THE PLASMACHROME PROCESS AT SWEDECHROME AB

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## INTRODUCTION

On July 14, 1984, the Swedish Government approved the location of a 78.000 tpy PLASMACHROME plant in Malmö, Sweden. PLASMACHROME is the registered trade mark for the process developed by SKF Plasma Technologies AB (formerly SKF Steel Engineering AB.

SKF Plasma Technologies AB was contracted to erect the plant on a turnkey basis. Construction started in May 1985 and the first tapping of pig iron was made on August 2, 1986.

The first campaign to produce ferrochrome was carried out in February 1987 but it took until October 1987 to achieve continuous ferrochrome production. From August 1986 to October 1987 many modifications were made to auxiliary systems so that mainly pig iron was produced.

An approved third-party inspection of the plant as well as the contracted test production were carried out during 1988 and the plant was handed over by the turnkey contractor on September 1, 1988.

## PLANT DATA

The plant site comprises 71.000 m$^2$ and is located just 1.000 m from a new harbor capable of handling vessels up to 60.000 tons. The plant is divided into five major areas: raw material storage, raw material preparation, melt shop, product processing, and slag treatment. Service facilities such as gas tanks, electrical, mechanical and refractory workshops, spare part storage, laboratory and office and personnel facilities are also included. A boiler for burning the off-gas to produce hot water for the district heating system is located within the plant. An overview of the plant is shown in fig. 1.

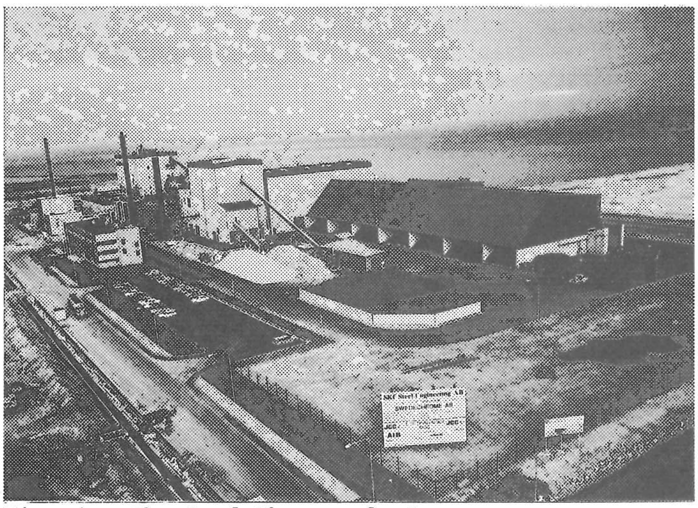

Fig. 1. The SwedeChrome plant

The plant is equipped with two shaft furnaces each with an installed effect of 28 MW. Electricity is supplied via underground 132 kV cables. The main transformer has a capacity of 75 MVA. Nominal plant data are presented in fig. 2.

| | |
|---|---|
| **INCOMING PRODUCTS** | |
| Chromite | 170,000 tons/year |
| Coal | 35,000 tons/year |
| Coke | 11,000 tons/year |
| Limestone | 5,000 tons/year |
| Silica sand | 20,000 tons/year |
| Electric energy | 345 GWh/year |
| **OUTGOING PRODUCTS** | |
| Ferrochrome | 78,000 tons/year |
| Heat energy | 380 GWh/year |
| Slag | 82,000 tons/year |

Fig. 2. SwedeChrome plant data

## THE PLASMACHROME PROCESS

### General features

A mixture of chromite and coal fines is injected into the high temperature zone of a coke-filled shaft furnace. To avoid slag formation in the shaft, fluxes are added with the injection mix and the coke.

The heat energy required for smelting and reduction is created from electricity by means of four plasma generators on each furnace shaft. Smelting reduction of the injected feed takes place in a "reaction zone" formed in the shaft in front of each plasma generator, see fig. 3.
A simplified drawing of the furnace is shown in fig. 4.

