



The transformation of ferrochromium smelting technologies during the last decades

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Synopsis

In the latter part of the 1980s Outokumpu Chrome in Tornio, Finland, was in a situation when its twenty-year-old ferrochrome plant was becoming too 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 as the Tornio FeCr-plant is considering 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 for better working conditions. The possibilities of resolving 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 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.

Introduction

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

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

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

- ▶ Chromite 30%
- ▶ Electricity 30%
- ▶ Reducing agent 20%
- ▶ Other 20%.

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

There is a certain theoretical minimum for the amount of reducing carbon and electricity needed for the process, regardless of production technology (Figure 2). In a real production process there are always heat and material losses, regardless of which equipment is used. However, these losses can be reduced by using an advanced design for 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.

The trend of decreasing prices in ferroalloy products draws producers' attention more and more to operation costs. The influence of unit processes, availability and unit size on operation costs have been studied. Also environmental protection and working conditions have been studied. This paper describes the results of these studies made at Outokumpu Chrome Oy's ferrochromium plant in Tornio, Finland.

Production technologies

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

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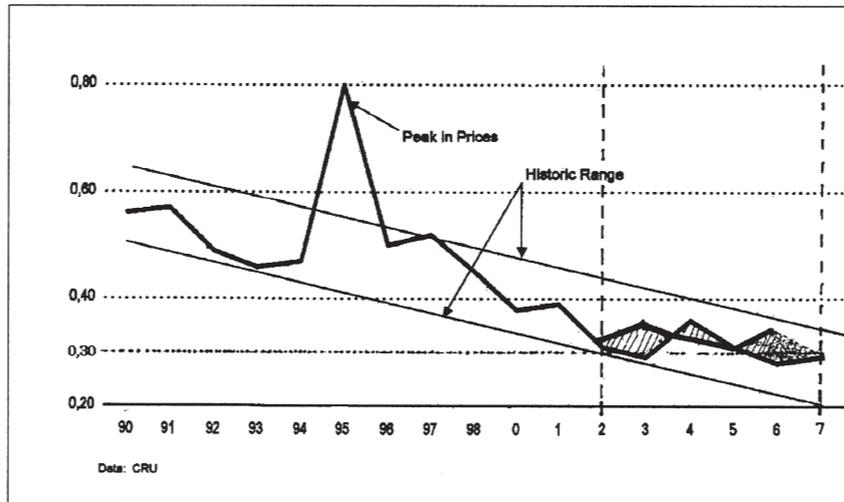


Figure 1—Spot price of charge chrome, Del. Europe, Real US\$/lb (Data: CRU, MBR and own)^{1,2}

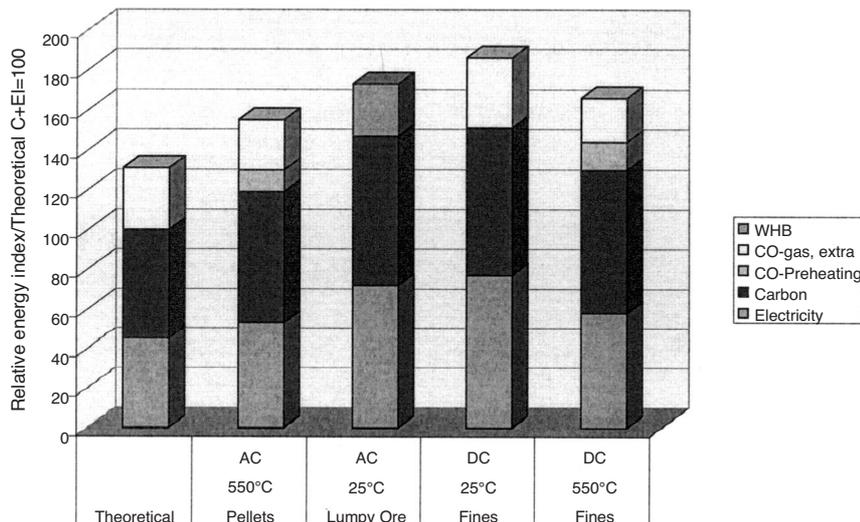


Figure 2—Consumption of electricity and carbon in FeCr production. Based on Kemi chromite

Today's production technologies

Ferroalloy 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 1980s, strong interest was seen 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 furnaces. The pretreatment methods for ferrochrome smelting, such as agglomeration and preheating and pre-reduction, are, however, developed and used commercially.

