DESIGN OF A MODERN LARGE CAPACITY FeNi SMELTING PLANT

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ABSTRACT

The FeNi technology is currently dominated by high-power submerged arc furnaces, often designed as smelter as "two-in-line-solution". To achieve the intended high efficiency, state-of-the-art design in good correlation with ores and reductants and an integrated layout of the whole plant is of great importance. An introduction will be given to general aspects in the production FeNi, plus a detailed overview of design principles for large FeNi smelters and finally some examples of innovations and research projects concerning Fe-Ni.

1. HISTORY, APPLICATIONS AND TRENDS

100 years of submerged arc furnace technology (SAF), a remarkable achievement by SMS DEMAG. We are proud of looking back at our involvement in this technology in which SMS DEMAG played a significant role in the development of this smelter.

Table 1: Major users applying SAF's

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,……**

During the last century, the submerged arc furnace has been one of metallurgy's most amazing diversified melting units which has found many applications in over 20 different industrial areas, including 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 more than 100 years and has supplied a diverse market with about 700 furnaces and major furnace components[2]. Numerous applications were constantly developed serving various users[3,4]. Such an evolution was only possible because of tremendous efforts in research and development and due to the large range of design solutions.

2. EXPERIENCES IN FENI-SMELTERS AND RECTANGULAR FURNACES

To this date, SMS DEMAG has supplied most of the large-scale Ferro nickel furnaces world-wide. These furnaces are in Venezuela, New Caledonia, Greece and Macedonia [6,7]. During the last 4 decades, we supplied around 40 furnaces. The reference record for large-scale rectangular furnaces demonstrates our superior market position in this field (figure 1).

1971	New Caledonia	Le Niquel	FeNi	3	48 MVA	32.5 m x 13.5 m
1977	Macedonia	FeNi Kavadarci	FeNi	2	84 MVA	34.9 m x 14.3 m
1984	Belgium	MHO	Pb/Zn slag	2	7 MVA	15.8 m x 5.8 m
1990	USA	Asarco	Cu slag	1	8 MVA	14.0 m x 5.4 m
1984	Italy	SAMIM	Pb slag	1	9 MVA	10.8 m x 6.0 m
1994	Canada	COMINCO	Pb slag	1	9 MVA	10.8 m x 6.0 m
2004	Zambia	MUFULIRA	Cu -slag	1	12 MVA	10.8 m x 6.0 m
2004	New Caledonia	ERAMET	FeNi	1	99 MVA	33.0 m x 15.0 m
2006	New Caledonia	ERAMET	FeNi Study for placing next SAF by end of 2006			
2006	Brazil	MOP	FeNi	2	120 MVA	36.5 m x 13.3 m

Figure 1: Locations of rectangular smelting furnaces

It should be mentioned that the furnace in New Caledonia represents the best available technique for producing FeNi. The customer has already announced his intention to purchase a second furnace with an identical power rating of 99 MVA.

We are currently supplying the world's largest furnaces to Onca Puma in Brazil, an affiliate of CVRD. The two 120-MVA furnaces are designed for an annual nickel production of approx. 60,000 tons. The new greenfield plant not only includes today's best available technology, but also considers intelligent proven design solutions from the logistic point of view to ensure smooth operation. The plant will be commissioned in 2008.

3. GENERAL TRENDS IN THE FENI-PRODUCTION; INDUSTRY DEMAND

The majority of ferroalloys are produced by pyrometallurgical smelting in submerged arc furnaces. The hydrometallurgical production of nickel 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 ferroalloys has been mainly achieved by the installation of advanced high-power smelting units. During the last decade numerous improvements had been developed providing efficient and safe operation with large scale FeNi-furnaces.

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 results in less mechanical stress of the furnace equipment.

Sidewall cooling and a thyristor control system are currently successfully in operation at a newly installed smelter for Eramet in New Caledonia. It represents the world best available large-scale FeNi-smelter. More details will be mentioned later.

Another trend is to design the smelters to a maximum possible capacity. Reasons for this trend are mainly [9,10]:

- Higher energy efficiency
- Safer and cleaner working conditions
- Fewer spare parts and less wear of critical parts
- Less maintenance results in higher plant availability (up to >98 %)
- Less manpower
- Overall much lower production and investment costs
- Complying high environmental standards
- More effective de-dusting solutions at lower specific investment

Regarding the high energy efficiency, these may be round or rectangular-shaped furnaces, depending on the requested capacity [9].

SMS DEMAG 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.

When speaking about rectangular furnaces, it should be mentioned that depending on the kind of process, e.g. for copper-slag-cleaning, smaller rectangular SAF's are the best solutions also for furnaces of, e.g., 10 MW. SMS DEMAG has introduced a new generation of three-electrode type rectangular furnaces in the market.

4. DESIGN PRINCIPLES OF LARGE SCALE FENI-SMELTERS

The smelter unit in the FeNi plant comprises

- the calcine transport system,
- the slag and metal tapping facilities,
- the off gas system,
- the refining plant and
- the metal granulation plant.

The capacity of each facility is calculated according to the mass and energy balance for the annual amount of dry ore or, respectively, calcined ore to be processed.

The design of the furnace vessel is also driven by the logistics and auxiliaries of the plant. An intelligent solution for the overall plant layout is the key to a smooth start-up and stable and flexible operation. It is very important that especially conveying systems and the charging system include a certain reserve capacity.