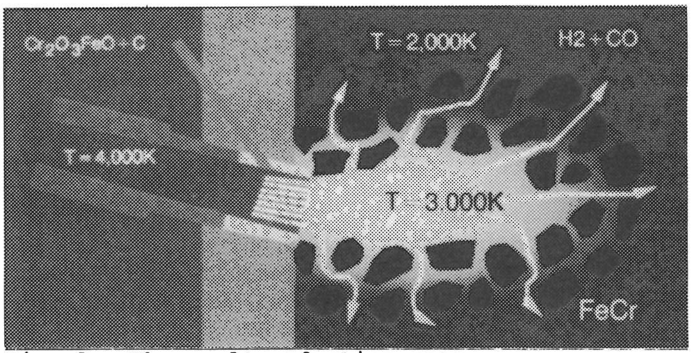

Fig. 3. The smelt reduction zone

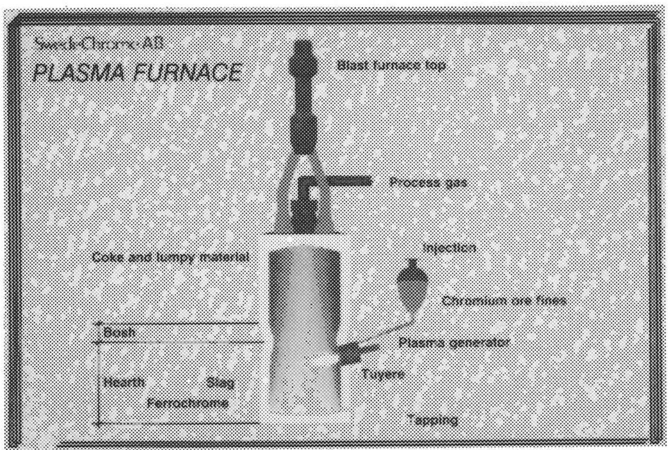

Fig. 4. The PLASMACHROME furnace shaft

Advantages of the PLASMACHROME process include:

* High grade chromite concentrates can be used directly without agglomeration.
* Efficient recovery of energy.
* Coal replaces expensive coke as the primary reducing agent.
* High chromium recovery.
* Simple process control as energy supply is independent of charge composition.
* Closed process system facilitates adherence to strict environmental regulations.
* Lumpy ore can be used by top charging.
* The process is flexible, enabling adaption to changing market conditions.

## The plasma generator

The plasma generators transform electric energy into thermal energy carried by a gas. An electric arc between two electrodes in the plasma generator provides sufficient energy to dissociate the supplied gas into ions, the plasma state.

The SKF plasma generator design, shown schematically in fig. 5, is tubular with magnetic coils and microalloyed copper electrodes at the opening and near the closed end. Electrode segments between the end electrodes enable the long arc to be built up gradually during startup.

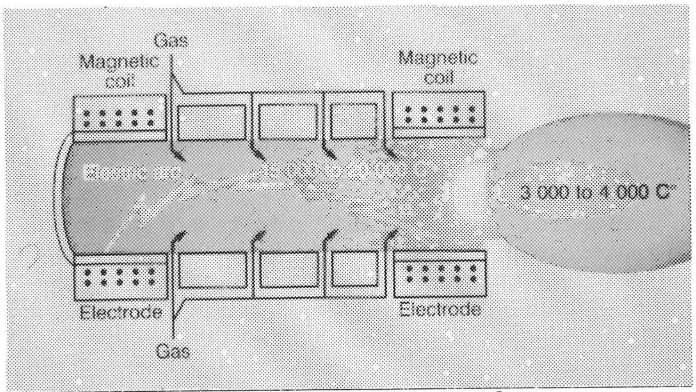

Fig. 5. The principle of the SKF plasma generator

Thyristor-controlled electrical power is supplied to the electrodes thereby forming the arc and producing direct current through the supplied gas. The electric arc is fully contained in the generator and only hot gas leaves the generator. The gas used is process offgas, a mixture of about 75 % CO and 20 % $H_2$.