Technologies introduced during the past 20 years

In the following we concentrate on ferrochrome production to avoid confusion by jumping from one material to another.

Fines smelting in open or semi-closed furnaces

More than half of the FeCr production is achieved with open or semi-closed furnaces today. There has been progress in decreasing 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. Cr⁶⁺ removal. The gas treatment systems of these processes are large in size for the large amount of gases that needs to be treated.

With the development of a new design for open or semi-closed furnaces, the ability to utilize fine feed materials has improved.

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However, new installations may be difficult, for environmental reasons.

Rotary kiln preheating

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

Rotary kiln prereduction

The use of a rotary kiln for prereduction of ore or concentrate is metallurgically interesting and three companies Outokumpu, Showa Denko and Krupp/MS&A have developed it on a commercial scale. Of these, Showa Denko's process, which prereduces pellets instead of fines in rotary kiln, is still in use.

Outokumpu studied its process for about ten years in the laboratory and on a pilot scale as well as for two years in a commercial scale operation (Figure 3). The process consisted of the rotary kiln with length of 55 m and inner diameter of 2.3 m. The major problem was to maintain an even prereduction degree. Consequently, the plant operation and availability were not good enough to make the operation viable and we returned to using the equipment for preheating. A more detailed description of the process is in the proceedings of INFACON 6 (pages 79–86), 1992³.

Plasma/DC-furnaces

The first DC transferred-arc furnace was introduced in 1878. Since then the construction and equipment have naturally developed considerably, but there are still many questions to study before this method is economically viable.

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

Low availability is due to extension of the graphite electrode. Much effort has been put into developing 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 at high voltage, the arc (or torch) between electrode and melt is long. The radiation of the 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, which does not create similar problems (Figure 5).

Preheating shaft kiln

The furnace charge preheating of the shaft kiln located on the top of the furnace was introduced to the Tornio plant in 1985 (see also INFACON 6, page 86)⁵. At the very beginning, the advantages of preheating pellets by this method were clear. The use of preheated sintered pellets, compared 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 later.