Based on the assumption of 95% availability each of the calcination plant and the smelter unit, the resulting overall plant availability is approx. 90 %, i.e. approx. 7,900 hours per year [11,12].

For large scale FeNi plants based on 2 rectangular smelters SMS DEMAG recommends a "two-in-line-solution", as shown in figure 2.

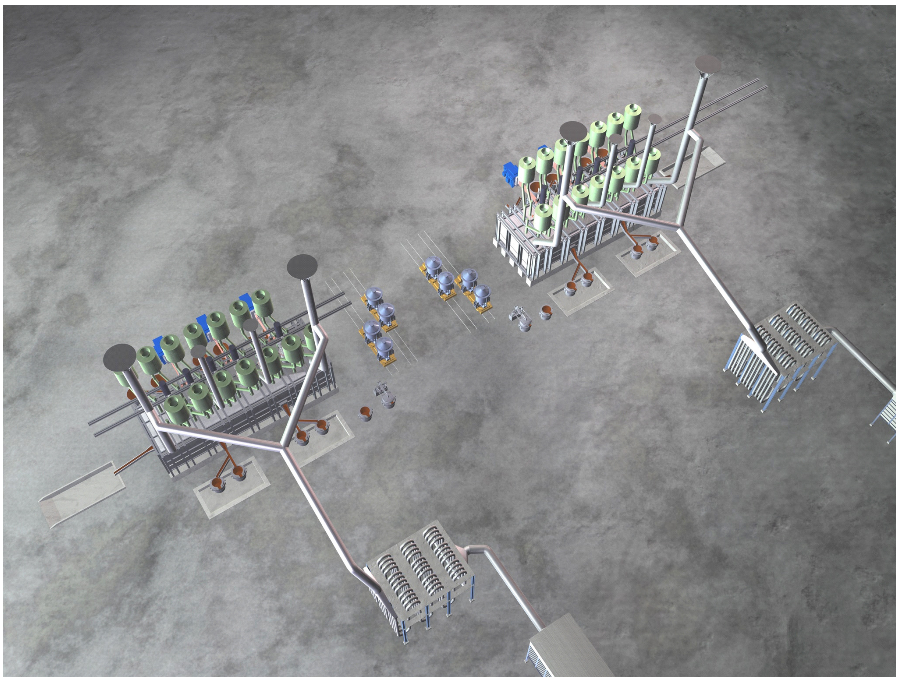


Figure 2: Two-in-line rectangular furnace solution

5. CALCINE TRANSPORT SYSTEM

The hot calcine will be transferred from the rotary kilns to the furnace charging bins by means of refractory lined transfer containers. The containers are moved via transfer cars between the discharge bins of the rotary kilns and the take over points underneath one of the four hoists. These hoists lift the containers and position them above the furnace bin with a demand for calcine for discharge. Each two hoists are serving one bin line of both electric furnaces.

The availability of two container transfer cars and two hoists for each bin line ensures interchange ability of these components and therefore allows uninterrupted furnace operation even if one of the transfer cars or hoists fails.

The solution provides the highest flexibility and allows a clear definition of the paths for incoming raw materials and outgoing products.

This system has proved its effectiveness on a large scale in several of our reference plants and yields the best flexibility (figure 3).

6. SUBMERGED ARC FURNACE (SAF)

6.1 Principle of submerged arc furnaces

The principle of a submerged arc furnace is 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.

6.2 Design principle of a large-scale rectangular FeNi-smelter

The general arrangement of a 2-in-line rectangular SAF configuration is shown in figure 4. A typical furnace with slag operation comprises a rectangular furnace shell with 4 – 6 tap holes for slag and 2 for metal. The