Each generator provides 6-7 MW at 3,6 KV. The electrodes are replaced at intervals of 150-300 hours. Changing the generator takes about five minutes and is done while the other generators are operating.

## TECHNICAL DESCRIPTION

### Material flow, raw material handling

The material flowsheet is shown in fig. 6.

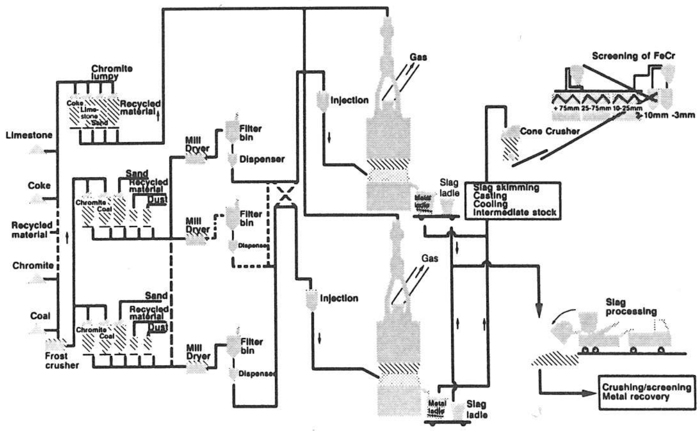

Fig. 6. Material flowsheet

The raw materials, which are stored under roof, are transported by front-end loaders and a covered conveyer belt into storage silos in the material preparation building. The materials are automatically discharged from the silos in quantities determined by the process control system.

Coke, limestone and lumpy ore, which are charged at the top of the furnaces, are loaded into lockhoppers above the shaft furnaces and are charged in batches on the basis of automatic radioactive level measurements. Charging is through double-sealed locks to prevent release of process gas, which is at an overpressure of about 20 kPa.

Chromite, sand and coal powder are taken automatically from the silos in proportions determined by the process control system to the combined mill/dryer (attrition mills, shown in fig. 7), where the materials are ground, dried and mixed.

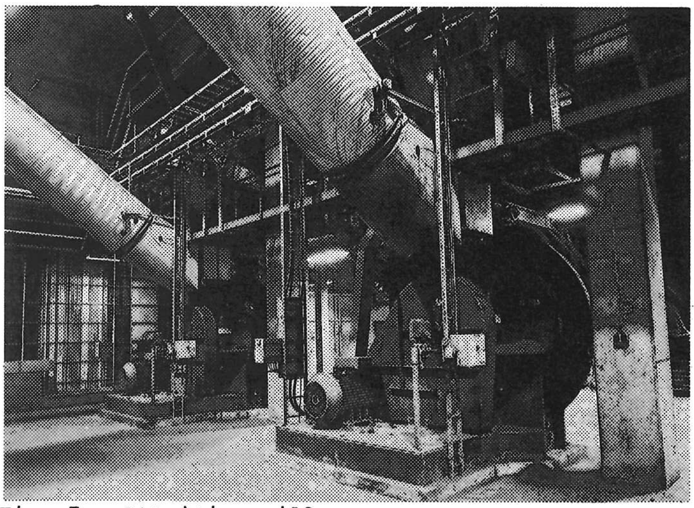

Fig. 7. Attrition mills

Particle sizes up to 25 mm can be fed to the mill, but so far only chromite concentrates, sand and coal powder have been used. After the attrition mill the solids are separated from the gas in a bag filter. The material is passed through a sieve and is then stored in a dispenser from which it is transferred pneumatically in 6 tonnes batches to the furnace building.

<u>The PLASMACHROME process</u>

The furnace building has two identical shaft furnaces, each provided with four 7-MW plasma generators, a total installed electric power of 56 MW. The shafts are water cooled with an inner refractory lining and are filled with lumpy coke, limestone and eventually lumpy ore.

When the shaft and the contained coke have been heated by means of the four plasma generators, the process is started by injecting the raw materials. Charging of the injection hoppers is done automatically by means of signals from radioactive level sensors.

