THE TRANSFORMATION OF FERROCHROMIUM SMELTING TECHNOLOGIES DURING THE LAST DECADES

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ABSTRACT

In the latter part of the 1980's Outokumpu Chrome in Tornio, Finland, was in a situation when its twenty-year-old ferrochrome plant was becoming inefficient to sustain economically sound production. The company made extensive studies on the then available processing methods to find out the best possible processing route. As a result the whole plant was practically rebuilt and expanded. When equipment was proven in practical operation an application for FeMn production was developed.

Now when Tornio FeCr-plant is considering the expansion the same type of exercise is to be performed with today's challenges, which will be discussed in the paper. These challenges include increasing costs or decreasing quality of raw materials, increasing energy costs, stricter environmental regulations and demand of better working conditions. The possibilities to respond to these challenges will be discussed in the paper.

The future and continuing development with FeCr includes the better utilization of process dusts and a lower consumption of energy. By adapting the latest automation tools to better control of the process even higher efficiencies can be achieved with present technology. New processes are considered for development in the future and some possible technologies will be described.

1. INTRODUCTION

The challenges of today's ferroalloys technology are minimizing of operation and investment costs, minimizing of different types of wastes and improving the working environment - All this with decreasing trend of world market prices. As with all bulk metal prices the long-term trend of ferroalloys prices is decreasing. This is visible also with charge chrome prices (Figure 1).

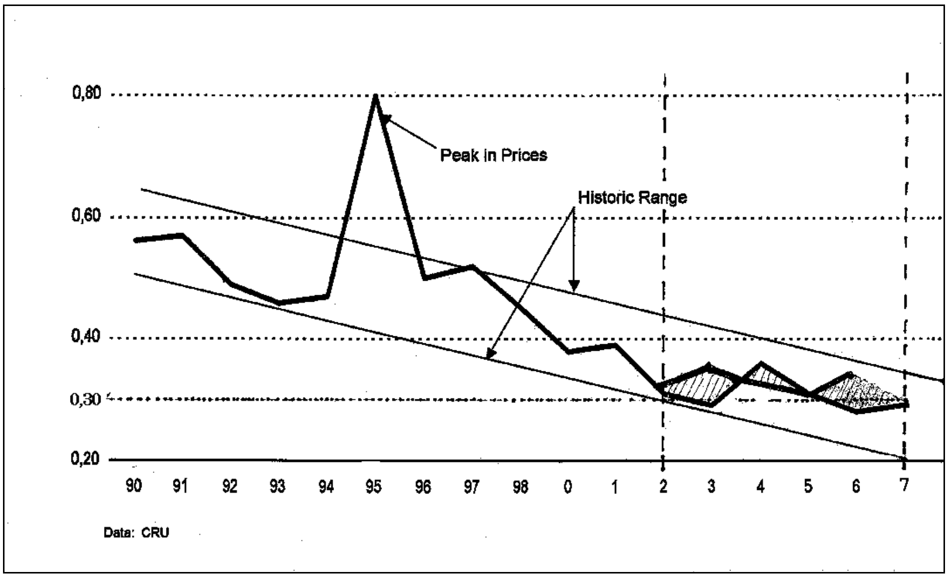

Figure 1. Spot Price of Charge Chrome, Del. Europe, Real US$/lb (Data: CRU, MBR and own)[1,2].

In the FeCr industry the operational costs can be divided into four different cost factors.

These cost factors and their influence is as follows in European conditions:

Chromite	30%
Electricity	30%
Reducing agent	20%
Others	20%

From these figures we can see that about half of all operational costs comes from electricity and reducing agent.

There is certain theoretical minimum on the amount of reducing carbon and electricity needed for the process regardless of production technology (figure 2). In the real production process there are always heat and material losses regardless what equipment is used. However these losses can be reduced by utilization of advanced design of the furnace and the process generally.

Increasing the furnace size reduces the relative energy loss. The CO-gas produced in the process is utilized with advanced gas treatment systems. Still, despite of all these tricks the availability of the furnace is the most significant cost factor.

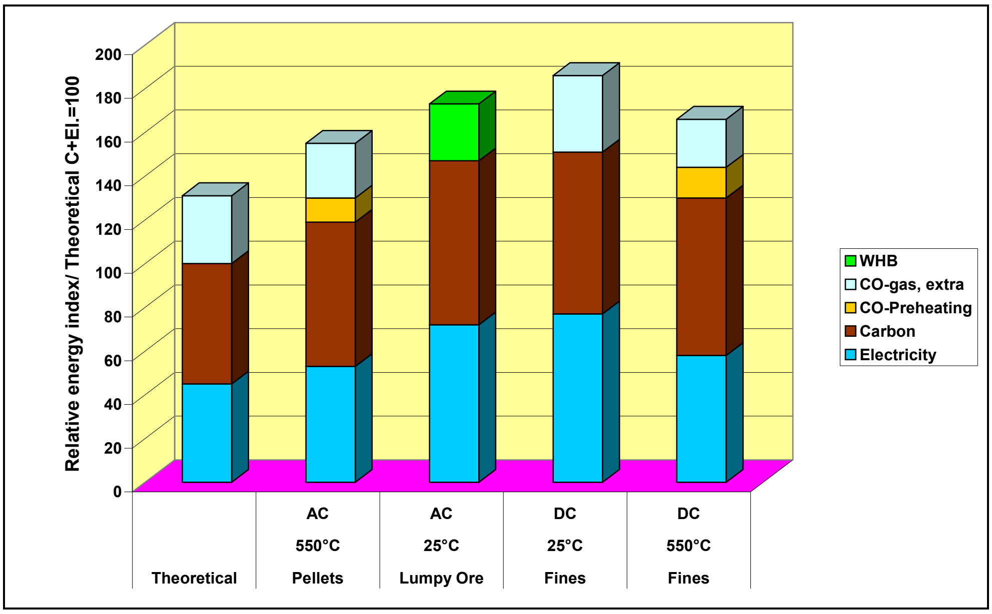

Figure 2. Consumption of electricity and carbon in FeCr production. Basis on Kemi Chromite.

