CHAPTER III

ELECTRIC SMELTING FURNACES

1.—Early trials at Darfo, Livet and at Sault Sainte Marie.

THE first experiments upon the smelting of iron ores in electric furnaces were made by an Italian, Captain Stassano, in the years 1899—1901, at Rome, and later at Darfo, in Northern Italy, where cheap power was available. The furnace used was of the arc type (Fig. 7), still employed by Stassano for electric steel refining, with three-phase current and water-cooled electrodes. The ore was first finely ground, and after mixing with the lime and coke was briquetted, before charging into the furnace. Any practical metallurgist could have foretold that the cost of this preliminary treatment of the ore would render the method expensive and impracticable. Although the trials at Darfo did not result in any financial success, they proved that steel of good quality could be produced in this way direct from the ore, and Goldschmidt, who made an official report upon the method for the German Patent Office, gave the following figures for the power consumption and cost of operating the process: power, 2,866 kw. hours per metric ton of steel; cost, £4 9*s.* per ton (power at £1 19*s.* per e.h.p. year), and ore at 12*s.* per ton.

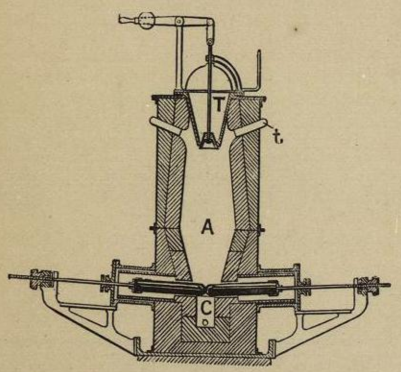

FIG. 7.—Stassano Arc Furnace (earliest type).

The next investigator of the subject was Keller, a French electro-metallurgist, who carried out extended trials with an electric furnace of his own design for ore reduction, at Kerrousse, and at Livet, in France, in the years 1901—1905. It was at the latter place, that the Canadian Commission upon electric furnace methods of iron smelting, carried out their trials in March, 1904. The furnace used for these trials was a double shaft - furnace (Fig. 8), connected by a lateral canal, which, when the furnace was operating, became filled with molten iron reduced from the charge of ore in the two shafts.

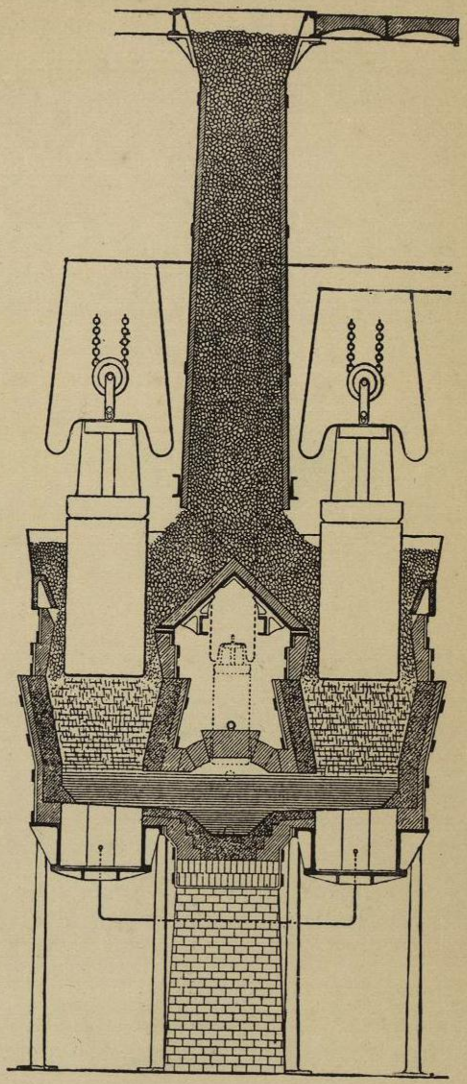

FIG. 8.—Keller Shaft Furnace.