Figure 3: Feeding system of a two-in-line FeNi smelter solution

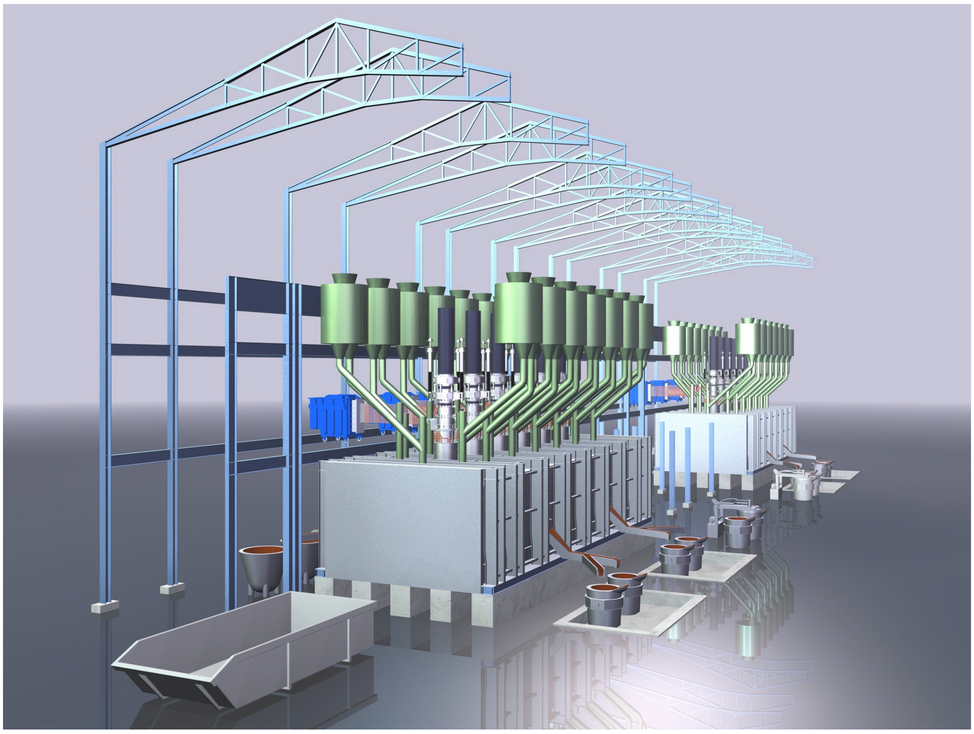


Figure 4: SMS DEMAG's six-in-line furnace

furnace shell is refractory lined and – if additional shell cooling is required by the process – water-cooled by a special sidewall copper cooling system. The shell bottom is cooled by forced air ventilation.

The brick type furnace roof comprises all required glands, openings and sealings for the electrode columns, charging pipes and off-gas ducts. Depending on the quality of the calcine, each furnace can have up to 40 charging tubes, to ensure best available smelting conditions and sidewall protection [12,13].

The electric energy is transferred into the furnace via 6 in-line self-baking electrodes arranged at the centreline of the furnace. The electrode arrangements depend on the process and the installed power.

The electrode is consumed by oxidation in the slag bath and the furnace freeboard. The self-baking electrodes with casings are periodically extended by new pieces. The electrode is semi-automatically slipped into the bath with the furnace at full electric load and with no interruptions in furnace operation. The electrode column assemblies contain all facilities to hold, slip, and regulate the penetration into the bath. All operations on the electrodes are performed hydraulically.

The electric power is normally supplied from the furnace transformers via high current lines, water-cooled flexibles, bus tubes at the electrodes and the contact clamps into the electrodes. Today, control and supervision are effected by a PLC and visualisation system. A back-up for manual operation is provided and is located in the control room.

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

The process gas created from the chemical reactions is fully combusted inside the furnaces. Together with a balanced addition of cooling air it is ducted to the filter system.

If the process generates off-gas which contains a certain amount of CO in the process gas or other hazardous substances, the furnace is designed as a closed furnace type.

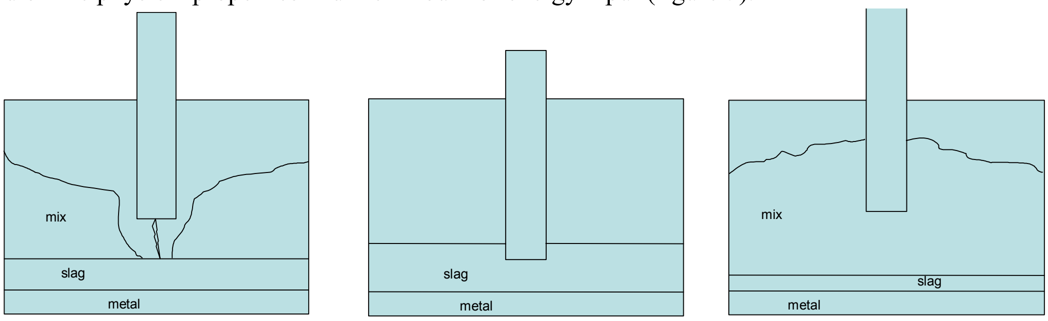
6.3 Process and furnace dimensioning

Successful operation is always based on the right choice of furnace design and furnace dimensions. In this respect SMS DEMAG's metallurgical excellence and process know-how is recognized all over the world. Prior to each project, our expert team generally follows the design steps shown below:

1. Choice of raw materials and desired production rate per hour in intensive dialogue with customer
2. Metallurgical calculation
3. Choice of the applied technology and kind of energy input
4. Assumption of thermal losses
5. Dimensioning of mechanical data
6. Recalculation of thermal losses
7. Calculation of electrical losses
8. Dimensioning of electrical equipment
9. Definition of nominal load
10. Definition of guarantees

Of course, the described steps will change if the customer mentions special preconditions or constraints, for example the consideration of special electrode diameters. In these cases the conditions will be checked, discussed and, if necessary, alternatives are suggested.

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 (figure 5).



Shielded arc mode
e.g. FeNi, wastes

Resistance mode
e.g. slag cleaning

Feeding mix resistance mode
e.g. FeCr, FeSi

Figure 5: Types of energy input according to the process

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.

Furnaces processing ores which yield a slag with a melting range below the liquidus temperature of the metal can never be operated in the shielded arc mode or with the electrodes penetrating the calcined material.

Modern large FeNi furnaces are mostly operated in shielded arc mode provided that the slag composition allows the use of this mode. This case is described in more detail below. The following figures shows the inside of a smelter operating in the shielded arc mode (figure 6) and a resistance mode (figure 7).

