A SURVEY OF VARIOUS ELECTRIC SMELTING PROCESSES AND THEIR APPLICATION TO INDIA—PART I

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NATURE has endowed India with an unusually large share of the mineral resources of the world. Iron ore, bauxite and manganese ore are available in practically unlimited quantities. Chrome, tungsten, vanadium, ilmenite and other ores are likewise plentiful, and there are abundant deposits of limestone.

So far, only a limited advantage has been taken of this wealth, but the growing industrialisation of India will undoubtedly call for an increased utilization of its mineral resources.

In this future development, the electric furnace is bound to play an important part, as the majority of ores and minerals are processed exclusively by electro-thermic or electrochemical means. The very favourable possibilities for inexpensive generation of hydroelectric power give India an advantageous position in the field.

Iron and manganese ore may, of course, be smelted in the common blast furnace, but the introduction of the electric smelting process would preserve the Indian coal and charcoal resources. In view of the scarcity of domestic coal supplies in many localities—at least coking coal—this process would be of great national importance. From an economical point of view, the question of blast furnace *versus* electric furnace depends mainly on the relative cost of coal and electric energy.

The Electric Furnace

The electric reduction process is usually carried out in a low-shaft furnace of simple design, the heat required to maintain the smelting temperature being mainly generated by the resistance of the charge to the electric current which flows between the electrodes.

The principle of a typical electric smelting furnace, as used for the production of ferrosilicon, for instance, is shown in Fig. 1. The voltage of the incoming high tension current is stepped down to operating voltage in one or more furnace transformers (*t*), located in the near vicinity of the furnace. From the transformer, the current is carried to the electrode (*e*) through interleaved heavy copper bus bars, copper tubes and cables. Contact with the electrode is ensured by means of water-cooled clamps.

The electrodes were previously of the prebaked type, which frequently had to be renewed at the expense of labour and breaks in production, but in the early twentieth century the Søderberg continuous self-baking electrode came into general use. This electrode, which is illustrated by Fig. 1, is prepared at site and baked by waste furnace heat. In principle it

