on lab scale. Furthermore SMS also improves 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.

CONCLUSION

The first SAF has been 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. With Metix and Paul Wurth the SMS group can offer a wide and complex product portfolio for AC- and DC-based smelter technology. This also includes intelligent solutions regarding energy recovery systems and coal based pre-reduction units. It is the SMS goal to offer plant and equipment concepts which are the best solutions for our clients from the economic and ecological point.

REFERENCES

[1] Degel, R.; Kunze, J.: History, current status of submerged arc furnace technology for ferroalloy metals, Steel Grips 1 (2003), No. 3

[2] 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

[3] Fröhling, C.; Babel, M.; Degel, R.: Energy recovery systems for electric smelters, Infacon XIII, 9 – 12 June 2013, Almaty

[4] Degel, R.; Schmale, K.; Kleinschmidt, G.; Oterdoom. H.: AC- and DC- Smelter technology for ferrous metal production; INFACON XII, Helsinki, 6th-10th June 2010

[5] Schmieden, H.; Schmale, K.; Degel, R. Köneke, M.: Application potential of SMS DC smelter technology for the pyrometallurgical industry in Southern Africa, Pyro 2011, April 2011, Johannesburg, South Africa

[6] Degel, R.*; Kempken, J.; Kunze, J.; König, R.: Design of modern large capacity FeNi-smelting plants, INFACON IX, 18. - 21. Feb. 2007 in Delhi, India

[7] van Niekerk, A.: Latest trends of Metix solutions for the ferro alloy industry; SMS Symposium in Johannesburg, November 2012

[8] Fröhling, C. Degel, R.: Ecological and economical solutions for electric smelters; SMS Workshop in Dubai, 2013, Proceedings

[9] Degel. R.; Kalisch, K.; Hecker, E.; Oterdom, H.; Brosnan, J.: Innovative electric smelter solution for the silicon industry, “Silicon for Chemical Solar Industry” in Trondheim/Norway on 24.- 27. June 2014

[10] Thiedemann, U.; Bader. J.: Innovations in Process Technologies, Infacon XIII, 9 – 12 June 2013, Almaty

[11] Degel, R.; Germershausen, T.; Nörthemann, R.; Köneke, M.; van Niekerk; A.: Innovative electric smelter solutions of the SMS group for the ferro alloy and Si-metals industry; Infacon XIII in June 2013 in Almaty, Kazakhstan

[12] Degel, R.; Oterdoom, H.; Fröhling, C.: High efficient electric smelters for ferro-alloy and non-ferrous metal production – SMS group solutions for CO_2-reduction, EMC 2011 conference in Düsseldorf, July 2011

[13] Degel, R.; Köneke, M.: Superior full-line process competence in ferrous and non-ferrous metals production, Metec 2011 SMS group symposium, July 2011, Düsseldorf, Germany