Energy from the process is supplied by recycled process gas, which is heated to 4-5 $KWh/m^3$ (STP*) in the plasma generators. The plasma gas is introduced through water-cooled copper tuyeres along with the injected feed materials.

When the raw material mixes with the hot plasma gas it rapidly heats and starts to melt. Reduction of the metal oxides begins and the partially-reduced droplets hit the hot coke pieces forming the walls of the raceway where final reduction and slag formation occur. Coal powder in the raw material mix is carbonized to coke in the hot plasma gas, and the coke particles hit the coke wall of the raceway where they provide most of the reducing medium for the reduction. In practice, 50-70 % of the reducing medium is coal powder, with the remainder coming from the coke.

The upper part of the shaft functions as a filter for the gas leaving the furnace and as a heat exchanger for the materials charged to the top of the furnace. The temperature of the exit gas is 1000-1400 °C depending on the amount of top charging.

A very high degree of reduction and good energy utilization are achieved by having the reaction zone in the form of a cavity in the coke column. The reaction rates are very high, and the residence time of the material in the reaction zone is less than two minutes. In this way, accumulation of the raw material in the furnace is obtained. This provides for a high degree of reduction, a uniform product quality, and a low metal content in the slag.

<u>Tapping, casting, crushing</u>

The tapping technique is similar to normal blast furnace practice: drilling and oxygen lancing. A taphole gun is used to close the taphole. After tapping, the slag is removed from the metal surface in the ladle with the aid of a mechanical skimmer. Ten tonnes of ferrochrome are tapped every two hours and then cast into 2,5 tonne blocks. After stripping, the product is crushed and sieved according to the customer specifications.

<u>Process control system</u>

The plant can only be operated through the process-computer system. The system has a built in redundancy and battery backup in case of power interruptions. The plant has three control panels for supervision and one extra for configuration on line during operation. The whole process, both shafts and the material preparation plant, can be operated from only one of the mentioned control panels if necessary.

<u>Heat recovery</u>

The offgas cooler is similar to a boiler. It cools the gas to about 160 °C. The gas then

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* STP= standard temperature and pressure, i.e. 0°C (32°F) and 1 bar (14.5 sig).

enters a fabric bag filter which cleans the gas to less than 4 mg particulate matter/$m^3$ (STP). About half of the gas is recycled as plasma gas, and the rest is sold as a fuel gas to the local district heating company. The thermal energy in most of the cooling water is also sold to the local district heating company.

The dust from the bag filter is mixed with chrome ore fines and water and after about two weeks storage it can be recycled.

Dust from all other filters is recycled to the raw material silos for immediate consumption.

## PLANT DEVELOPMENT

During the first three years of operation several problems were encountered, particularly during the first two years. These problems and the solutions developed are discussed in reference (1). More recent developments to improve the auxiliary systems are discussed in the present paper.

### Raw material preparation

To improve the classification of the raw materials, both for top charging and injection, a Mogensen sizer was installed early in 1988. This resulted in better movement in the shafts, fewer interruptions, and a more accurate injection system due to lower contamination.

### Mill/drier

Wear in the attrition mills was severe from the beginning. It was foreseen so that three mills were provided, two in operation and one standby for repair. The attrition mills are a critical link in the pneumatic system that transports the ground feed mixture to the bag filter.

This autumn, extensive work started to extend the life of the mills and reduce costs. The pressure in the mill filter system is being optimized as well as the velocity of the raw material in the mill filter system. Improved spare parts are also being used. Mill life has been doubled, and additional improvements are expected.

### Injection system

Pneumatic transport lines: Abrasion was severe. However, tests showed that dense phase transport could be used to eliminate the problem. During the summer shutdown in 1988, the dispensers to transport material from material preparation to the furnace building were rebuilt to operate with a velocity of 10-15 m/s. This provided the improved life expected in the transport lines.

The lines from the final dispenser to the tuyeres were also modified. Tests showed that a life of more than 2.000 hours could be obtained by changing from 0,35 mm basalt tubes to 0,25 mm steel tubes using a velocity of 15-18 m/s.