The trend of decreasing prices in ferroalloys products draws producer’s attention more and more to operation costs. The influence of unit processes, availability and unit size to operation costs have been studied. Also environmental protection and working conditions has been studied. This paper describes the results of these studies made at Avesta Polarit’s ferrochromium plant in Tornio, Finland.

2. PRODUCTION TECHNOLOGIES

Conventional methods are still generally used in bulk ferroalloys production. There has been though equipment developed, and modern automation systems have been adopted. Until today these techniques have enabled economical ferroalloys production especially in countries with domestic chrome resources. But the industry has to face evident challenges such as downward trend of the prices and increasing awareness about environmental and working conditions.

2.1 Today's production technologies

Ferroalloys production processes are very traditional and no revolutionary new technologies have been launched in the markets. Ferronickel is produced by the conventional rotary kiln/electric furnace and ferrosilicon and ferromanganese in a submerged arc furnace. Certainly equipment technologies and process automation have developed considerably and thus the operation of the plants improved.

A major part of new process technology has been launched in ferrochrome production. Especially in 1980'ies there was seen strong interest in research and implementation of new methods, such as plasma smelting, pre-reduction and direct reduction. Still, all ferrochrome, excluding some DC-furnaces, is produced with submerged arc furnace. The pre-treatment methods for ferrochrome smelting, such as agglomeration and preheating and pre-reduction, are, however, developed and used commercially.

2.2 Technologies introduced during previous 20 years

In the following we are concentrating in ferrochrome production to avoid confusion by jumping from one material to another.

2.2.1 Fines smelting in open or semi-closed furnaces

More than half of the FeCr production is made with open or semi-closed furnaces today. There has been development to decrease the emissions of these furnaces and to increase their ability to handle fine feed materials.

Nowadays open or semi-closed furnaces have effective ventilation systems with dust collection. Dust is then treated for f.ex.Cr^{6+} removal. The gas treatment systems of these processes are big in size for the large amount of gases that needs to be treated.
With new design developed to open or semi-closed furnaces the ability to utilize fine feed materials have been better.

However these furnaces continue the production with new development, but new installations may be difficult for environmental reasons.

2.2.2 Rotary kiln pre-heating

In principle the rotary kiln can be effectively used for preheating of the charge and thus make use of the furnace gas. Outokumpu used rotary kiln for preheating the pellet charge from 800 to 1000 ^{o}C before continuous feeding to a closed furnace. The process operated satisfactory. The main problem was the availability of the rotary kiln and it is difficult to get it to the same level with the availability of electric furnace. Due to that overall availability of the plant was not satisfactory. Also the grinding of the ore became significant when upgraded lumpy ore were started to use as part of the feed and the kiln was replaced by stationary preheating equipment.

2.2.3 Rotary kiln pre-reduction

The use of rotary kiln for pre-reduction of ore or concentrate is metallurgically interesting and three companies have developed that to commercial scale. Outokumpu, Showa Denko and Krupp/MS&A. From those Showa Denko's process, which is pre-reducing pellets instead of fines in rotary kiln, is still in use.

Outokumpu studied its process about ten years in laboratory and pilot scale as well as two years in commercial scale operation (figure 3). The process consisted of the rotary kiln with length of 55m and inner diameter of 2,3 m. The major problem was to maintain even pre-reduction degree. Consequently the plant operation and availability was not good enough to make the operation viable and we returned to use the equipment for preheating. The more detailed description of the process is in the proceedings of INFACON 6 (pages 79 – 86), 1992[3].

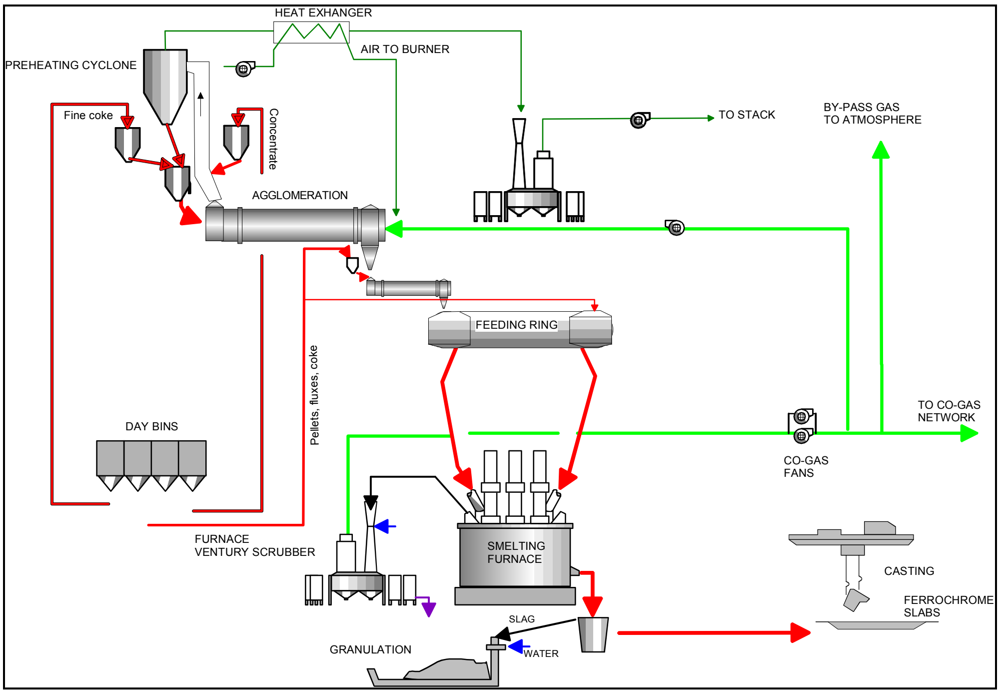

Figure 3. Outokumpu pre-reduction process.