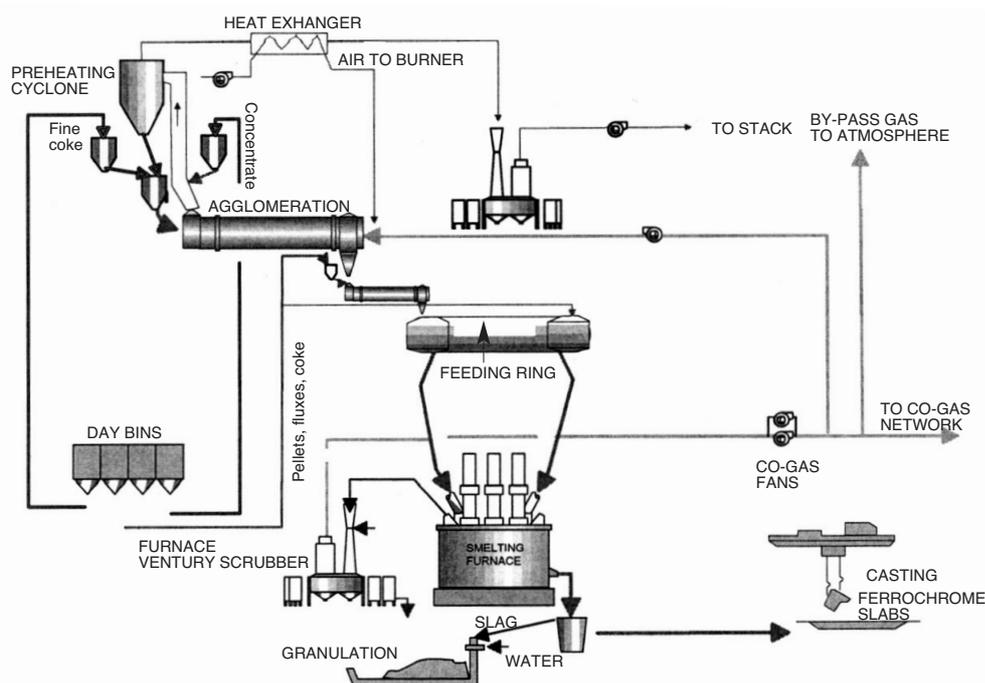


Figure 3—Outokumpu prereduction process

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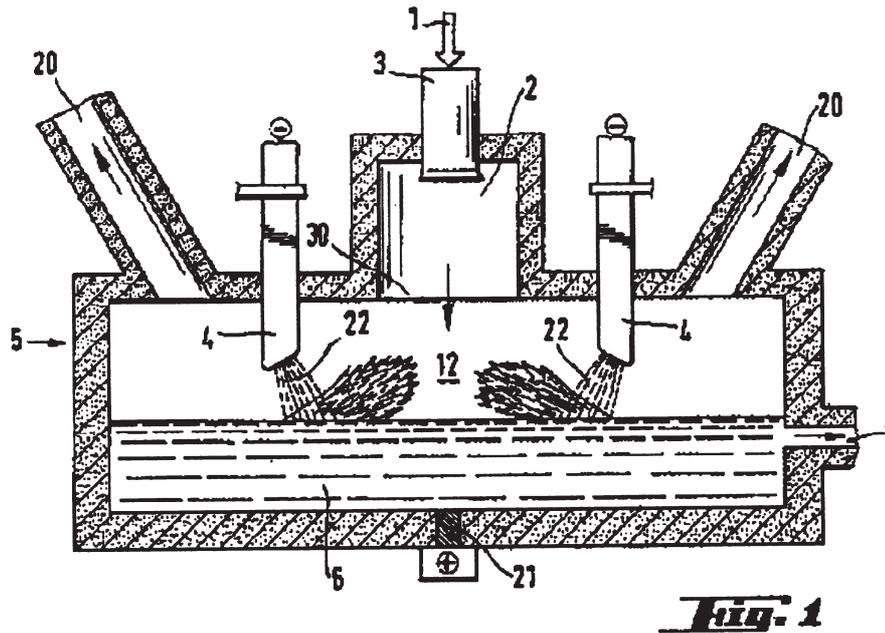


Figure 4—Outokumpu patent for DC-plasma smelting⁴

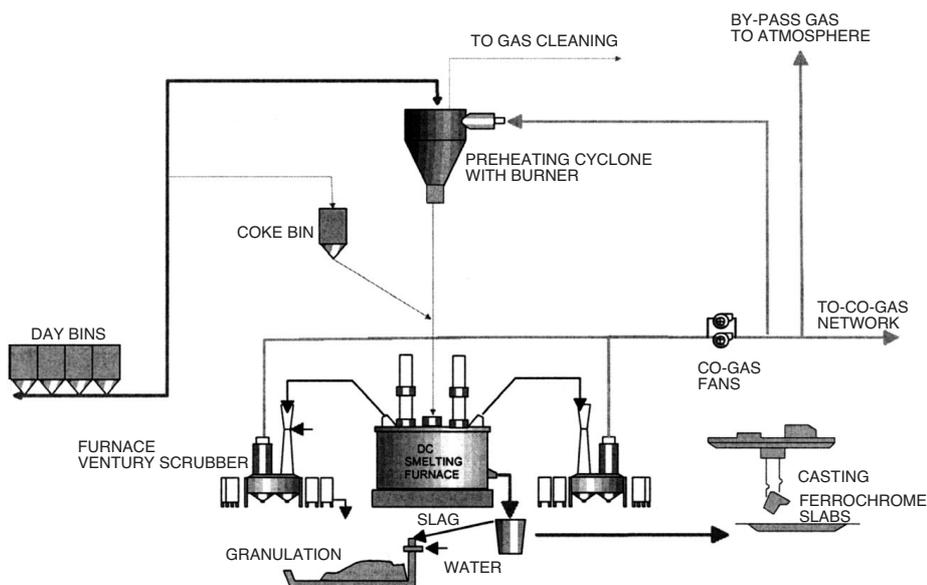


Figure 5—Outokumpu DC-smelting process

Advanced automation

The operation of smelting processes has been improved by advanced automation systems. Almost all new or 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 for commercial use. Mintek's system has found wide use among South African ferroalloy producers and Outokumpu's system is in use at Outokumpu Chrome's ferrochrome plant. The more sophisticated control systems, like fuzzy logic, neural calculations and genetic algorithms, could provide substantial benefits especially in the case of large production units.

Principles affecting technology and equipment design

The long-term trend of ferroalloy prices is clearly downwards (Figure 1). This will put pressure on 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 round the world. A similar principle has also been found in other fields of industry: reduction of iron and other ferroalloys.