## PRODUCTION AND METALLURGICAL EXPERIENCE

### Production

Since the first tapping in 1986 the following production history was obtained:

| | 1986 tonnes | 1987 tonnes | 1988 tonnes |
|---|---|---|---|
| Pig iron | 2.283 | 6.284 | 3.314 |
| Charge chrome | - | 6.785 | 31.383 |

The average production of the plant during December 1988 was 8,8 tonnes FeCr per hour, which is about 85 % of rated production.

The utilization of the total plant has today reached a level of 70-80 % (shaft 1: October 78,2 %, December 77,1 %). The objective is to have at least 80 % utilization by the end of 1989 and to average more than 90 % in 1990. This will be accomplished by improving the planned maintenance from one stop per week to a maximum of 8 hours every two weeks in combination with additional experience with planned parts replacement.

### Metallurgical experience

In reference (1), the results were presented for injection of chrome ore, sand and coal, and top charging of coke and limestone. During the spring of 1988 a short campaign was made with top charging of lumpy ore and quartzite to use the energy and reducing power of the shaft gas. The results were promising and it was decided to extend these trials in November. This trial started with lumpy iron ore (30-60 mm) and continued with lumpy chrome ore during January 1989.

This technique enables economic production of charge chrome from high Cr/Fe ratio chrome ore by adding lumpy iron ore. It is also possible to reduce the specific amount of coal and increase the coke consumption and ferrochromium output when market conditions warrant this approach.

One metallurgical advantage of the PLASMACHROME process over the submerged arc furnace process is the ability to choose slag composition. Figs. 8-10 show the $Cr_2O_3$ losses in the slag versus different basicity indexes.

Operations with slags with CaO content from 2-20 % have been studied. With 6-8 % CaO Cr-recovery is good as slag volume is low. The good slag fluidity also promotes transfer of suspended metal droplets in the slag to the metal phase.

This unique possibility to combine top charging of chromite and iron ore and the flexibility in slag selection provides the possitility to optimize production and economy.

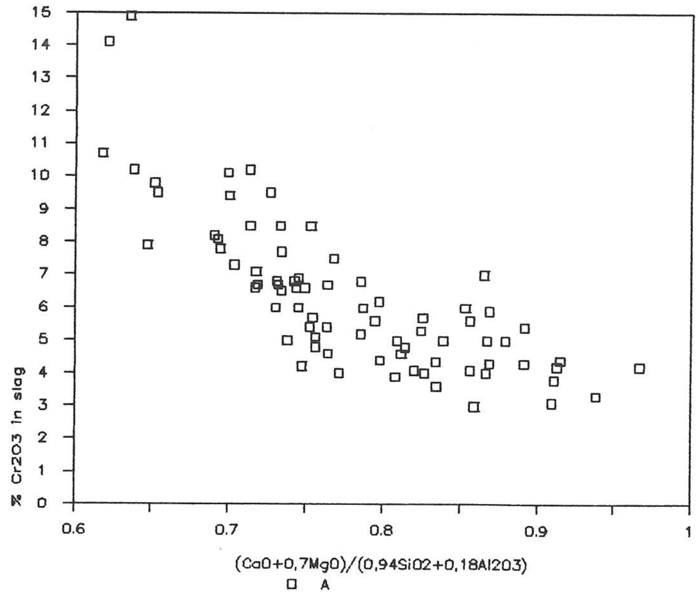


Fig. 8. $Cr_2O_3$ in slag = f (basicity).
SwedeChrome, Oct-Dec 1988, furnace no. 1

