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PROGRESS IN ELECTRIC PIG IRON SMELTING

by

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ABSTRACT

The electrical smelting process has undergone refinement and technical progress in the last few years. The original conception of electric smelting was to supply the thermal requirements of the process from electrical energy and the chemical requirements from carbon. The present trend, however, is to substitute carbon or other fuels for a portion of the thermal energy previously supplied entirely by electricity. The preheating and prereduction of the charge makes it possible to meet the demand for larger and larger reduction units since the power consumption per ton of pig iron may be drastically reduced by the thermal pretreatment.
INTRODUCTION

The electric pig iron process is one of the very few alternatives to the conventional blast furnace process in the production of liquid pig iron. Electric pig iron production is already established in fourteen different countries and this type of smelting plant has been ordered for three other countries. In this paper the author will deal with some of the reasons for this quite widespread adoption of the electric reduction partly in remote and industrially somewhat less developed areas.

The electric smelting process has undergone refinement and technical progress in the last 50 years. The original conception of electric smelting was to supply the thermal requirements of the process from electrical energy and the chemical requirements from carbon. The present trend, however, is to substitute carbon or other fuels for a portion of the thermal energy previously supplied entirely by electricity. The preheating and pre-reduction of the charge makes it possible to meet the demand for larger and larger reduction units since the power consumption per ton of pig iron may be drastically reduced by the thermal pretreatment.

The results of pilot plant tests in preheating and pre-reduction and electric smelting of the hot charge will be discussed in this paper.

2. THE BLAST FURNACE PROCESS

Before discussing the electric process it is useful to have as a yardstick for comparison the blast furnace process which has dominated the pig iron field until recently. The average capacity of the 266 blast furnaces in operation in USA was per January 1st, 1959, 960 metric tons per day. In Western Germany 127 blast furnaces were in operation in 1961 with an average production of 550 tons per day. Approximately 1000 tons per day appears to be a typical production capacity for newer blast furnaces. There are, however, very few big blast furnaces with capacity of up to 2000 tons. The three integrated iron and steel works recently erected in India have capacities of approximately 1 million tons per year each. These works are equipped with blast furnaces designed for about 1000 metric tons production per day.

The performance of the blast furnace has been improved over the last years, mainly by installation of sinter plants in the large steel countries. With self-fluxing sinter the coke consumption has been reduced from about 1000 kgs per ton of pig iron to 600 - 800 kgs. The important reduction in the consumption of the rather expensive blast furnace coke has been accompanied by the use of about 200 kgs of coke breeze in the sinter plant.

Blast furnace coke - or coal of the type suitable for blast furnace coke consumption - is not available in many countries and areas. Transport or even import of coke or coal from abroad will establish higher costs and dependence of supply from overseas.
The electric pig iron furnace is not depending on the same high quality and strength of coke. Coke of small size or coal, even lignite, may be used. This is the main reason for the adoption of electric smelting in so many countries.

3. DESIGN FEATURES OF ELECTRIC FURNACES

In an electric pig iron furnace the charge is distributed to the furnace bins by transport with skip-hoist and teipier bucket. From the bins above the electric furnace the charge flows by gravity through the chutes to charge openings in the roof, and automatically keeps the electric furnace filled with charge.

All the furnaces which have been built by Elektrochemisk during the last twenty years are equipped with circular furnace pots and three Soderberg electrodes arranged in delta formation. Below each electrode considerable quantities of coke float in the slag, the so-called coke bed, which constitutes an important element in the smelting process. The electrode current passes from the electrodes through the preheated part of the charge, which is conductive to electricity, and then through the coke bed and the slag.

The main reaction as well as the fusion of the charge takes place in the vicinity of the electrode tips where the liberation of electric energy is most extensive. As the height of the charge around the smelting zone is relatively low and the quantity of gas is considerably smaller than in blast furnaces, because no air is blown in, relatively little preheating and CO reduction take place in the electric furnace, except with a specially prepared porous charge.

As for blast furnaces, iron and slag are tapped from a tap hole near the furnace hearth. Reaction gases are sucked off from openings in the furnace roof, scrubbed with water and distributed to gas holders and the gas distribution system.

The pioneer furnace for closed operation with collection of unburnt CO gas was the Tysland-Hole furnace operated by Christiania Spigerverk in the outskirts of Oslo. This furnace was in operation from 1923 to 1947 under inspiring leadership of Mr. Gunnar Schjelderup. Table 1 presents a list of electric furnaces of Tysland-Hole and ELKEM type in operation and presently under construction. In this table are not included furnaces for 100 to 150 MW built by other furnace manufacturers or the iron and steel producing companies themselves. Excluded are also a number of smaller furnaces built after the war by the Japanese steel works.