2.2.4 Plasma/DC-furnaces

The first DC transferred-arc furnace was introduced in 1878. Since then the construction and equipment have developed of course a lot, but still there is plenty questions to study before this method is economically viable.

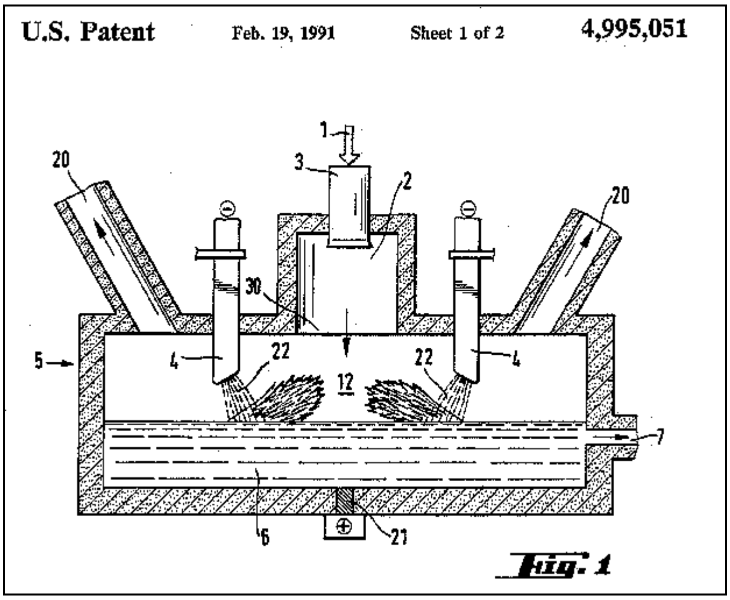

Figure 4. Outokumpu patent for DC-plasma smelting [4].

Outokumpu have studied DC-technology continuously from the mid 80's and we even have a US-patent from 1991 (figure 4), but still we are confident that isn't as economical as AC-technology because of lower availability, higher power consumption and shorter lifetime of brick lining.

Low availability is due to extension of graphite electrode. A lot of development has been done to develop equipment and automation to decrease the power down time. Still the power must always be taken down and the feeding stopped for a while.

While operating with high voltage the arc (or torch) between electrode and melt is long. The radiation of arc will create high heat losses through the roof of the furnace. If the material is fed through a hollow electrode the material flow creates disturbances to the arc. Therefore the capacity of feeding is limited. In the Outokumpu patent the material is fed separately to the middle of three electrodes that do not create similar problems (figure 5).

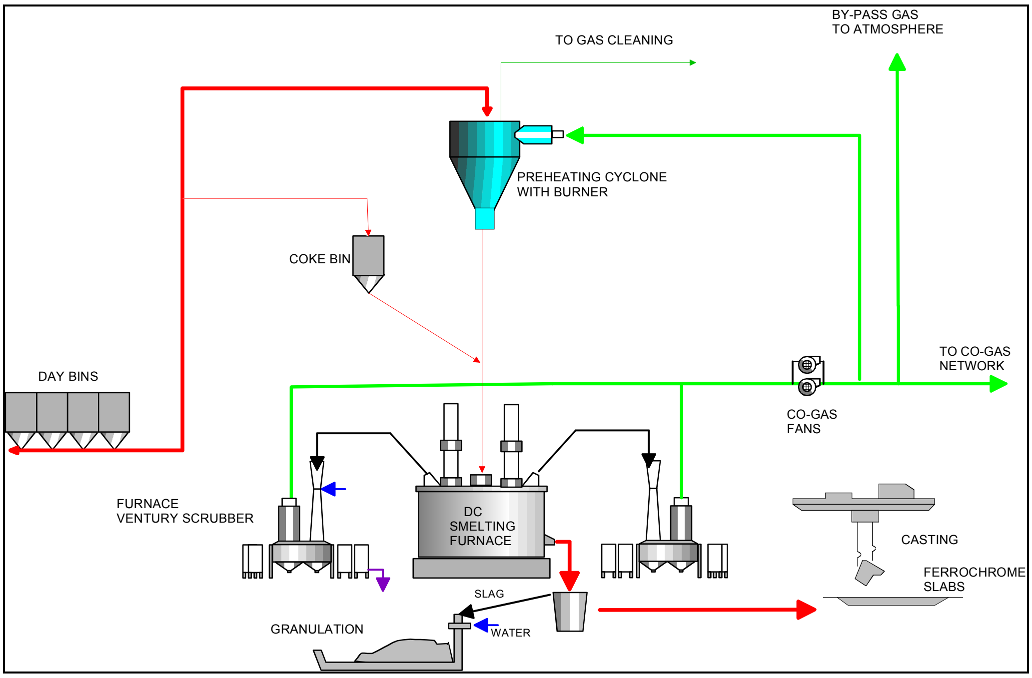

Figure 5. Outokumpu DC-smelting process.