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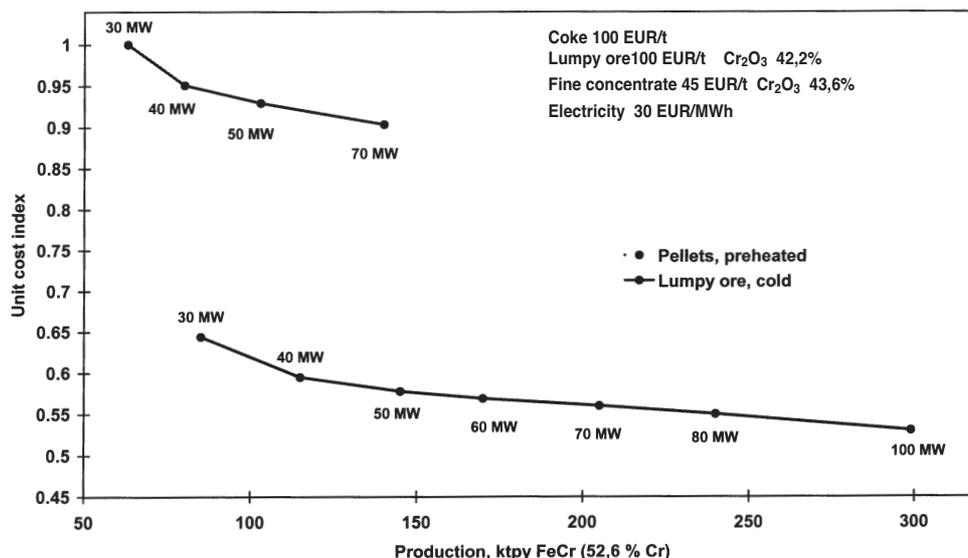


Figure 6—Smelting cost comparison, lumpy ore / pellets

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%
- Preheating 1%
- Smelting (closed furnace) 89%.

On the other hand the savings of these unit processes on 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%
- Preheating -15%
- Smelting (closed furnace) -5%.

It is clear that investment in a preheating unit is essential for cost-effective operation. This is also shown in Figures 2 and 6.

Energy consumption

Though there are no expectations of a decrease in the price of electric energy, there are possibilities of reducing the cost by improving the effective use of the energy. In the conventional processes, much of the electrical energy is wasted as the energy content of furnace gases. Also, the less effective power utilization in the smelting furnace and lower availability of the plant increase the power consumption.

When the low-cost fines are agglomerated to even-sized, hard and porous feed material, their behaviour in the furnace is even better than that of hard lumpy ore 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 on an 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 further decreases the primary energy consumption considerably. The gas can also be used internally 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 for by selling the extra furnace gases to other possible consumers.

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

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 costs, 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 because some investment costs such as design and project management remain the same, regardless of the furnace size.

The size of the smelting units used in ferroalloys' production has increased 6–7 times during the past 30 years. 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 decreasing smelting costs by pretreating charge and increasing the size of the furnace, compared to an open furnace with lumpy ore charge and DC-furnace installations.

So far the biggest ore smelting furnace has reached an annual average power of about 50 MW, with annual production of about 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 being achieved. Raw material pretreatment, as well as automation development, have had a significant effect on the growth of smelting plant size.

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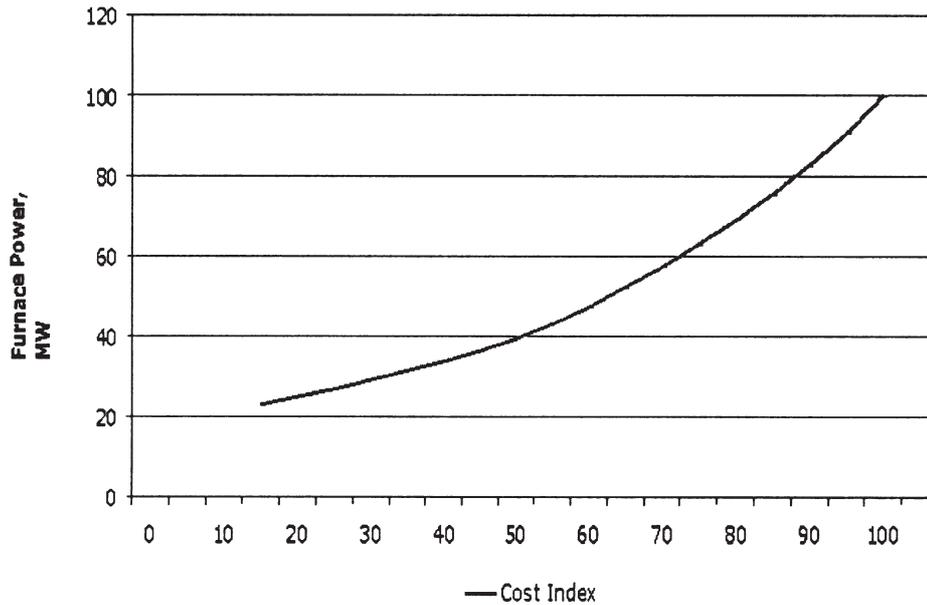