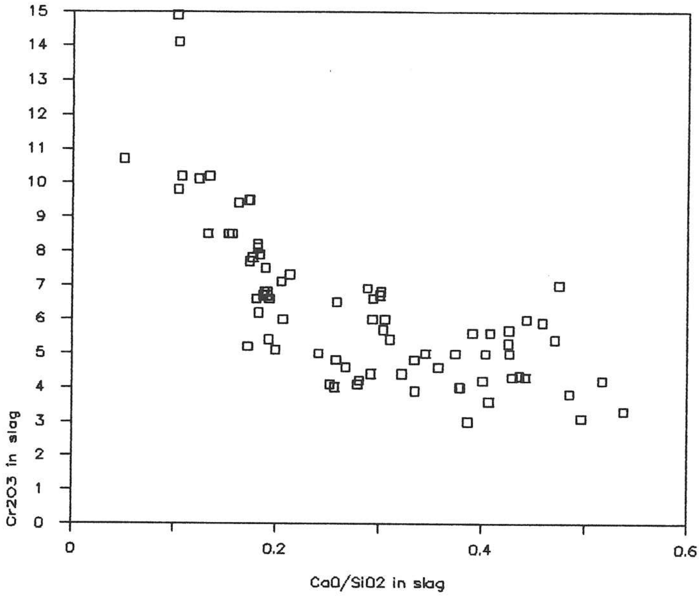


Fig. 9. $Cr_2O_3$ in slag = f ($CaO:SiO_2$)
SwedeChrome, Oct-Dec 1988, furnace no. 1

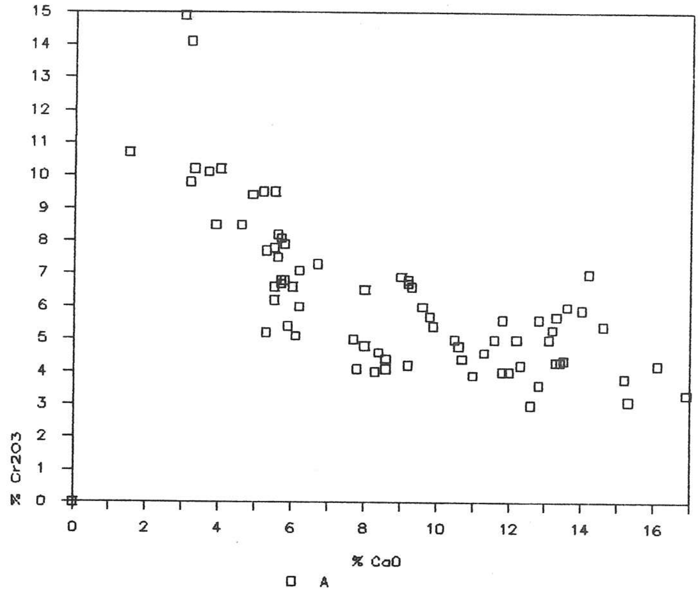


Fig. 10. $Cr_2O_3$ in slag = f (CaO)
SwedeChrome, Oct-Dec 1988, furnace no. 1

The results of the December campaign are summarized below.

Injected raw material:

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Coal: Moisture 10 %, Ash 9 %, C tot (dry ash-free) 89,9 %, H 4-5 %, S 0,8 %, FSI 1, HGI 65.
Size -25 mm.

Sand: $SiO_2$ 98,8 %.
Size -3 mm.

Chrome ore
A = South African origin
B = Turkish origin
C = Turkish origin

| | Amount used % | $Cr_2O_3$ % | FeO % | $SiO_2$ % | $Al_2O_3$ % | MgO % |
|---|---|---|---|---|---|---|
| A | 57,1 | 46,7 | 25,7 | 0,8 | 14,6 | 10,1 |
| B | 23,4 | 51,4 | 15,0 | 4,1 | 8,4 | 15,9 |
| C | 19,5 | 47,9 | 15,1 | 6,2 | 10,2 | 14,8 |

Top charged material:

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Coke: Moisture 3,0 % (stored under roof), Ash 8,8 %, C min 88 %, P 0,018 %, S 0,7 %, M 40 min 80.
Size 40-80 mm.

Limestone: $CaCO_3$ 96,8 %, $SiO_2$ 1,1 %, P 0,004 %.
Size 40-60 mm.

Iron ore: $Fe_3O_4$ 66,6 %, FeO 3,6 %, MnO 1,7 %.
Size 30-60 mm.