2.2.5 Preheating shaft kiln

The furnace charge preheating with shaft kiln located on the top of the furnace was introduced to Tornio plant 1985 (see also INFACON 6, page 86)[5]. At the very beginning the advantages of preheating pellets with this method were clear. Compared the use of preheated sintered pellets to the attempt of using cold feed of lumpy ore and briquettes the unit cost per ton of FeCr went down 35% (figure 6). The division of costs by process units is described in item 3.1.

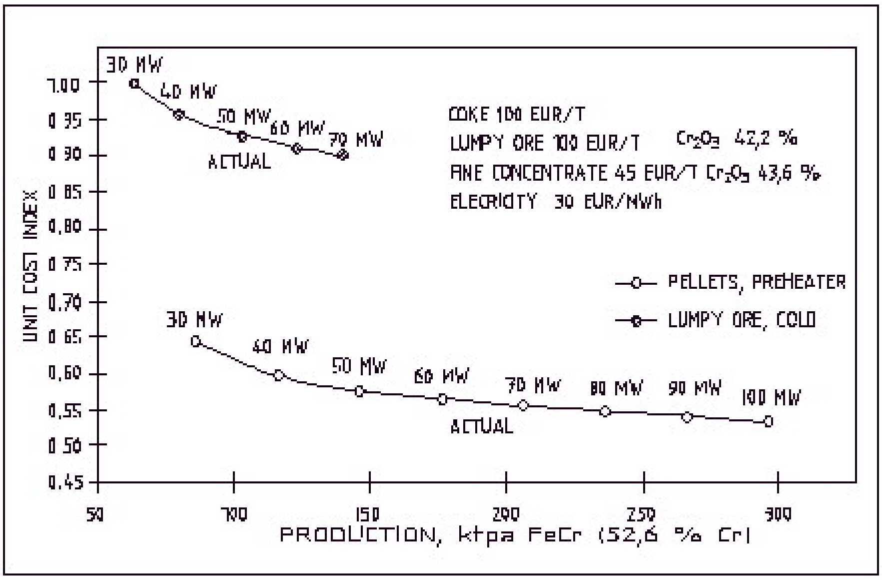

Figure 6. Smelting cost comparison, lumpy ore / pellets.

2.2.6 Advanced automation

The operation of smelting processes has been improved by advanced automation systems. Almost all new ore renewed plants have centralized digital control systems, which facilitate monitoring and development of operation. Mintek, South Africa, and Outokumpu have developed the advanced furnace power control systems to commercial use. Mintek's system has found wide use among South African ferroalloy producers and Outokumpu's system is in use at AvestaPolarit's ferrochrome plant. The more sophisticated control systems, like fuzzy logics, neural calculations and genetic algorithms, would provide substantial benefits especially in the case of large production units.

3. PRINCIPLES AFFECTING TECHNOLOGY AND EQUIPMENT DESIGN

The long-term trend of ferroalloy prices is clearly downwards (figure 1). This will put a pressure to the producers to decrease overall production costs in order to maintain the profitability of the industry. In the next paragraphs we present the profit calculations we have made at Tornio ferrochromium plant. Even though, we have used our prices the same factors are valid all around the world. This similar principle has been found also in other fields of industry; reduction of iron and other ferroalloys.

3.1 Influence of different unit processes on operation costs

Production costs in the present Outokumpu FeCr process is composed of unit processes as follows:

• Agglomeration/pelletizing	10%
• Pre-heating	1%
• Smelting (closed furnace)	89%

On the other hand the savings of these in unit processes to operation costs compared to "classic" lumpy ore and fines feeding to open or semi-open furnaces is about 35 % and can be divided as follows:

• Agglomeration/pelletizing	-15%
• Pre-heating	-15%
• Smelting (closed furnace)	-5%

It is clear that investment to pre-heating unit is essential for cost effective operation. This is also shown in figures 2 and 6.

3.2 Energy consumption

Though there are no expectations for decrease in the price of electric energy, there are possibilities to reduce the cost by improving the effectiveness of using the energy. In the conventional processes lot of the electrical energy is wasted as the energy contend of furnace gases. Also the less effective power utilization in the smelting furnace and lower availability of the plant increases the power consumption.

When the low cost fines are agglomerated to even sized, hard and porous feed material, their behaviour in furnace is even better than that of hard lumpy and the consumption of electric energy in smelting is reduced considerably. The furnace operation is more stable and plant availability high. These benefits are well demonstrated in industrial scale with sintered pellets (figure 2).

The utilization of the latent heat of carbon monoxide gas from the furnace for the calcining and preheating of the furnace charge is further decreasing the primary energy consumption considerably. The gas can be used internally also in the agglomeration, for instance sintering, and thus decrease the additional costs involved in that operation. In addition, the energy costs can be partly compensated by selling the extra furnace gases to possible other consumers.

Because of the latest environmental legislation the price of energy, electricity and coke has been increasing substantially and there is obvious upward trend in the labour, transportation and fixed costs. Thus the delivered costs of the existing plants are increasing if nothing is done to change the cost structure.

3.3 Size of the production unit

To respond to the increasing investment cost due to e.g. environmental protection equipment and increasing fixed costs due to e.g. personnel cost, the tendency to bigger processing units is apparent.

The investment cost of the smelting furnace does not increase linearly with the active power. Instead the extra cost per MW will decrease as the furnace size increases (figure 7).

This is due to fact that some investment costs remains the same regardless of the furnace size as design and project management.