Figure 7—The relation between furnace size and investment cost

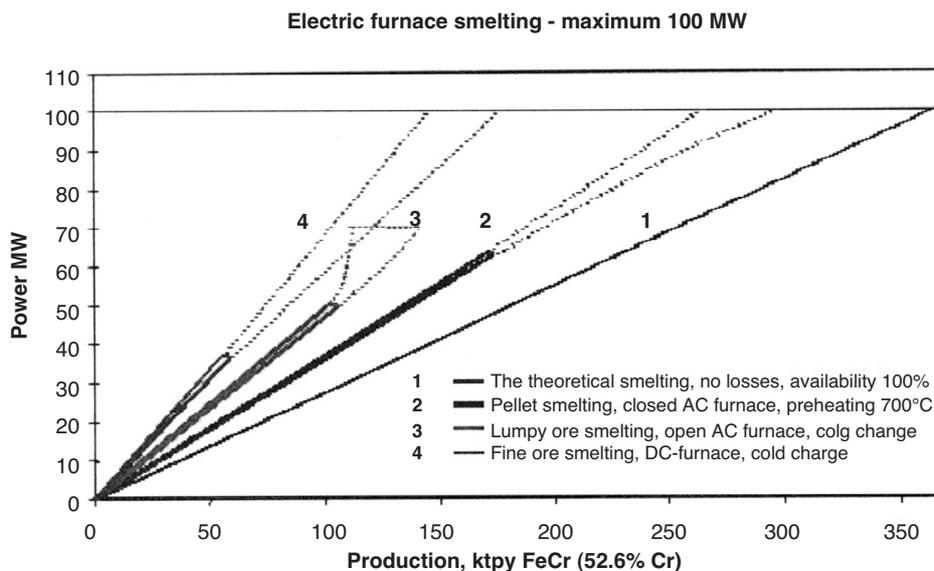


Figure 8—Relation of effective power and production of existing furnaces to theoretical values. Dashed line is for expected production

The operation costs of a smelting unit decrease 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 for building Söderberg electrodes with a diameter over 2.0 m.

The biggest available graphite electrode is 0.8 m in diameter and it seems possible to make a DC-furnace for higher than 100 MW with three electrodes⁶. The biggest DC-furnaces today are 35–40 MW. The feasibility of a big DC-plant is, however, yet to be proven.

Availability

As cost-effective production is the aim of an investment, the availability of the furnace is key. A 10% increase in

availability reduces the production costs by about 10% in the case of 65 MW furnace (Figure 10). For this reason, one should pay great attention to the furnace design and related equipment.

As the availability increases, the variable costs decrease 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 the profit margin, as result, is more dramatic. As can be seen in Figure 11, when the availability decreases from 99.5 to 88%, the profit falls over 50%.