Recipe for production:

Raw material mix for injection

| | |
|---|---|
| Cr ore mixture | 1.000 kg |
| Sand | 120 kg |
| Coal | 115 kg |

Top charging, each batch

| | |
|---|---|
| Coke | 450 kg |
| Limestone | 100 kg |
| Iron ore | 250-300 kg |

The following products were obtained

Metal:

| | |
|---|---|
| Cr average | 52,5 % |
| Si " | 2,7 % |
| C " | 7,8 % |

Slag composition:

| | |
|---|---|
| $Cr_2O_3$ | 4- 6 % |
| FeO | 3 % |
| $SiO_2$ | 30-31 % |
| $Al_2O_3$ | 25-27 % |
| MgO | 24-26 % |
| CaO | 6- 8 % |

Slag to metal ratio: 0,8

These results correspond closely to the calculated values for the raw material mix used and Cr-recovery achieved. Fig. 11 shows the daily Cr--recovery for December 1988.
For December 1988, the Cr-recovery was 92,5 % based on FeCr cast in ingots and skulls in the ladles.

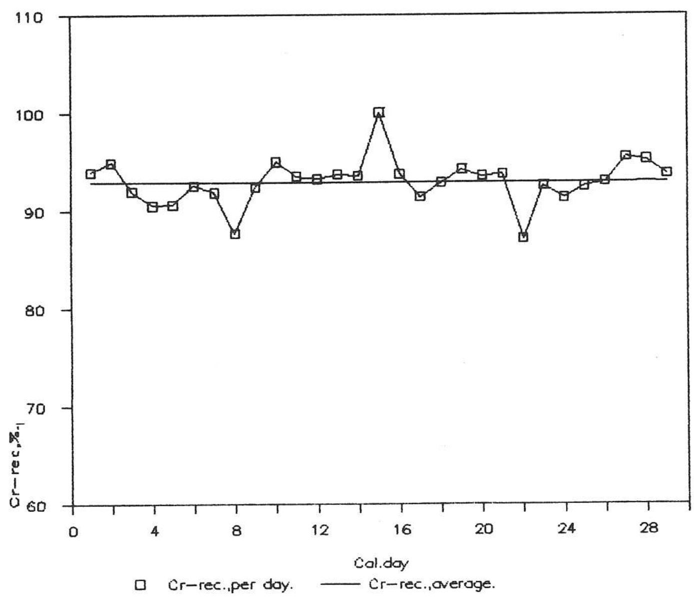


Fig. 11. Cr-recovery
SwedeChrome, Dec 1988, furnace no. 1

The total coke and coal consumption is also in the calculated region for the process even though operation today is based on a low consumption of coal to maximize production.

## ENERGY AND HEAT RECOVERY

In the submerged arc process the specific electric energy consumption is a measure of efficiency. For the PLASMACHROME process the situation is more complex and therefore the two processes should not be compared in the same way.

Heat recovery is an essential part of the PLASMACHROME process; SwedeChrome provides 13 % of the distributed energy to the district heating system in Malmö, see fig. 12. During December, the plant delivered 4.537 KWh per tonne of FeCr compared to the original calculated value of 4.900 kWh per tonne FeCr. The lower value for December was due to the high coke ratio used. This figure will also increase because at present, the gas is not always used in the boiler.

This high degree of heat recovery gives SwedeChrome very competitive energy costs.

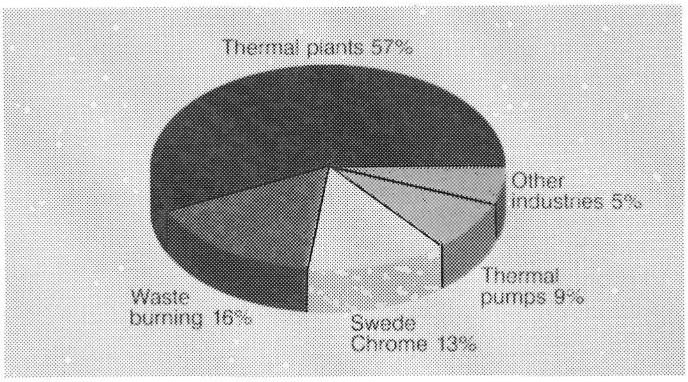


Fig. 12. Distribution of energy suppliers to the district heating system of Malmö.