Figure 6: Shielded arc mode

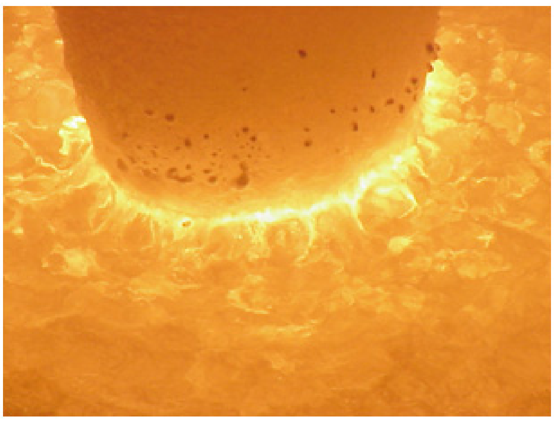


Figure 7: Resistance mode

The composition of the slag produced influences the liquidus lines, the necessary operating slag temperatures, the cooling concept and the electrical conductivity of the slag. This last feature is also important for the calculation of furnace resistance and electrical equipment and for determining the operating point. Figure 8 shows the possible wide range of different slag characteristics. In respect of the locations of the furnaces marked in the diagram one can recognize local dependences and can therefore draw conclusions as to the ore qualities.

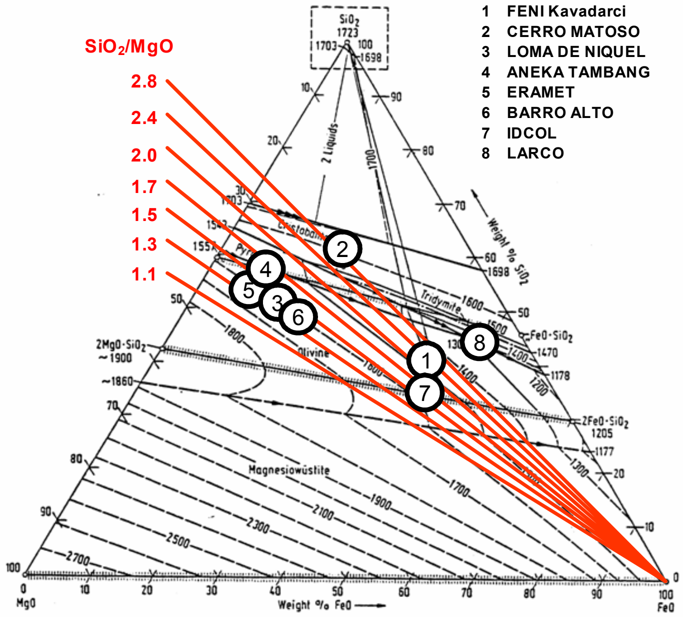


Figure 8: Slag composition of various plants

It can be stated that dimensioning of the furnace is one of the most critical items during the design stage and needs to be done with care. Additional factors, for instance in the case of FeNi, such as specific calcine input, type of charging, ratio arc/power, specific hearth load, reduction rate, energy supply and type of cooling system needs to be incorporated in furnace dimensioning (see figure 9).

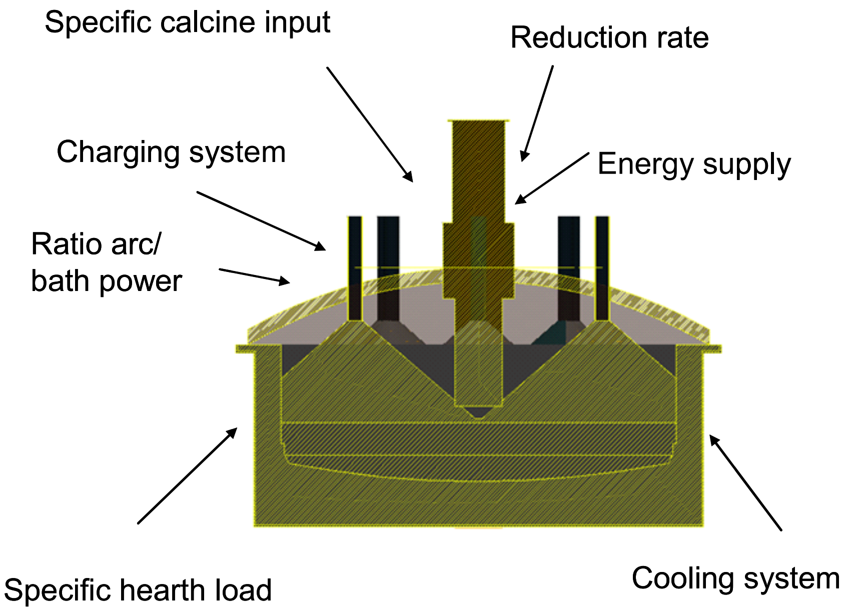


Figure 9: Aspects for dimensioning a FeNi – SAF

6.4 3-D fluid dynamic modelling

With the application of SMS DEMAG's modelling tools, the understanding of up-scaled new processes is becoming more transparent. One example is the 3-D-modeling of large-scale submerged arc furnaces which is shown in figure 10. This model was first successfully applied for two large-scale submerged arc furnaces in Chile. The modelling provides important data for proper furnace sizing and correct dimensioning for the cooling system. Furthermore, it gives a realistic indication of operational conditions.