4. ELECTRIC PIG IRON SMELTING TO-DAY

Only a short description will be given here of the latest electric pig iron furnace installations.

Christiania Spigerverk, who pioneered in electric pig iron smelting by development of the first closed top unit, acquired a smelting plant at Bremanger in Western Norway in 1952. Here a 33 MVA electric furnace and a new sintering plant was installed in 1959. This furnace is in production on a special grade titanium and vanadium bearing pig iron.
An important and courageous step was taken by A/S Norsk Jernverk just after the war, in their decision to install three electric pig iron furnaces, later supplemented with a fourth furnace unit, each with 33 MVA transformers.

This state-owned plant in Mo i Rana, just below the Polar Circle, has been in continuous operation since 1955. The yearly production is now about 360,000 metric tons, partly for the company's own steel works and partly for sale.

Typical data for the present operations are as follows:

<table>
<thead>
<tr>
<th></th>
<th>20,000 - 28,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furnace load</td>
<td></td>
</tr>
<tr>
<td>Power consumption for pig iron with 1% Si</td>
<td>abt. 2000 kWh per metric ton</td>
</tr>
<tr>
<td>Coke consumption</td>
<td>350 - 400 kgs</td>
</tr>
<tr>
<td>(85% fixed C) - dry basis</td>
<td></td>
</tr>
<tr>
<td>Electrode paste</td>
<td>5 - 10 kgs</td>
</tr>
<tr>
<td>Down-time</td>
<td>2 - 5%</td>
</tr>
<tr>
<td>Labour man-hours per ton</td>
<td>1.0 - 1.5</td>
</tr>
</tbody>
</table>

Presently the plant is being expanded with two 40 MW furnace units scheduled for completion towards the end of 1963. It is expected that the total annual capacity of the six furnaces will then reach 700 - 750,000 tons.

At Matanzas in Venezuela the large integrated iron and steel plant planned and built by Innocenti, Milan, was started up in 1961. Here eight 33 MVA ELKEM units have been put into operation, and one is expected to be ready for operation shortly. This state-owned enterprise is founded on the famous Cerro Bolivar "Iron Mountain" said to be the world's richest iron ore body so far discovered.

Other recent additions to the furnace family are two 18 MVA furnaces for Israel Steel Mills, and a 13.2 MVA furnace designed for the Consolidated Mining and Smelting Company of Canada Ltd., in Kimberley, British Columbia.

Early 1962 an 18 MVA ELKEM furnace for the smelting of sintered beach sand concentrate was started up by Nisso Steel Mfg. Co. Ltd., Hachinohe, Japan.

5. PREPARATION OF RAW MATERIALS

As in the blast furnace operation progress has been made in raw materials preparation for electric pig iron smelting. Also for electric furnaces smelting the lump size of the charge components and elimination of fines and dust in the charge are important for the furnace performance. Careful control of fines by screening is now standard practice with most larger electrothermic plants.

Systematic charge preparation has improved charge porosity and gas distribution. This provides a wider reaction and smelting zone in the electric furnace as well as smoother descent of the charge. Self-fluxing sinter eliminates calcination of raw limestone and dolomite by electric power. Apparently the self-fluxing sinter has increased chemical reactivity which is reflected in higher
CO₂ content in the furnace gas. Also the self-fluxing sinter is supposed to lower the formation temperature of the slag in the furnace, whereby reduced temperature in the reaction zone has been established.

b. CHEMISTRY OF PIG IRON SMELTING

1) \[ 3 \text{Fe}_2\text{O}_3 + \text{CO} \rightarrow 2 \text{Fe}_3\text{O}_4 + \text{CO}_2 \]
2) \[ \text{Fe}_3\text{O}_4 + \text{CO} \rightarrow 3 \text{FeO} + \text{CO}_2 \]
3) \[ \text{FeO} + \text{CO} \rightarrow \text{Fe} + \text{CO}_2 \]
4) \[ \text{CO}_2 + \text{C} \rightarrow 2 \text{CO} \]