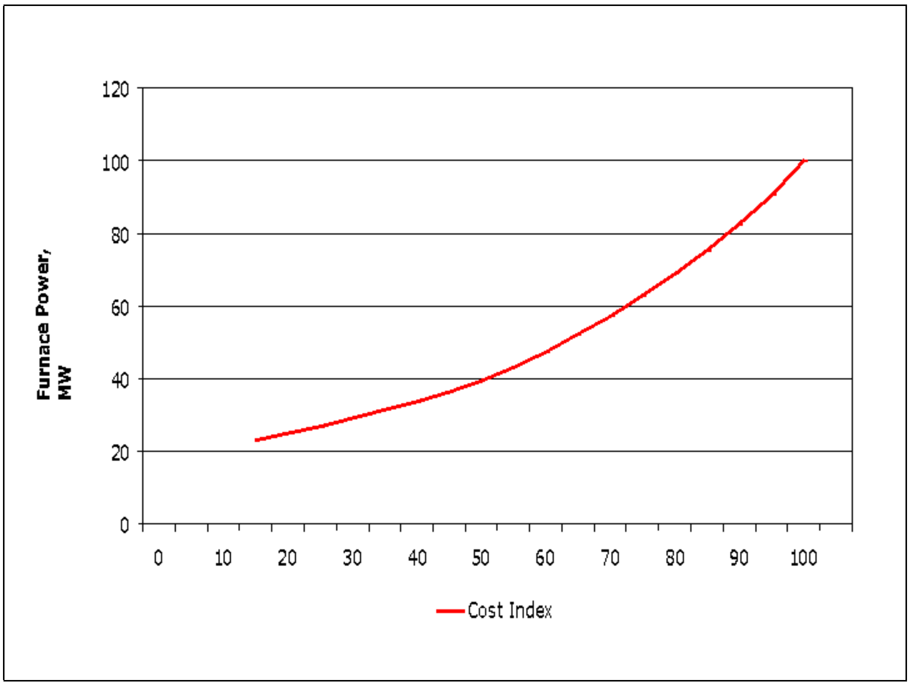

Figure 7. The relation between the furnace size and investment cost.

The size of the smelting units used in ferroalloys production has increased during the past 30 years 6-7 times. The annual average power of FeCr furnaces, for instance, has accordingly grown from 10 MW up to 65 MW. At the moment it is known that it is possible to build smelting units with a power of about 100 MW. Figure 8 shows the possibilities for smelting cost decrease with pre-treated charge and increased size of the furnace compared to open furnace with lumpy ore charge and DC-furnace installations.

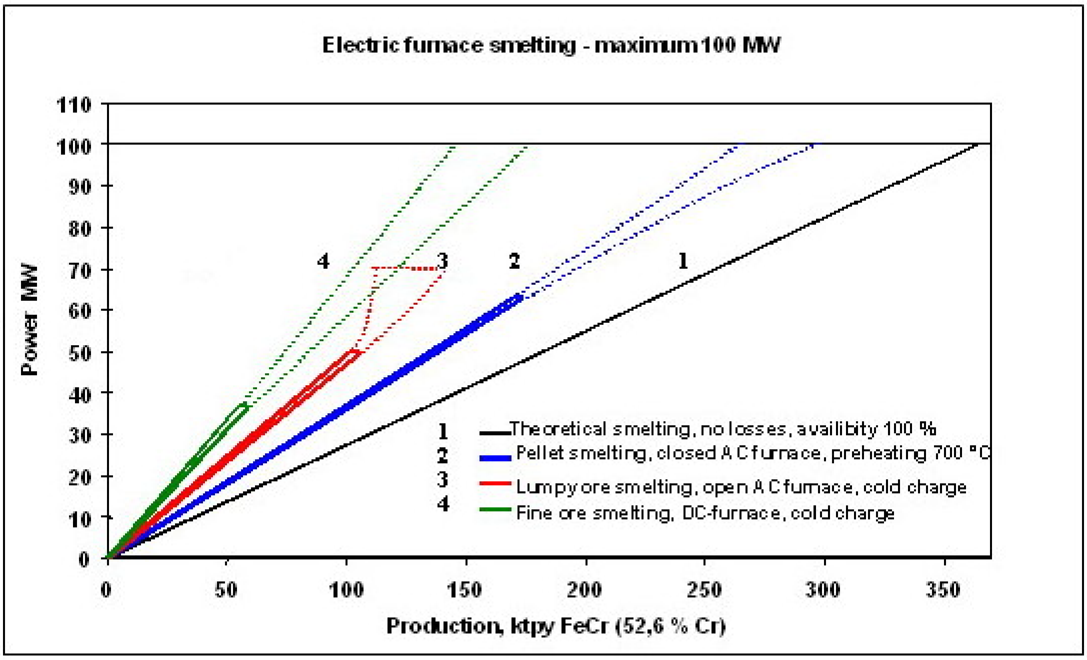

Figure 8. Relation of effective power and production with existing furnaces to theoretical values. Dashed line is for expected production.

So far the biggest ore smelting furnace has reached an annual average power of ab. 50 MW with annual production of ab. 100 000 tpa. For the time being the yearly average power of about 64 MW and production of close to 180 000 t with sintered pellets and preheating is achieved. Raw material pre-treatment as well as automation development has had a significant affect on the growth of smelting plant size.