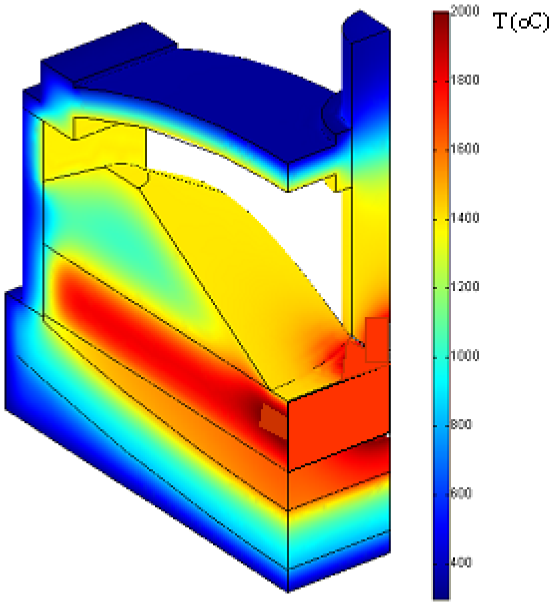


Figure 10: Example of temperature distribution in a rectangular furnace

Major factors which are considered in the model:

- Joule's heat generation in ohmic resistors: slag, metal, arc and electrodes;
- heat consumption in the bank and bank/slag interfaces due to endothermic reactions of reduction and melting;
- heat transfer by conduction and convection in the slag and metal/matte;
- heat transfer by conduction in refractory, shell and electrodes;
- heat transfer by convection through furnace shell/water, shell/air interfaces;
- heat transfer by convection and radiation at slag/gas, bank/gas, electrodes/gas and refractory/gas interfaces;
- slag and metal/matte motion induced by buoyancy forces (natural convection).

We assume that the model developed by us is the best available model for the simulation of large-scale smelting plants in the industry.

The advanced modelling tool of SMS DEMAG therefore contributes:

- to obtaining a better understanding of new process approaches
- to having more orientation points for furnace design
- to matching long-term experiences with new advanced modelling tools
- to supporting customers and suppliers in their decisions for new process procedures
- to having a better understanding for sidewall cooling concepts
- to considerably reducing up-scaling risks

6.5 Control and operation

The new generation of thyristor controlled smelters allows a better furnace and maintenance friendly operation. Overall the advantage of the thyristors is:

- Enhanced control function for fast regulation of electrode current and voltage
- Higher energy input to the furnace due to more stable arc power and the possibility of extended operating window (higher furnace impedances become possible)
- Smoother furnace operation with enhanced smelting and reduction performance due to reduced electrode movements.
- Less unbalance to power grid, caused by process disturbances
- Less stressing or demand placed on furnace transformers, OLTC, electrode columns and hydraulic system resulting in reduced maintenance activities
- Balancing fluctuations of calcine quality and property

The basic control philosophy is illustrated in figure 11:

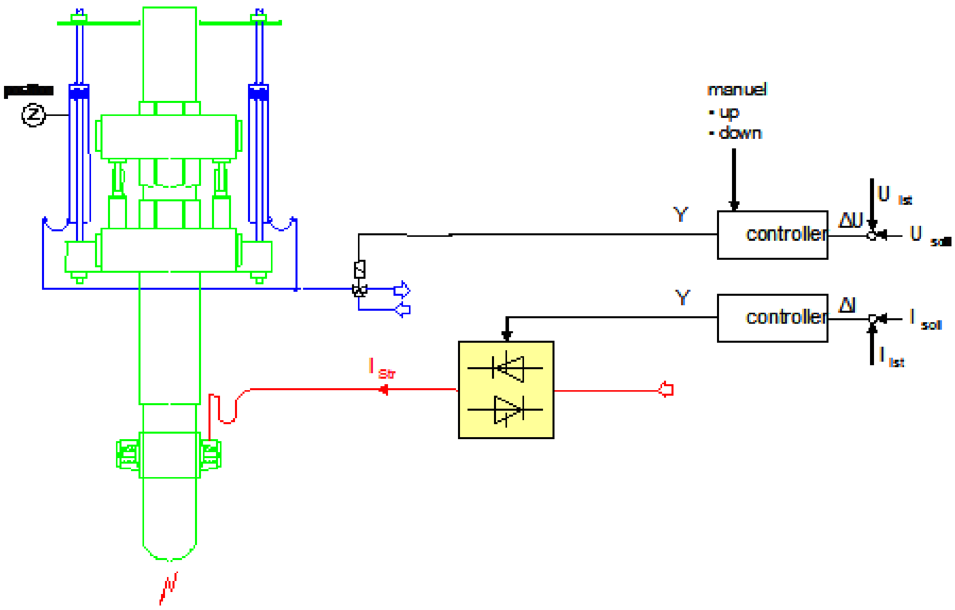


Figure 11: SMS DEMAG AG control system for large-scale FeNi furnace

6.6 Furnace integrity and cooling

SMS DEMAG's SAF design is well-known for its solid furnace integrity. Especially the incorporation of a reliable and safe operating sidewall cooling system requires intelligent solutions (figure 12). A major progress in advanced sidewall cooling had been achieved in 2001 with the development and installation of a side wall cooling system for Eramet in New Caledonia. In comparison to other available copper cooling systems, it is far superior regarding safety, furnace integrity and investment.

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, SMS DEMAG has built a full-size test facility located in their workshop in Germany.