Hematite: \[ \text{Fe}_2\text{O}_3 = \text{Oxidation degree} \quad 100 \% \]
Magnetite: \[ \text{Fe}_3\text{O}_4 = " " \quad 88.8 \% \]
Wystite: \[ \text{FeO} = " " \quad 66.7 \% \]
Metallic iron: \[ \text{Fe} = " " \quad 0 \% \]

Knowledge of the chemical reactions which take place during the production of pig iron ore is required in order to understand properly the prevailing technical and economical conditions. The equations 1 - 2 represent the well known step by step reduction of iron ore to metallic iron. Iron ore, in the form of red hematite, has the composition \( \text{Fe}_2\text{O}_3 \) and an oxidation degree of 100 %. In this type of ore, iron is at its highest oxidation stage. A lower oxidation stage is \( \text{Fe}_3\text{O}_4 \), which occurs as the black and dense magnetite ore with a oxidation degree of 88.8 %. The formula \( \text{FeO} \) corresponds to a degree of oxidation of 66.7 %. Wystite has a composition close to \( \text{FeO} \). Finally metallic iron has a degree of oxidation of 0 %.

In the reduction of hematite with solid carbon in a pig iron furnace, the ore will pass through the various oxidation stages. According to the first 3 equations the ore reduction may be considered as a primary reaction between solid iron ore and \( \text{CO} \), with formation of \( \text{CO}_2 \). Part of this \( \text{CO}_2 \), however, will react with solid carbon resulting in regeneration of \( \text{CO} \). In the pig iron processes the equilibrium and velocity of the reaction between carbon and \( \text{CO}_2 \) is decisive for the gas composition and carbon consumption. At 1000 °C and above, the reaction 4 is completely displaced to the right in formation of \( \text{CO} \), and the rate of reaction increases rapidly. This means that in pig iron furnaces close to 100 °C \( \text{CO} \) is formed in the zones of the charge where the temperature is above 1000 °C. The reduction of the iron oxide gives an increasing equilibrium concentration of \( \text{CO}_2 \) in the gas as the oxidation degree increases. This means that the equilibrium for formation of high content of \( \text{CO}_2 \) in the gas is much more favourable at the beginning of the reduction than towards the final stage. To simplify the matter the chemistry may be considered as follows:

Production of liquid pig iron from ore comprises endothermal chemical reaction and heating of the reaction products to high temperature. The energy requirement is covered, in the electric furnace, partly by utilization of the heat from carbon oxidation, and partly by electric power. To the extent that \( \text{CO}_2 \) is formed in the charge by reaction between oxygen in
the charge by reaction between oxygen in the ore and carbon; in the case the carbon consumption is only 50%, although the heat liberation is considerably higher. The formation of CO takes place in the temperature range 800 to 950°C. The reduction rate of the charge in this temperature range in the electric furnace is so slow that a considerable amount of charge that is to be reduced has to be formed as CO formation or sintering.

8. SHAFT PREHEATING

A simple way to improve the performance is to preheat the complete charge in shafts installed directly above the electric furnace. In Elektrochemisk's Research Station at their electric smelter at Fisker Værk near Kristiansand in South Norway, a number of pilot plant shafts and a commercial-size prototype shaft have been built. A pilot shaft for a capacity of 500 to 1000 tons of charge per hour is erected directly above an electric furnace. Here the complete charge is heated counter-currently in a stream of hot combustion gases. Fuel oil or CO gas from the electric furnace is burnt with a controlled quantity of air and the hot gases are passed through a bed of charge in the shaft.

A considerable number of tests has been made with different iron ore and sinter charges. Reduced power consumption and increased production are obtained not only due to the sensible heat in the charge but also due to more indirect reduction (ex thermal formation of CO by gas reduction), in the electric furnace.
The main purpose of the pre-treatment in blast furnaces is to preheat the charge. The preheating is accompanied by a small amount of pre-reduction when using coke pellets. By shaft preheating a considerable CO₂ formation in the electric furnace occurs. This is due to the fact that the retention time of the charge in the electric furnace in the important temperature range 800 - 950°C is increased. Hereby a reduced consumption of carbon as well as power is accomplished.

The combination of preheating shaft and electric furnace in some respects makes the electric smelting process adopt some of the same features as the blast furnace process.

The charge is first heated to reaction temperature in a shaft, then kept in the important temperature range for indirect reduction in contact with CO at 800 - 950°C and finally smelted and iron carburized. In the blast furnace the CO₂ in the top-gas is used for preheating the blast. In the improved electric smelting process the CO₂-gas covers the requirements for preheating of the charge, thereby improving the over-all heat balance.