## ENVIRONMENTAL EXPERIENCE

Because SwedeChrome is located only about 2.000 m from central Malmö, it is subject to very strict pollution regulations.

### Air

All the dust from raw material handling and smoke from the furnaces, tapping and casting are collected in bag filters with the emission limit 10 $mg/m^3$ air. The actual operating level so far has been 2-4 $mg/m^3$ air. For the process gas dust, which is very difficult to handle due to clogging effects and autoignition properties, emission levels are maintained at about 2 $mg/m^3$ air.

All dusts except the process gas dust are immediately recycled. Only 80 % of the process gas dust can be recycled to limit the amount of alkali and ZnO in the offgas. Further development work will have to be carried out to enable total recycle because the Swedish authorities expect to enforce this requirement.

Based on today's emission data it is estimated that total emission will be 0,16 kg per tonne of FeCr, compared with Swedish steel plants, which normally have 0,3-0,6 kg per ton steel.

Water

All rain water is collected and brought to a basin. Most of this water is used for slag cooling and evaporates, so that a very small amount of water is discharged from the plant. Daily and weekly samples are taken from the water discharged and the results are shown to the Environmental Control Authority to demonstrate that established emission limits are adhered to.

The cooling water is kept in a closed system including a heat exchanger to provide heat for the district heating system.

Slag

The slag will be stored on site until the authorities give permission to use it for construction purposes or landfilling. Laboratory tests have shown very good results with no leaching of elements. These tests will now be followed by a test road on site where leaching samples will be taken. When these tests are completed permission to distribute the slag for landfilling or construction purposes is expected.

## QUALITY

The product is accepted by our customers and so far only charge chrome has been produced with following specifications:

| | | | | | |
|---|---|---|---|---|---|
| Cr | 51 | - 55 % | | | |
| C | 7 | - 8 % | | | |
| Si | 2 | - 4 % | | | |
| P | 0,008 | - 0,018 % | weighted | average | 0,013 % |
| S | 0,018 | - 0,045 % | " | " | 0,029 % |

A campaign to produce FeCrHC with 60-65 % Cr will be run during 1989.

## COMPETITIVENESS

For a West European producer the following characteristics are essential to operate a competitive metallurgical process.

* Use of high grade chrome ore concentrates directly.
* Highest possible degree of energy recovery.
* High Cr yield.

In addition the following parameters are also important:

* Availability and CIF cost of chrome ore.
* Cost of electric energy.
* Distance to the market.

The SwedeChrome plant fulfills the first three characteristics and locating the plant at a large coastal harbor provides low freight costs for chrome ore coupled with relatively short distances to the major West European steel plants.

The freight cost disadvantage due to transport of ore instead of metal is in our case compensated by our ability to use the cooling water for district heating.

The price of electricity in Sweden is controlled by the Government, however, the high degree of heat recovery at SwedeChrome from burning the offgas provides low net cost.

Sweden has an embargo against trade with South Africa but the PLASMACHROME process has shown that we in a competitive way can use high ratio Cr/Fe ore and top charge lumpy iron ore and by this way produce normal charge chrome grade in case our customers demand it.

## SUMMARY

The first PLASMACHROME plant has been in operation for almost three years and with regular ferrochromium production for about one and a half years.

The process has proven to be a suitable and economic process when there is a use for the excess heat. The high degree of energy recovery compensates for the freight cost disadvantages due to the lack of chrome ore deposits in Sweden.

The SwedeChrome plant has demonstrated that very high standards of environmental protection in metallurgical processes can be obtained.

The extended trimming period for the plant and the work done to solve the startup problems have been an invaluable school for training SwedeChrome personnel. They are now very well prepared and skilled ferrochrome producers.

## ACKNOWLEDGMENT

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