The main features of the cooling concept are:

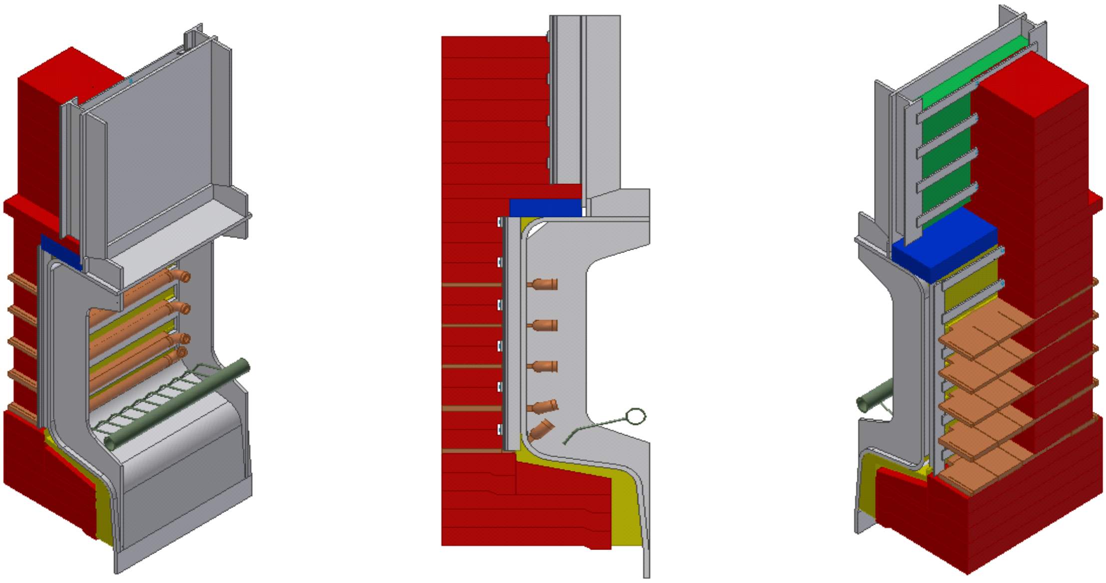


Figure 12: SMS DEMAG AG patented side wall cooling system

- Safe system with water passages outside the shell => no explosion risks
- 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 tidal-zone level possible
- Spacing of the copper stripes and their thickness can be varied over a wide range and thus be adapted to all reasonable heat loads to be expected; this way the cost-optimized solution for each application can be selected
- Cooling elements are easy and cheap to fabricate
- Thickness of plates allows thermal expansion of the lining
- Bricks are ensured to remain in full contact with the copper elements
- In case of cooling water interruption => no break-out risks

The skew bricks are locked in the corner of the furnace bottom, which minimized the vertical movement of the refractory in the side wall. The result is that expensive highly maintenance intensive down holding systems are not required.

Depending on the spacing and sizing of the copper stripes, a heat removal rate of up to 250 kW/m² is possible. This has been demonstrated successfully in a test stand at the University of Aachen. You will find additional aspects in the chapter below. However in practice it has been demonstrated that this copper cooling system is not a water heating system but just a safe furnace cooling with thermal losses limited to 10-15 kW/m² under stabilized operating conditions.

As mentioned before, this cooling system has been installed in a 6-electrode rectangular SAF with a transformer rating of 99 MVA and an operating load of 75 MW in New Caledonia.

The furnace has been placed on the original foundations in an existing building. With the modified furnace, the target to double the power input/capacity while keeping the original dimensions has been exceeded. Figure 13 shows the sidewall cooling system of this furnace.

Figure 13: Sidewall cooling system for a FeNi rectangular furnace

6.7 Further application of side wall copper cooling for rectangular furnaces

Besides the application of advanced furnace modelling we are making tests on a 1:1 model (located in Hilchenbach/Germany) as well as in a test furnace located at the IME (Technical University for Non-Ferrous Metals) in Aachen/Germany. A test was carried out to prove the performance of a copper cooling system for a fayalitic slag being completely liquid at 1,300 °C and operated at 1,650 °C. After the test, the furnace was cut in half to get information of the refractory wear. The results confirmed our expectations and our modelling work.

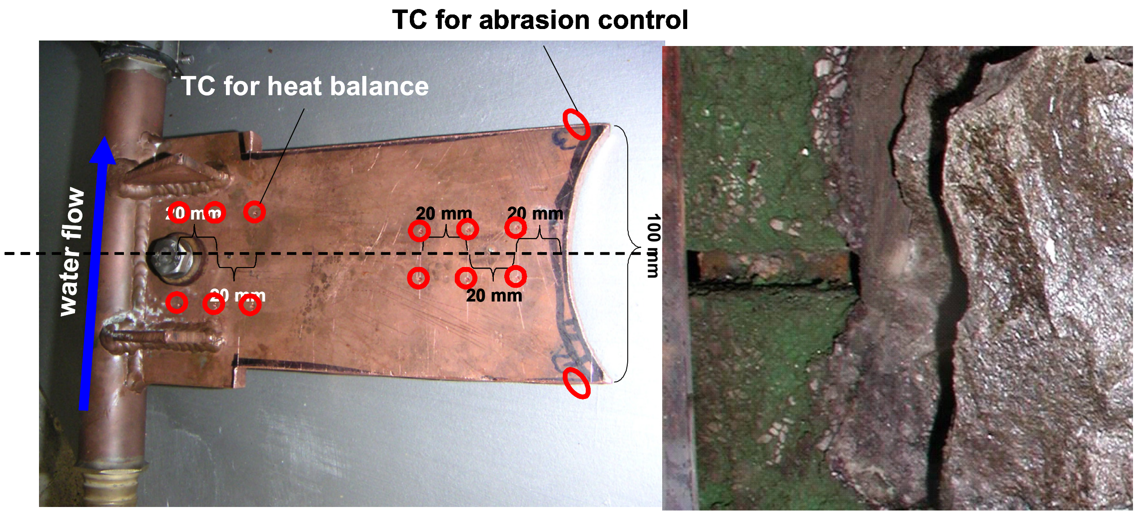


Figure 14: Test furnace for measuring the heat removal rate with copper stripe cooler

Figure 14 shows the test set-up of a furnace with a measurement of the possible heat removal rate through the copper stripe cooling and the crucible of the test furnace with no wear in the vicinity of the copper cooling plate.