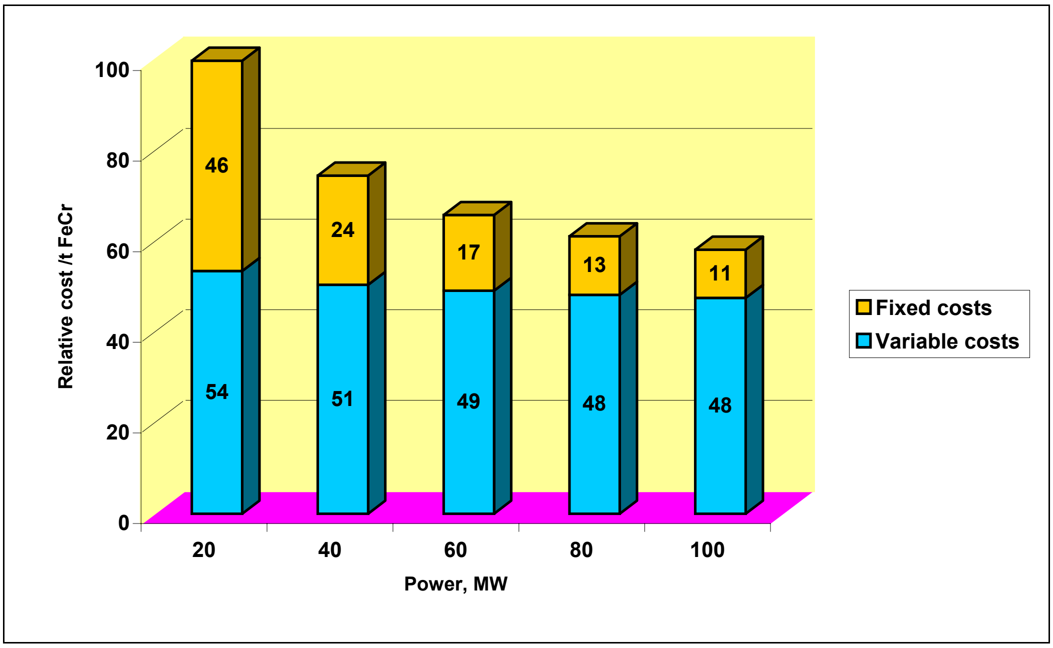

Figure 9. The influence of furnace size on production costs in FeCr plant.

The operation costs of smelting unit decreases against ton of FeCr produced as the unit size increases (Figure 9). The capacity growth over 100 MW is limited by the diameter of self-baking electrodes. For the time being there are technical facilities to build Söderberg electrodes by diameter over 2,0 m.

The biggest available graphite electrode is 0,8 m by diameter and it seems possible to make DC-furnace for higher than 100 MW with three electrodes [6]. The biggest DC-furnaces today are 35-40 MW. The feasibility of a big DC-plant is however yet to be proven.

3.4 Availability

As a cost effective production is the aim of the investment the availability of the furnace is in key role. The 10 % increase in availability reduces the production costs about 10 % in a case of 65 MW furnace (Figure 10). For this reason man should pay a great attention to the furnace design and related equipment.

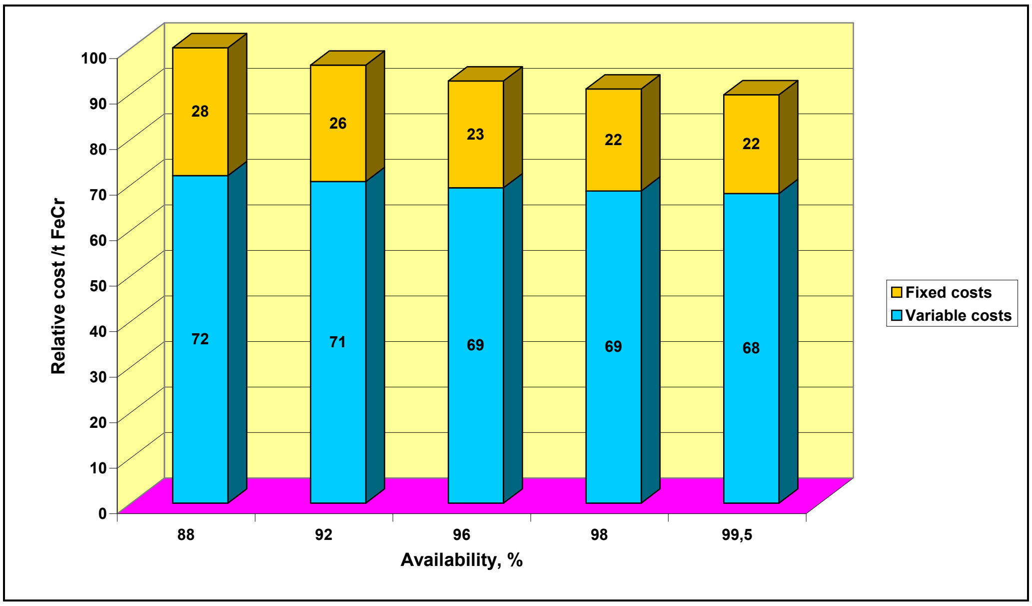

Figure 10. The influence of availability on production costs in Tornio FeCr plant.

As the availability increases also the variable costs decreases as electrode, coke and electricity consumption decreases per ton of FeCr. When the loss of production due to decreasing availability is taken into account with increasing operating costs the decrease of profit margin, as result, is more dramatic. As can be seen in the Figure 11, when the availability decreases from 99,5 to 88 % the profit falls over 50 %.