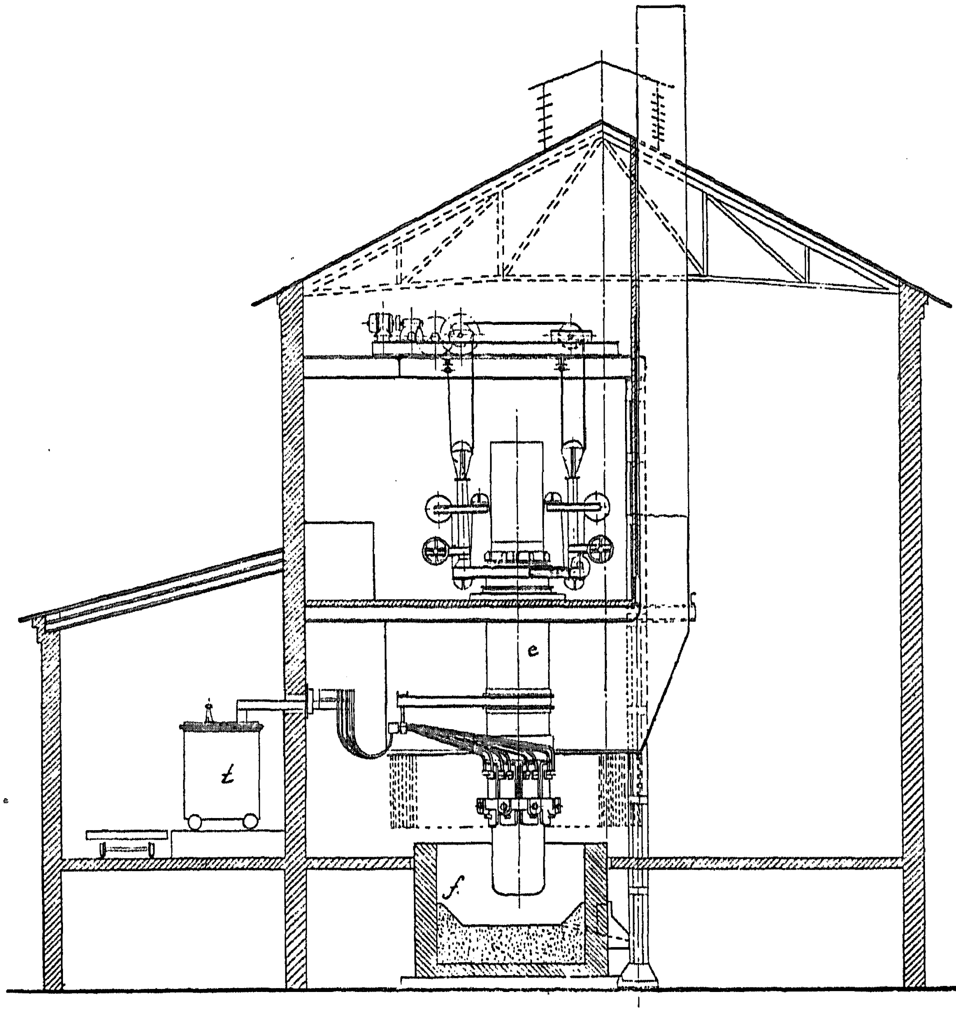

FIG. 1. Section through smelting plant.

consists of a steel sheet casing, filled with electrode paste. As the electrode is consumed in the smelting process the top end is extended by welding on new sections of electrode casing and re-filling paste. This electrode is now widely used in the smelting industry, and has been described in detail in various technical literature.

The furnace body (*f*) consists of a steel shell, lined internally with heat-resisting brick and rammed carbon/tar paste.

The molten product is tapped through one or more tap-holes into tapping pans or ladles, and is crushed after cooling.

The electric smelting furnace may be equipped with up to three electrodes (in special cases even six), but it is now almost unanimously accepted that the three-phase furnace is to be preferred for high loads, *i.e.*, from about 4,000 kW and upwards. In smaller furnaces it may be desired to use one electrode only, for greater simplicity of design and operation. Two such single-phase furnaces may be coupled in Scott to give a uniform load on a three-phase power distribution line.

Owing to the rectangular shape of the pre-baked electrodes used, these were originally placed in line, but the more recent practice is to arrange the electrodes in an equilateral triangle in order to obtain electrical symmetry.

Most electric smelting furnaces are of the open type, where the gases burn on the surface of the charge, and are subsequently sucked off through stacks, or in some cases put through a dust removal plant. The open furnace is simple in operation, but the CO gas evolved is, of course, wasted.

Ferrosilicon

Ferrosilicon is an electro-thermic product which is usually smelted in an open furnace, owing to the high temperature required for ore reduction.

The lower grades of FeSi (containing less than 20 per cent. Si) may be produced in blast furnaces from silica-rich iron ores, but all other grades are smelted exclusively in electric furnaces. The process is simple, and consists of the reduction of quartz by coke, anthracite or charcoal. Scrap-iron is used when necessary, to obtain the desired Si-content.

The quartz should be as pure as possible (96-99 per cent. SiO_2) and free from impurities which may cause slag formation or appear in too large quantities in the tapped product. This is, of course, of primary importance when producing silicon metal. There are no special requirements as to the quality of the coke, and even coke breeze is employed to a very large extent.

However, when producing alloys containing 90 per cent. or more silicon, the coke must obviously have a low enough iron content to ensure that the desired metal quality is obtained. In the production of silicon metal it is necessary to use charcoal or petrol coke, in order to limit the iron and alumina content of the charge to a minimum.

Owing to the high melting point of the raw materials used, and in the case of high grade FeSi and also alloy, the primary object in the ferrosilicon furnaces is to obtain the greatest possible concentration of heat in the smelting zone. This may be accomplished by operating with a high current density in the electrodes.

Furnaces for the production of 45-50 per cent. and 75-80 per cent. ferrosilicon are generally built in capacities up to 8-9,000 kVA, whereas for silicon metal, 5,000 kVA may be considered a large unit.

The latest improvement in electric furnace design, the rotating hearth furnace, has found its first application in the production of ferrosilicon. According to this design the furnace body is placed on a turntable which rotates or oscillates at a low speed. The electrodes, suspended vertically at three points of an equilateral triangle, remain stationary. The smelting zone will thus move sideways in relation to the electrodes.