Environment protection

The environment will be an essential matter to be taken care

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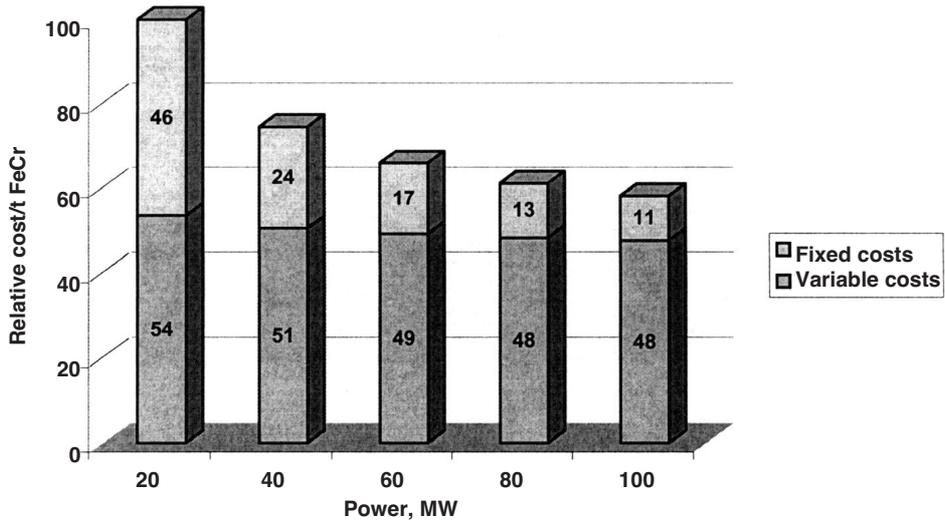


Figure 9—The influence of furnace size on production costs in FeCr plant

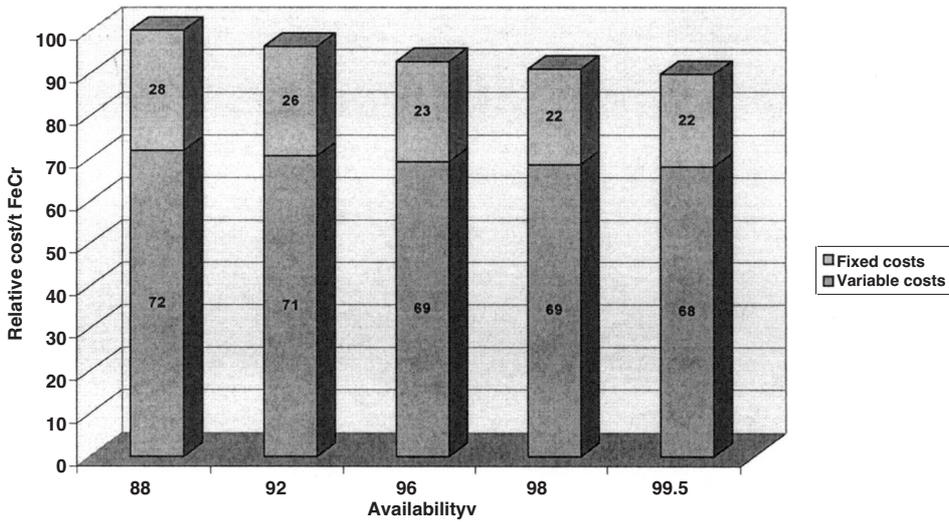


Figure 10—The influence of availability on production costs in Tornio FeCr plant

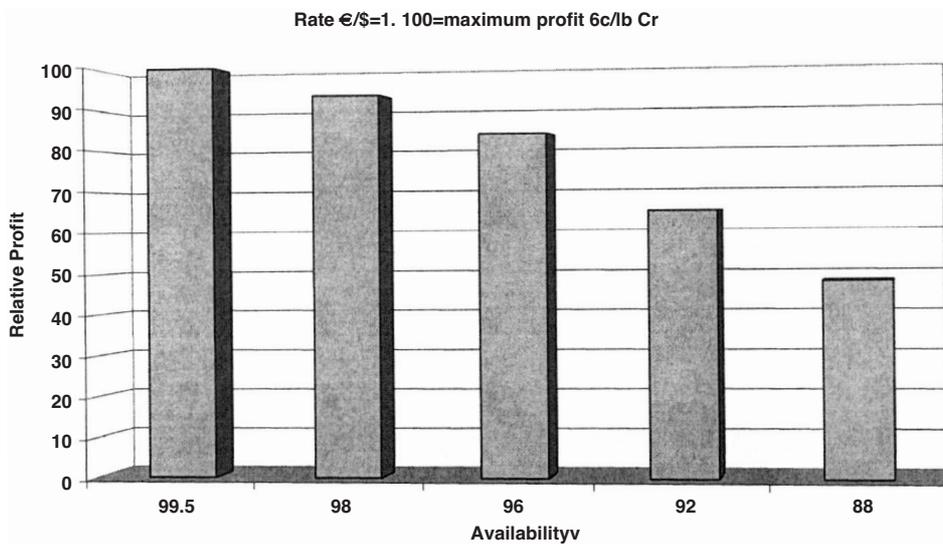


Figure 11—The influence of availability on plant profits

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of when constructing new ferroalloy plants or renewing the old ones. This requires the construction of gas cleaning and water treatment plants. By sealing the gas furnaces tightly 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 by reduced material losses and maintenance costs and, above all, by 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 an ecological point of view (Figure 11). Reducing conditions of the closed furnace, for instance, prevents 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 that ferrochrome works load into the Baltic Sea is 2% chrome and 1% zinc of 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.