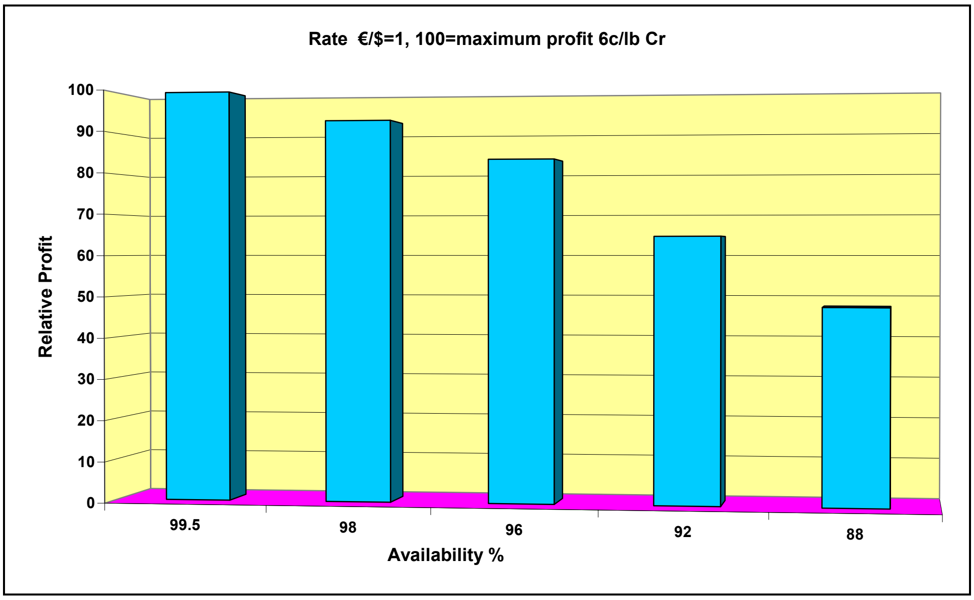

Figure 11. The influence of availability on plant profits.

3.5 Environment protection

The environment will be an essential matter to be taken care when constructing new ferroalloy plants or renewing the old ones. This requires the construction of gas cleaning and water treatment plants. By sealing the furnaces gas tight the gas cleaning equipment can be made smaller and less expensive. At the same time the furnace gas is taken in the form of fuel to be used internally and/or externally.

The additional costs involved in the environmental protection equipment can be recovered with reduced material losses and maintenance costs and, above all, as the improvement of the availability of the process.

Low energy consumption, small process gas volumes and closed process water circulation make today's smelting process acceptable also from the ecological point of view (Figure 12). Reducing conditions of the closed furnace, for instance, prevent the formation of toxic 6-valent chromite. These emissions from the closed furnace are 5-100 ppm while from the open furnace they are 1000-7000 ppm in furnace gas. The 98% use of secondary energy (CO-gas) in sintering and preheating decreases stack emissions (sulphur ferrochrome compounds, ref. heavy fuel oil). The burden which the ferrochrome works load to the Baltic Sea is 2% in chrome and 1% in zinc from the total amount of these elements in the Tornio river water. It should be noted that the Tornio river is a boarder river between Finland and Sweden and practically in natural stage.

The local emissions of CO_2 from the ferrochrome works are low because of the process equipment and the external use of the CO-gas. These emissions may be more than double in the conventional ferrochrome production.

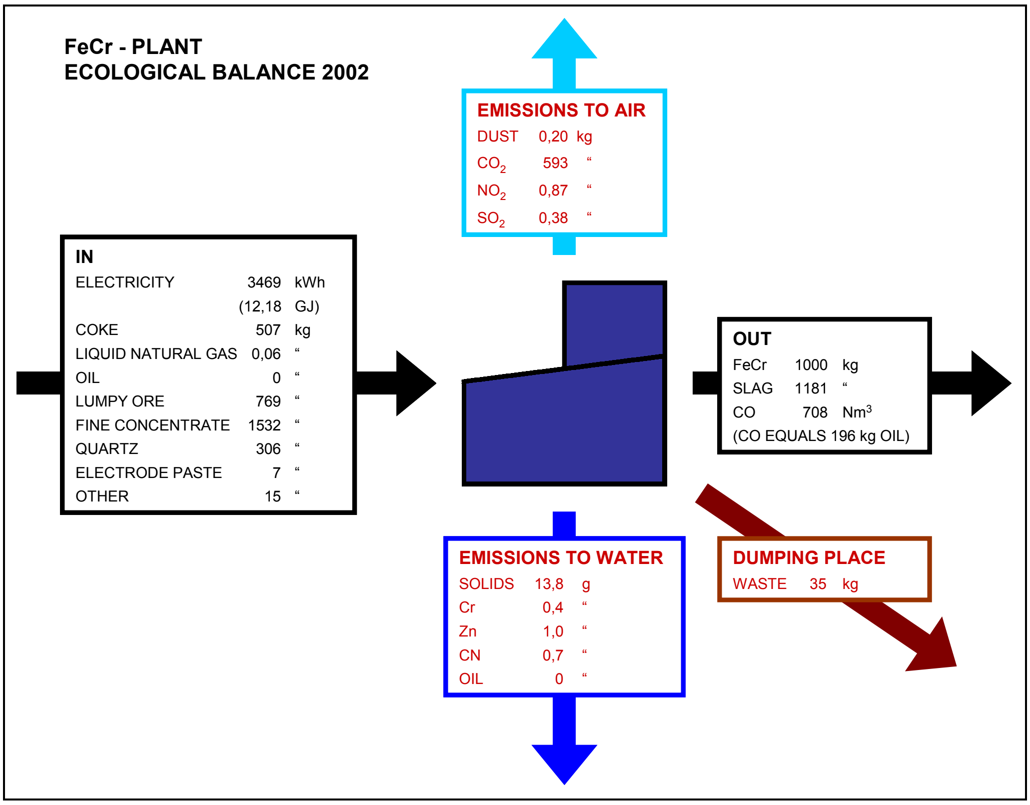

Figure 12. The ecological balance of Tornio FeCr –plant.

The demand for environmental protection is becoming stricter all over the world and rightly so. Responding to that demand is not a big challenge for modern technologies, but it becomes a challenge when the industry has, at the same time, to adapt itself to lower prices of the products. The environmental protection requires always additional equipment and thus extra investment costs. The operation of the equipment has its own costs too.