The advantages claimed for this furnace type are that the smelting conditions are improved, as the charge is kept porous by the motion, and the gases may escape freely. "Bridge" formations and explosive gas eruptions, which may sometimes be experienced in a stationary furnace, are reduced. The power and raw material consumption is also stated to be decreased, and wear on hearth and lining is reduced. Furthermore, the furnace pot may easily be cleaned out during shut-downs, or when a change-over from one product to another is contemplated.[1]

Below are tabulated some operational figures for various qualities of ferrosilicon. The better figures refer to modern installations with Søderberg electrodes.

Ferrosilicon Operating Data (per ton tapped ferrosilicon)

FeSi grade	45%	75%	90%	Si metal
Power consumption, kWh ..	5000–6000	9000–11000	12000–15000	18000–22000
Electrodes, kgs ..	30–40	60–70	100–120	150–180
Coke, kgs ..	550–650	1100–1200	1400–1600	..
Charcoal, kgs ..	..	..	..	2000–2200
Quartz, kgs ..	900–1100	1800–2000	2300–2600	3000–4000
Scrap iron, kgs ..	500–600	200–250	10–30	..
Man hours (furnace operation and tapping only)	10–12	15–20	23–30	40–50
Silicon yield %	90	85	80	60–65

1. Ellefsen, T., "The ELKEM Rotating Hearth Furnace for Electrothermic Process," The Electrochemical Society, 1946.

It should be noted that the figures are based on normal operating conditions, and that they are subject to considerable variations according to quality of raw materials, efficiency of labour and operation, etc.

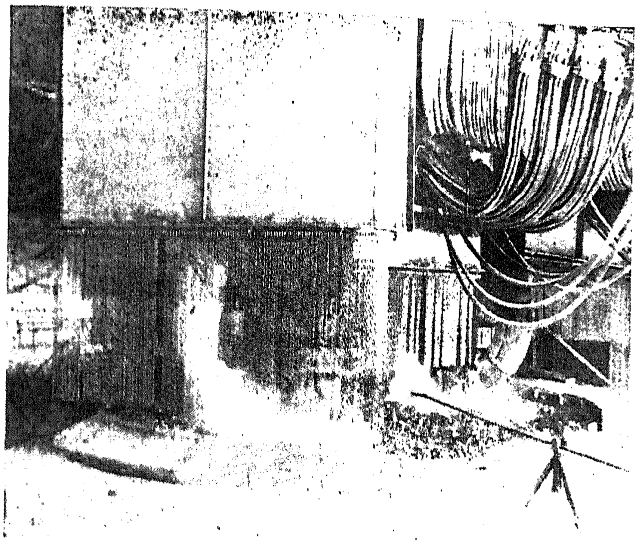

FIG. 2. 15,000 kW carbide furnace.

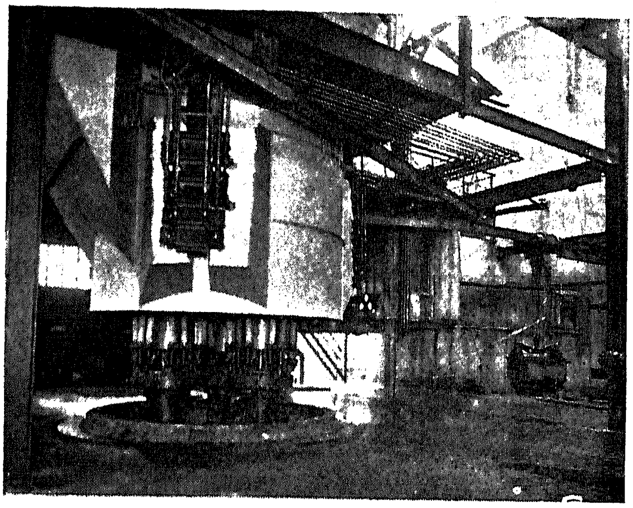

FIG. 3. 10,000 kVA ferro alloy furnace.

CALCIUM CARBIDE

Calcium carbide is prepared exclusively in the electric furnace, lime being reduced by a carbonaceous material under high temperature (2,000-2,200° C.), according to the equation:

$$CaO + 3\ C = CaC_2 + CO.$$

Commercial grade carbide which according to international specification should yield 280-300 litres of acetylene, contains some 80-82 per cent. CaC_2.