The highest heat flux measured during this test was 280 kW/m², which means that even on the condition that a highly superheated and chemically aggressive slag is in contact with the refractory lining, the build-up of a freeze lining line as a protection for the furnace wall can be expected (figure 15).

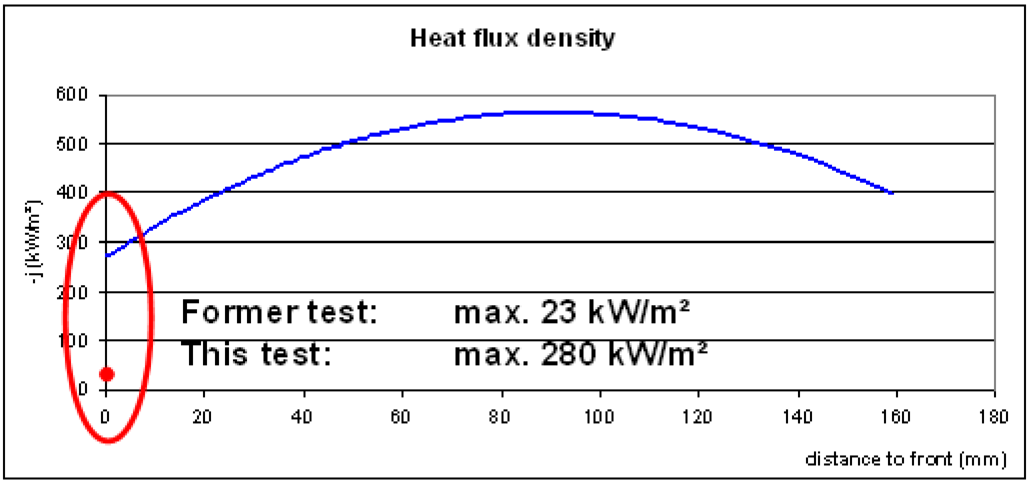


Figure 15: Heat flux during laboratory test

7. ADDITIONAL TECHNOLOGICAL HIGHLIGHTS

7.1 SMS DEMAG Tapping Machines

The tapping machines are of great importance. SMS DEMAG supplies reliable combined tapping machines (drilling and tapping). We provide a 30-liter and a 50-liter machine (see figure 16). The machines will also be installed in the new rectangular furnaces for Onca Puma in Brazil.

Figure 16: New SMS DEMAG tapping machine

7.2 Off-gas system

The process gas produced in the electric furnaces is completely combusted inside the furnace and at the same time by the addition of diluting air cooled down to approx. 1,000 °C.

This concept avoids any formation of an explosive mixture of carbon monoxide and air inside the furnace and the build-up of accretions in the off-gas duct due to post combustion. To minimize the capacity of the de dusting plant, the off gas is routed through a water-cooled duct. After leaving this part of the duct, further cooling of the off gas is effected by hair-pin coolers. Before entering the filter bag house, the off gas temperature is decreased to the allowable entrance temperature by quenching with the secondary fumes collected via hoods above the metal and slag tap holes. (see figure 17).

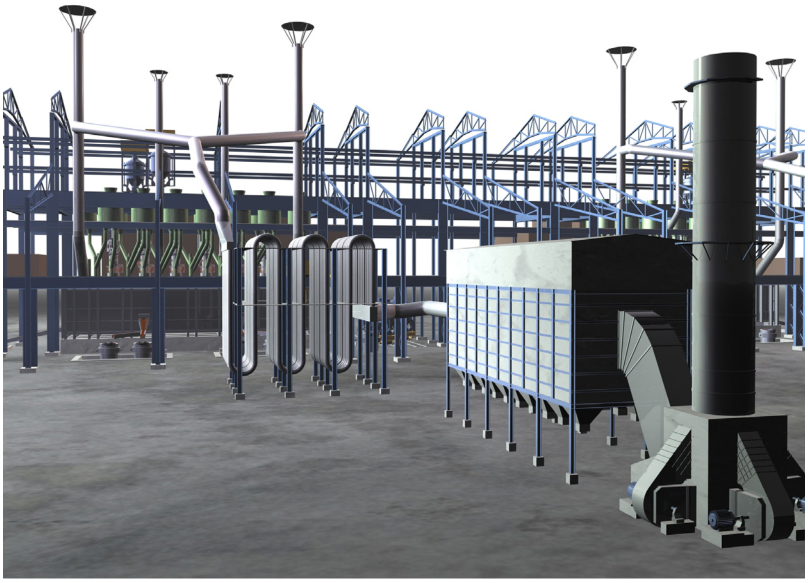


Figure 17: View from the off-gas treatment plant

8. PLANT START UP

Plants all over the world demonstrate that a quick and progressive commissioning and ramp-up of the smelting plant is essential for the profitability of a FeNi-plant. While the necessary conditions for a smooth hot commissioning are included in the layout of the furnace, the proper preparation of the furnaces for the hot commissioning is very important.

In some instances a wrongly timed heat-up curve could result in a quick failure of the refractory material or could (in the worst case) even damage the furnace shell. It is also essential that the transformer allows a start-up in resistance mode, even if at a later stage a shielded arc operation is foreseen.