3.6 Working conditions

With closed process the working conditions inside and in the near vicinity of a plant can be improved so that they are meeting with today’s requirements. Of course, the house keeping has to be made properly and we claim if it is made as a common practice it is less costly than living without it.

At the stainless steel plant of AvestaPolarit Steel Oy, including the ferrochrome plant, a research program on health effects of occupational chromium exposure was conducted covering the time from 1987 (Dr. Markku Huvinen & al.)[7].

In the following are the main results of the study:

- Exposure to chromium and its evaluation by biological monitoring in the production of stainless steel (1993)
- The exposure levels to chromium and especially to hexavalent chromium are low. In the Kemi chromite mine and at the Tornio works, the workers absorb small amounts of chromium, but no accumulation of chromium was observed.
- Respiratory health of workers exposed to low levels of chromium in stainless steel production (1996)
- An average exposure time of 18 years in ferrochromium and stainless steel production and exposure to dusts containing low concentrations of hexavalent or trivalent chromium do not lead to any respiratory changes detectable by lung function tests or radiography nor to any increase in symptoms of respiratory diseases.
- Estimation of individual dust exposure by magnetopneumography in stainless steel production (1997)
- The accumulation of magnetic dust in the lungs was low in a modern stainless steel production chain.

Working conditions at production plants are most probably going to be a more important issue in the future. This far there has not been so much open discussion about it, though at individual works it has been taken up. Ferroalloy plants have traditionally not been very clean and the effect of the working conditions to the people continuously working there has not been carefully investigated. However, awareness about this aspect is increasing and the industry has to be prepared to respond, again with the falling price trend.

4. DEVELOPMENT OF NEW TECHNOLOGIES AND EQUIPMENT

Though the challenges are very much similar in bulk ferroalloy production, each of them is requiring a different process concept. Thus the market for the potential technology suppliers to start alone a novel development work is not very encouraging. Even with ferrochrome consumption increase of 150 - 200 000 tons annually, there are only 1 - 2 new plants per year needed. It is difficult to recover the development cost of a new technology in an acceptable time period by technology sales only. Thus the involvement of a production plant is essential to share or actually take the major part of the development cost.

The driving force of the equipment development is more and more the overall awareness of the society about environmental issues as well as the health of plant personnel. The tightening of environmental restrictions may force to use even more sophisticated gas cleaning and water treatment systems as well as utilization of totally new technologies. The advanced automation systems will help to obtain optimal process conditions with low emissions.

There are, however, new ideas waiting for the producer who is prepared to take the risks involved and see the potential advantages tempting enough. One of these new technologies is pre-heating or pre-reduction of the feed materials in fluidized bed. Pre-heating in fluid bed is already widely utilized in other fields of industry, but there are also some applications in ferroalloys industry. Pre-reduction with coal could be most beneficial with ilmenite or FeNi smelting.

As well as proven technologies new technologies have to satisfy the economical and environmental requirements of the society. Also a new technology needs uniform feed of uniform and good quality materials to respond on expectations. There isn’t likely to come a technology that would accept poor quality feed materials and would be able to produce good quality product with reasonable profit at the same time.

5. CONCLUSION

The production of ferrochromium is a continuous smelting process. Therefore the availability and unit size are the most important factors influencing profits. After all, it is minor factor whether the production unit is operating with AC, DC or other technology the major factors on profits are big size and high availability.
As the conclusion it can be stated that the ferroalloy industry is facing demanding challenges, but they can be responded to by already existing technologies and by the process development.

The main features for the future of the industry to remain profitable and attractive for owners and personnel are:

- Increase use of lower cost raw materials and especially in the case of ferrochrome by advanced beneficiation and agglomeration or corresponding technologies.
- Increase in the size of production unit in order to benefit the economics of scale.
- Effective use of energy and the utilization of the secondary energy produced.
- High degree of automation to improve operation.
- Strict environmental control becomes an essential part of production.

Closed processes and high automation level can improve the working conditions to the level required by the future standards. This will also make it easier for the industry to hire qualified persons to operate the plants.

6. REFERENCES

[1] CRU Special steels and alloys team, “Ferrochrome Market Service, December 2002”, Ref No 2898/18, 2002.

[2] Bennet, A., and Mills, S., A Strategic Analysis of the global Ferro-chrome Industry, Prospects out to 2006”, Metal Bull. Res., November 2002, p. 6.

[3] Honkaniemi, M., Krogerus, H., Daavittila, J., and Oikarinen, P., “The importance of chromite pre-treatment in the production of ferrochromium”, The proceedings of INFACON 6, 1992, pp. 79-86.

[4] Hakulin, N., Heikkilä, R., Honkaniemi, M., Krogerus, H., and Lilja, L., Smelting furnace and method for feeding material to be processed therein, U.S. Patent no. 4,995,051, 1991.

[5] Honkaniemi, M., Niemelä, P., Heikkilä, R., Jankkila, M., and Lilja, L., Feed apparatus for batch preparation feed mixture for feeding into smelting furnace, U.S. Patent no. 6, 099,301, 1999.

[6] Friedrich, C., Jäger, H., Wimmer, K., Hauswirth, C., Fuchs, H., and Schäfer, H., “The world’s first 800 mm diameter graphite electrode for a DC electric arc furnace, MPT International, no.2, 2002, pp. 42-49.

[7] Huvinen, M., “Exposure to Chromium and its Long-term Health Effects in Stainless Steel Production”, Kuopio University Publications D. Medical Sciences 287, 2002, 108 p.