The lime should be of the best quality available (96-98 per cent. CaO), and particular attention must be paid to its physical characteristics. The most common reducing agents employed are coke and anthracite. In connection with high grade lime, bituminous coal may also be used in open furnaces. Charcoal is normally too expensive, but is otherwise an excellent reducing agent, which will produce a pure carbide. Charcoal of the heavy tropical type is especially suitable. It is most essential that the raw materials are correctly sized, and too high a moisture content in the reduction materials should be avoided, as otherwise the lime will be slaked after the charge has been mixed.

Carbide is produced in electric furnaces constructed on the same principle as those employed for ferrosilicon, but much larger units have been built in the endeavour to obtain increased production and reduced production costs. The transformer capacities may vary from about 3,000 kVA to as much as 40,000 kVA. The greater number of carbide furnaces in the world are still of the open type, but, semi-closed and closed furnaces are also much used. The semi-closed type has found particular application in many of the modern carbide works in Germany.

These furnaces are usually rectangular, with three oblong electrodes connected in line. The electrodes were previously made up of four to six blocks of pre-baked carbon sections, but even before the war they had been to a great extent exchanged for oblong Søderberg electrodes. "Bridges" of water-cooled pipes covered with a heat-resisting material are arranged between the electrodes, and also between the end electrodes and the furnace wall. The purpose of the bridges is to improve working conditions for the furnace operators, and to collect some of the furnace gases which may then be sucked off through a stack, or passed through a gas-cleaning plant.

The gas may contain as much as 55-65 per cent. CO, and some 35-40 per cent of the amount evolved may be collected.

Entirely closed carbide furnaces, equipped with electrodes in triangle, have been in operation in the United States for a number of years. The furnace cover is usually constructed of water-cooled, alloy steel sections. Around each electrode is a hopper, fed with raw material mixture from overhead bins. According to reports, this type of furnace operates very satisfactorily, but it is dependent on a mixture feed containing little or no fines, as the small particles would prevent the passage of gases, and thus cause "blowings".

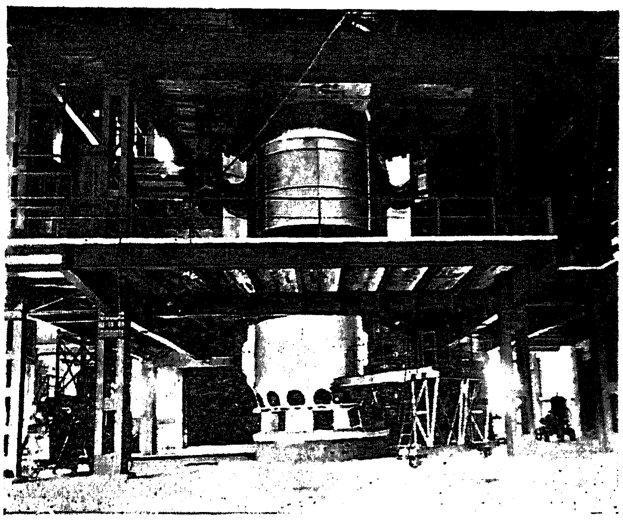

FIG. 4. 6,000 kW rotating hearth furnace.

Closed carbide furnaces as designed by Elektrokemisk A/S, Oslo, Norway, are now also being introduced on the principle of the Tysland-Hole furnace (see next chapter). According to this design the charge is fed to the furnace through water-cooled shafts, located at a distance from the electrodes, the advantage being that the evolved gases are permitted to escape more freely, and operation is far less dependent on the physical qualities of the raw materials.

Closed furnaces are generally more economical in operation than open furnaces, and the working conditions for the furnace crew are greatly improved. The furnace gas is, furthermore, a valuable by-product, and may be used for heating, chemical synthesis or other purposes.

Below is given a table of operating data for carbide furnaces, the better figures relating to large furnaces. Operating conditions and quality of raw materials are assumed to be normal.

Calcium Carbide Operating Data

	(Per ton 300 ltr. carbide)
Lime (96–98% CaO), kgs	900–1000
Coke (10–12% ash), kgs	600–650
Power, kWh ..	2900–3600
Man hours (furnace operation and tapping only)	2–7
Electrodes, kgs ..	10–30

Calcium carbide was previously used almost exclusively for welding and lighting purposes, but an ever-increasing amount is now being absorbed by the chemical industries.