9. REFINING OF FeNi

The refining step of the FeNi is strictly related to the quality of the raw FeNi tapped from the smelter and the desired quality of the customer. The simplest form of FeNi refining, as for example applied in a project is done by temperature control and desulphurization. More complex applications require a more complex treatment as e.g. shown in figure 18.

The necessary steps for the sequence shown above are carried out in a ladle furnace, a chemical heating station and a de slagging station (figure 19). To ensure maximum flexibility in operation, the ladles and lade cars are equipped with inductive stirring systems.

10. CONCLUSIONS AND OUTLOOK

The first SAF was commissioned 100 years ago in Germany. Since then a tremendous development of this smelting tool was observed all over the world and submerged arc furnaces are now operating in at least 20 different main industrial fields. SMS DEMAG as a leader in large-scale electrical smelters proudly looks back at the significant role of the company in the history of this unique and highly efficient unit. Especially in the field of rectangular furnace technology, SMS DEMAG could enhance its market position. The last orders for rectangular furnaces demonstrate our clients' trust in our intelligent solutions (such as side wall cooling system, furnace integrity). Our recent innovations also focus on the additional recovery of precious metals out of liquid slag.

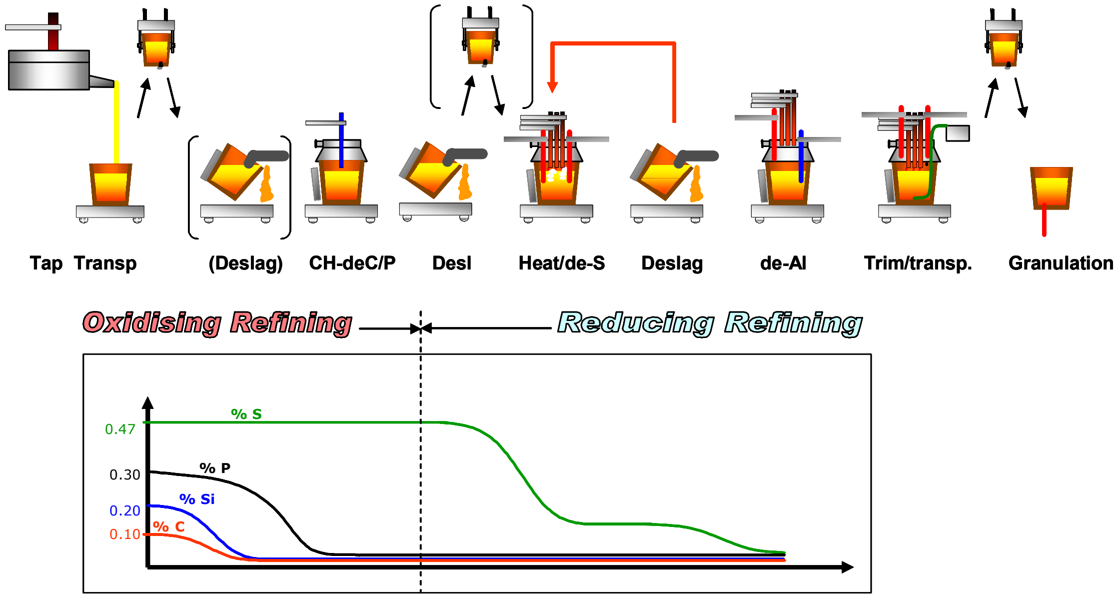


Figure 18: Complex refining – Si, C, P and S

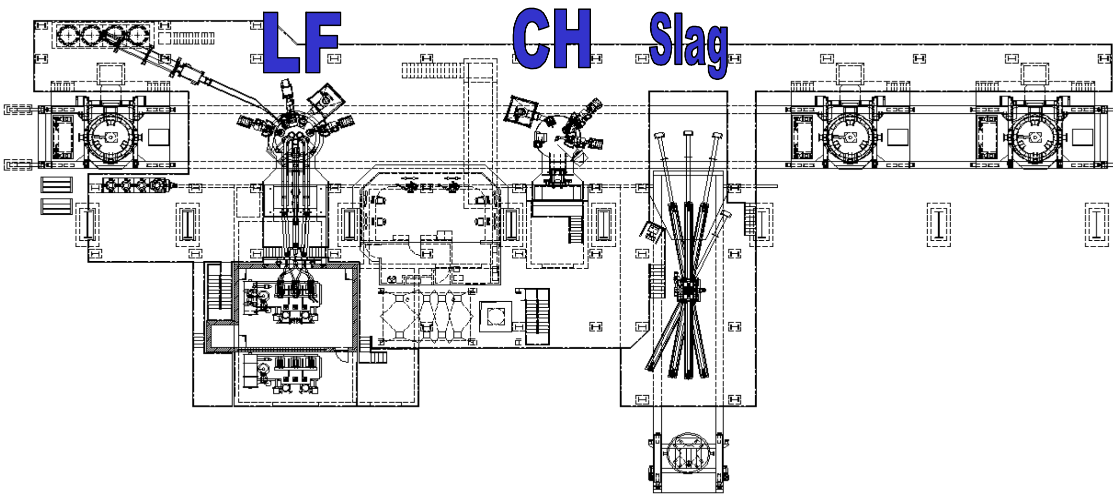


Figure 19: Arrangement example of a complex refining station for Si, C, P and S

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