9. ROTARY KILN

A mixture of iron ore, limestone and coke (or raw coal) is heated to about 1000°C in rotary kiln, whereby reactions between iron oxides and carbon is started, without fusion of the charge. The kiln product is transferred hot to the electric furnace in insulated containers.

The pre-reduction kiln is of the same type as used in other industries, for instance for burning of Portland cement clinker. These kilns are mechanically strong and have a long life. By placing thermocouples through the kiln lining the temperature may be accurately controlled, so as to make sure that the working temperature is below the softening point of the charge. Thereby the cumbersome formation of rings is avoided. CO₂ gas produced from reaction between iron oxides and carbon in the charge is burnt above the charge bed in the kiln by air supplied in controlled quantities through ports in the kiln shell. This supplies heat for the iron ore reduction.

Raw coal is a preferred reducing agent for kiln pre-reduction. By feeding raw coal through special scoop feeders directly through the kiln shell, an instantaneous carbonization of coal takes place due to the contact between the coal and the hot charge in the kiln. Hereby ring formation on the kiln lining is avoided even with strongly baking coals. This type of
coal charging sideways into the kiln liberates volatiles from the coal which burns with oxygen in the kiln and supplies additional heat of combustion for the prereduction and preheating of the charge. Many types of raw coal produce char of high chemical reactivity, advantageous for high rate of reduction in the kiln.

By combustion of all CO gas formed in the kiln and electric furnace as well as volatiles from the coal, 50% or more of the oxygen in the ore may be removed by pre-reduction in the kiln. Preheating and pre-reduction decreases power consumption drastically with corresponding increase in the iron production. In a Peruvian pilot plant test with high-grade ore from Algeria and Labrador and sintered magnetite pellets, power consumption figures in the range of 750 - 1300 kWh have been obtained. With low-grade silicious ores, the range 1500 - 1800 kWh is typical.

For industrial use of the combination rotary kiln-electric furnace, the kiln would have to be placed on unreasonably high foundations if the hot charge should be transferred directly to the electric furnace charge openings. The practical arrangement on a large scale, therefore, is to place the rotary kilns on normal foundations at ground level, discharge the hot pre-reduced material into a surge bin and transport in insulated containers to the electric furnace feed bins.

10. NEW INDUSTRIAL INSTALLATIONS

Preheating in rotary kiln with transfer of hot feed has already been in operation since 1958 in four 13,5 MVA ferro-nickel furnaces belonging to S.A. Le Nickel at their New Caledonia Plant. A description of the plant and operation in New Caledonia has been published in Journal of Metals, March 1960.

The smelting technique adopted in this large plant, which now consists of 8 electric furnace units, originates from three smelting test campaigns at Elektrochemisk's Research Station.

A plant with one 4,8 MVA ferro-nickel furnace smelting preheated charge from a rotary kiln has been started up recently in Brazil by Morro do Nickel S.A.

In the pig iron field Rudnice 1 Zeleznara SKOPJE in Yugoslavia is installing 3 34,5 MVA furnaces, each with a rotary kiln. Further expansion is planned by the authorities. Here a low-grade chamomile ore, limestone and raw lignite coal will be heated in F. L. Smith rotary kilns with scoops for feeding the lignite directly through the kiln shell. Despite the very low grade of the ore, the CO gas produced in the kilns and electric furnace and hydro-carbons and other volatiles from the lignite coal will cover the heat requirements for drying and heating of the charge in the kilns as well as partial reduction of ore and calcination of limestone.

Sinai Manganese Corporation have recently ordered a rotary kiln and 13.2 MVA electric furnace for extraction of pig iron and ferromanganese from low-grade iron manganese ore in Egypt.
In Portugal a 15.2 MVA pig iron furnace installed five years ago for conventional pig iron smelting is now being rebuilt for shaft preheating of the charge. Presumably this plant will be in operation within the end of 1962.

In addition to these new ELKEM installations, furnace No. 8 in the Venezuelan pig iron plant is presently being rebuilt in cooperation with Stratma Ltd. and Koppers Inc. for the use of the Strategic-Udy technique in pre-reduction and smelting.

11. THE ECONOMY OF ELECTRIC PIG IRON SMELTING

A complete and detailed study of the costs involved in pig iron production is a complicated matter. However, sufficiently accurate data for comparison between different processes are achieved by considering the main cost items.