Pig Iron

The electric furnace is also widely used for the production of pig iron. It finds its main application in regions where good quality coke is scarce, and hydro-electric power available at comparatively low cost.

Electric smelting of iron ores was first introduced in the beginning of the twentieth century, with the Swedish "Elektrometall" furnace.

This furnace, which was only designed for the use of charcoal as a reducing agent, has since been superseded by the Tysland-Hole furnace, the first commercially successful electric pig iron furnace also to be adapted to the use of coke.

The Tysland-Hole furnace is a low-shaft, closed electric furnace, which can operate with almost any kind of reduction materials, and which is generally much less dependent on the high physical strength of the raw materials than the blast furnace.

The furnace is equipped with three Søderberg electrodes, usually arranged in triangle. The furnace arch is built of fire-brick, and rests on water-cooled steel beams. The charging system, by which the raw materials are fed to the furnace at a distance from the electrodes, is of particular interest.

The main advantage of this system is, as mentioned before, that furnace operation is far less sensitive to fines in the charge, than with other closed furnaces.

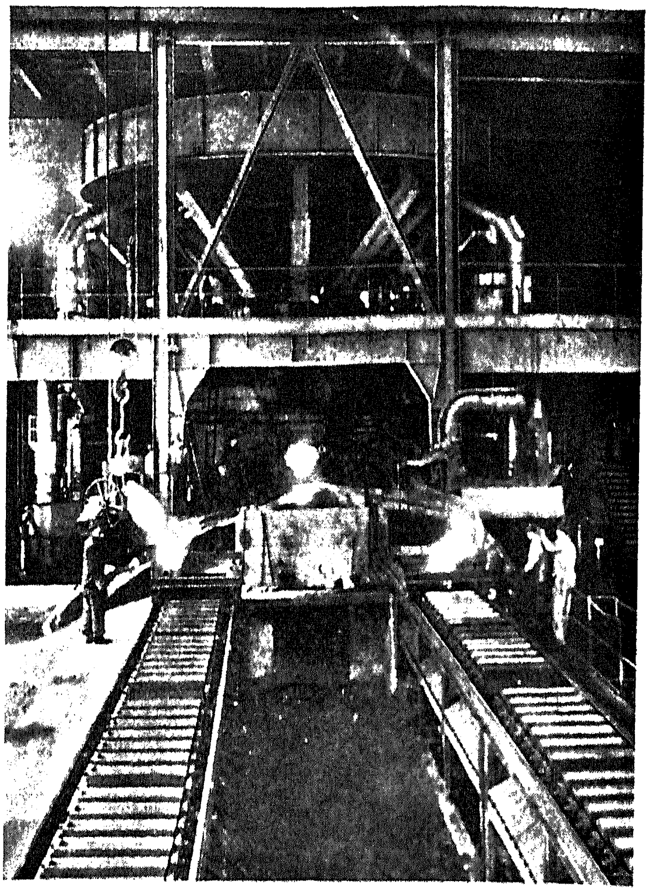

FIG. 5. 7,500 kVA Tysland-Hole furnace.

Owing to the high slag temperature in the electric furnace, exceptionally good desulphurization may be obtained.

The furnace gas is a valuable by-product, which may be used for chemical synthesis, sintering of fine ores, heating or other purposes. Some 650 Nm^3 of gas is produced per ton pig iron, the calorific value being about 2,500 kCal/Nm^3. A typical gas analysis is as follows:

Gas constituent	Volume %
CO_2	15
CO	72
C_mH_n	3
H_2	8
N_2	2

As the gas usually contains a certain amount of dust, it is purified in a gas-cleaning plant before entering the distribution line.

The Tysland-Hole furnace can be operated on 50 per cent. of the normal load, without any disturbances or unreasonable increase in the consumption figures.

The furnace is usually built in two standard sizes, *viz.*, 7,500 and 13,200 kVA capacity, corresponding to a daily output of approximately 50 and 90-100 metric tons of pig iron respectively. A larger unit of 24,000 kVA, with an estimated daily capacity of 200 tons, has also been designed, and three or four of these units will be erected for the new iron and steel plant which is being built by the Norwegian Government.

Below are tabulated some operational figures for Tysland-Hole furnaces. The figures are based on a burden giving 50-55 per cent. pig iron with a Si-content of 1-2 per cent., under normal operating conditions.