The local emissions of CO₂ 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 conventional ferrochrome production.

The demand for environmental protection is becoming stricter all over the world, and rightly so. Responding to this 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. Environmental protection always requires additional

equipment and thus extra investment costs. The operation of the equipment has its own costs, too.

Working conditions

Using a closed process, the working conditions inside and in the near vicinity of a plant can be improved so that they meet with today's requirements. Of course, house-keeping has to be carried out properly, and we claim that if it is a common practice, it is less costly than living without it.

At the stainless steel plant of Outokumpu Stainless Oy, including the ferrochrome plant, a research programme on health effects of occupational chromium exposure was conducted covering the time from 1987 (Dr. Markku Huvinen *et al.*)⁷.

In the following, the main results of the study are:

- 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
- The 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)

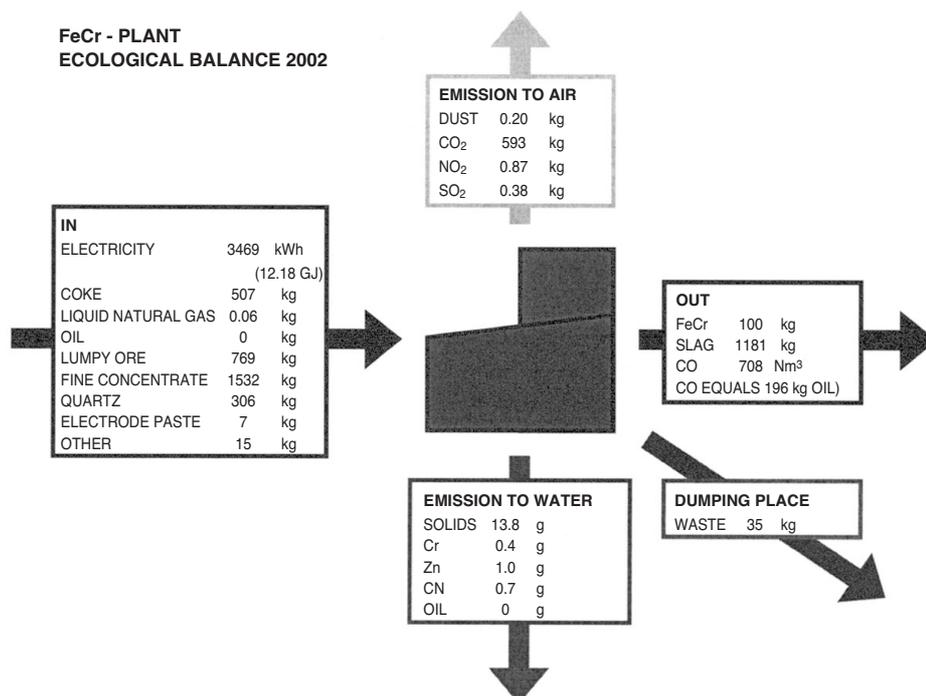


Figure 12—The ecological balance of Tornio FeCr plant

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- ▶ 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. Thus 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 on 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 a falling price trend.

Development of new technologies and equipment

Though the challenges are very much similar in bulk ferroalloy production, each of them requires a different process concept. Thus the market for the potential technology suppliers to start novel development work is not very encouraging. Even with a 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 the 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 who see the potential advantages as tempting enough. One of these new technologies is pre-heating or prereduction of the feed materials in a fluidized bed. Preheating in fluid bed is already widely utilized in other fields of industry, but there are also some applications in the ferroalloy industry. Prereduction with coal could be most beneficial with ilmenite or FeNi smelting.

As well as proven technologies, new technologies have to satisfy the economic and environmental requirements of the society. Also, a new technology needs uniform feed of uniform and good quality materials to respond to expectations. There isn't likely to be 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.

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 a 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.

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 development of the process.

The main features for the future of the industry to remain profitable and attractive to 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 the production unit in order to benefit the economies 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 levels 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.

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