As in the blast furnace smelting the cost of the ore is very often the largest single cost item. Also for electric smelting concentration of the ore by mechanical ore dressing is preferable to smelting low-grade ore. Sintering of the fines is often cases is preferred for pre-reduction and smelting of fines. Generally, the ore cost is the same for blast furnace and electric pig iron smelting.

Electric pig iron smelting the field of ores that are now wider. Particularly the use of titaniferrous iron sand concentrates in the coastal areas of many countries of the world. So far electric smelting of iron sand concentrates has only been developed in Japan. However, with reduced power consumption by pre-reduction the utilization of beach sand in the electric furnace industry is likely to expand considerably in the coming years.

Another important cost factor is the cost of carbon for reduction and supply of thermal energy for the process. Here the blast furnace depends on hard coke with high resistance to abrasion and lump size between 30 and 100 mm.

Traditionally in Europe electric pig iron smelting has mainly been based on gas coke and gas coke breeze. Gas coke has lower abrasion strength and higher reactivity than metallurgical coke and is actually a somewhat better reducing agent for the electric furnaces. By introduction of preheating and pre-reduction, raw coal even high volatile coal and lignites, may be used as reducing agents. Raw coal is carbonized by successive heating in the preheating or pre-reduction step. Hydrocarbons and hydrogen are developed and participate in the pre-reduction, and supply heat by combustion with air for the preheating and pre-reduction process.

There is in many areas of the world a very substantial price difference between raw coal and blast furnace coke. This makes raw coal favourable as reducing agent for pig iron production. The lower consumption of carbon and the use of raw coal cut down the carbon costs considerably for electric, as compared to blast furnace smelting.

For electric pig iron, the cost of electricity has to be considered. Before pre-reduction was introduced, the electric process was only economical.
for areas with supply of cheap power. With prereduction of the iron ore, the
power consumption can be brought down to the same order as for electric
steel smelting. Electric power produced in thermal power stations comes
into the picture now for electric smelting. In areas with cheap fuel in the form
of coal, oil or natural gas, power can be produced at low or medium cost in
modern power stations. The diagram of Fig. 9 shows the cost of thermal
power as a function of the fuel price. The cost of installation is estimated to
140 US dollars per kWh and the fuel consumption 2500 kcal per kWh. The
fixed charges are 2.7 US mills per kWh while the fuel expenses are proportional
to the price of fuel. Considering for instance the price of large tonnage of
heavy fuel oil in ports around the world as about 13 - 14 dollars, the corre-
spanding power price is about 7 US mills. With this power price the electric
pig iron process is competitive in many areas of the world.

12. FUTURE TRENDS

Electric pig iron smelting is a special iron ore reduction process
used and under installation in 17 different countries. The electric furnaces are
used not only in small iron works, but also in integrated iron and steel works
of intermediate size with 300,000 - 700,000 tons annual capacity. The obvious
fields for electric smelting of iron ore are areas in the world where coking
coal of suitable quality for production of metallurgical quality coke is not
available, while electric power such as water-power or cheap thermal power
is at disposal.

By reduction of the power consumption and increase in furnace
unit capacity, the pig iron process may gradually achieve a more important
part of the new pig iron production capacity, perhaps mainly by expansion to
countries and areas which have not so far developed steel industry. The great
tolerance of the electric furnace with regard to quality of iron ores and
reducing agents will justify electric smelting for new pig iron plants. Each
project has to be examined very carefully with testing of the raw materials
concerned to find the cheapest solution with regard to installation and operating
costs.
<table>
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<th>Country</th>
<th>Number of furnaces in operation</th>
<th>MW</th>
<th>Number of furnaces under construction</th>
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</tr>
</tbody>
</table>

| Total      | 47                              | 600.0| 11                                   | 236.0| 58                      | 836.0    |

- Table 1.

September/1963
Fig. 1. From Fron Premanger Smelteverk, Ovelgen, Norway.
Fig. 3. From Corporación Venezolana de Guayana, Matanzas.
Fig. 4. Pilot Preheating Shaft, Elektrokemisk A/S, Fiskaa Verk, Norway.
Fig. 5. Pilot Furnace for Shaft-preheated Charge.
Fig. 6. Pelletizing Plant at Fiskaa Verk

Fig. 7. Pilot Rotary Kiln, Fiskaa Verk
Fig. 8. From ferronickel plant in New Caledonia.
FIGURE 9

Mills per KWh.

Coal price US $ per metr. ton.

Oil price US $ per metr. ton.

Fixed charges.