Tysland-Hole Furnace. Operating Data

Transformer capacity kVA	7,500	13,200
Normal operating load, kW	6000-6500	10000-11000
Annual production, M. tons	17000-20000	30000-33000
Labour (entire staff included) man hours per ton		
For one furnace ..	5	3
For two furnaces ..	3·5	2

	Per metric ton of pig iron
Slag produced, kgs ..	350-500
Gas produced, Nm^3 ..	650-700
Ore, kgs ..	1500-1700
Limestone, kgs	300-400
Reducing agent, kgs (coke, coke breeze, anthracite charcoal, etc., 10-15% ash)	375-450
Electric power, kWh ..	2400-2600 (*)
Electrodes, kgs ..	8-15

* Under favourable conditions, the power consumption may be as low as 2200 kWh. If foundry pig iron containing 2-3% Si is produced, the kWh-consumption will increase to about 2600-3000 kWh per metric ton.

FERROMANGANESE

The most important manganese alloy is standard ferromanganese, containing 78-82 per cent. Mn and 6-8 per cent. C. Other commercial grades are "Spiegeleisen" (15-30 per cent. Mn) and silico manganese, containing approximately 25 per cent. Si, 55-70 per cent. Mn and less than ·5 per cent. C. Low carbon ferromanganese and manganese metal is also produced for special purposes.

Standard ferromanganese may be produced either in the blast furnace, or electrically. Electric furnaces have found application in regions where the cost of power is low, and where coal of a quality suitable for blast furnace use is scarce. The process is simple, comprising the reduction of manganese ore by coke, under high furnace temperature. Limestone is added for slag formation.

In order to obtain satisfactory, economical operation, rich manganese ore should be used 50% Mn), but low grade ores (35-45% Mn) may also be employed, provided the silica content is not excessive (below 10%). In contrast to the blast furnace, electric production of ferromanganese may also be accomplished with inferior quality reduction materials. Coke breeze is a common and inexpensive reducing agent, and charcoal or anthracite may also well be used.

Owing to the fact that manganese is easily volatilized, it is essential to keep the operating temperature as low as possible, in order to reduce evaporation. For this reason, comparatively large electrodes with a low current density are used, and closed furnaces are employed to a certain extent.

The American type furnace, as previously described, is much used, but ferromanganese is now also smelted successfully in the Tysland-Hole furnace. Capacities may vary from 2,000 to 15,000 kVA, the larger units being more economical in operation.

The following table gives various operational figures for ferromanganese furnaces. The figures are based on normal operating conditions.

Ferromanganese Operating Data

Analysis: 78-82% Mn, 6-8% C	(Per ton tapped product)
Power consumption, kWh ..	2500-3500
Manganese ore, kgs (50% Mn, 7% SiO_2) ..	1800-2000
Limestone, kgs ..	450-600
Coke (10-15% ash), kgs ..	550-650
Electrodes, kgs ..	15-25
Man hours (furnace operation and tapping only) ..	4-5
Manganese yield % (approx.) ..	80-90

FERROCHROME

Ferrochromium containing more than 4 per cent. C is produced in the electric furnace without any serious difficulties, through the direct reduction of chrome ore (48-50 per cent. Cr_2O_3) by a carbonaceous agent. Working with a surplus of ore, and using firebrick lining for the furnace instead of carbon, the carbon content may be reduced to approximately 1 per cent., although the chromium yield will thereby decrease.

Low carbon ferrochrome (0·5-0·4% C) used to be produced alumino-thermically. But reduction in the electric furnace by means of a two or three-step process is the accepted modern method. The French Moutiers process for the production of ferro alloys low in carbon, is also used with success in the manufacture of L.C. ferrochrome.

Ferrochrome Operating Data

(Analysis: 4-6% C and 68-72% Cr)	(Per ton FeCr)
Power consumption kWh ..	5000-6000
Ore (50% Cr_2O_3), kgs ..	approx. 2200
Quartz, kgs ..	,, 300
Coke (10-15% ash), kgs ..	,, 600
Electrodes, kgs ..	50-60
Chromium yield, % ..	90-95

The electric furnace is also employed in the production of a number of other ferro alloys, such as ferrotungsten, ferromolubdenum, ferro-