Composite massive carbon electrodes, 34 ins. square and 56 ins. in length, were used with this furnace. The raw materials were roughly crushed and mixed, before charging into the shafts. The experimental trials made at Livet yielded the following mean results: power, 2,292 kw. hours per ton (2,000 lbs.) of pig iron; cost, £2 8*s.*

per ton of pig-iron, with power at 41*s.* 8*d.* per e.h.p. year, and ore at 6*s.* 0*d.* per ton.

After these early trials of the electric furnace for iron smelting, nothing more was done until 1905—1906, when Heroult, the noted French metallurgist, arranged that his own type of shaft furnace should receive trial at Saulte Sainte Marie, in Canada, under the auspices of the Canadian Government. The furnace used in these trials was a square shaft furnace of a much simpler design and construction than those used by Stassano and Keller. Fig. 9 shows Heroult's original design for an iron ore smelting furnace and Fig. 10 the furnace actually employed at Sault Sainte Marie. The iron bottom plate of the latter furnace, 24 ins. square, served as one electrode; the other was a carbon rod, 16 ins. square by 72 ins. long. As raw materials, the native magnetic iron ore of the district, with charcoal in place of coke, were used. Although the method and process were found to be feasible from the scientific point of view, the commercial prospects were less satisfactory, and the project of establishing an electric smelting industry on the Canadian side of the Great Lakes was reluctantly abandoned by its supporters.

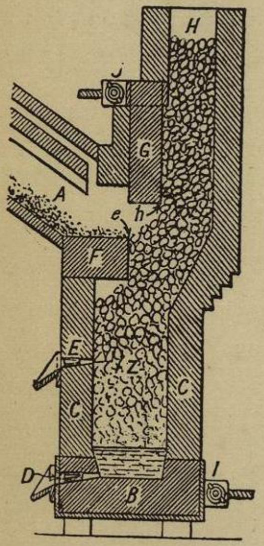

Fig. 9.—No. 1 Heroult Shaft Furnace (early type).

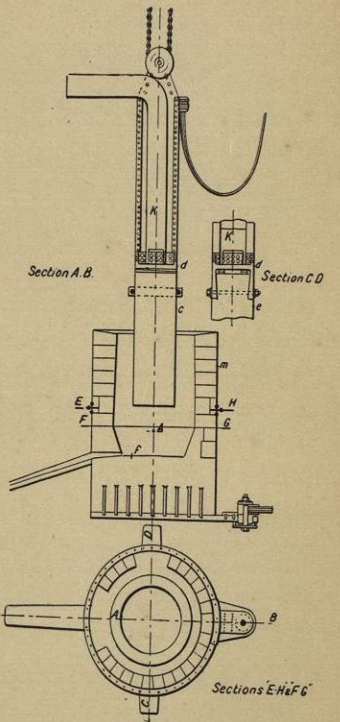

Fig. 10.—No. 2 Heroult Shaft Furnace (Canadian type).

The estimated power consumption, based on Dr. Haanel's trials at the Soo, with the Heroult furnace for a large 10,000 h.p. plant, was 1,000 e.h.p. days per 12 tons of pig, equivalent to 1,470 kw. hours per ton. The estimated cost for Canadian conditions of labour, ore and power supply, was $10·69 per ton of 2,000 lbs. (£2 4*s.* 6*d.*). In this estimate, ore was taken at $1·50 per ton; charcoal at $6·00 per ton; and electric energy at ·165 cent per kw. hour, or $10·71 per e.h.p. year (£2 4*s.* 7*d.*).

2.—Recent Trials.

(a) The Trials at Ludvika and Domnarfvet in Sweden.

The success, from the scientific standpoint, of these early trials with electric iron smelting furnaces led three Swedish engineers, Messrs. Grönwall, Lindblad and Stralhane, to undertake further trials of this method of iron smelting in Sweden in the years 1906—1907. The special aim of these inventors was to design an electric smelting furnace which should prove *commercially* successful, when operated with Swedish ore and under Swedish conditions of power and labour supply. In carrying out their plans for this work they were greatly assisted by a group of Swedish iron masters, who not only provided technical facilities, but also assisted the three engineers in obtaining the necessary funds for the experimental work. The first furnace, of 300 h.p., was ready for operation in April, 1907, and a second one, with the improvements based on the experience gained in operating the first, was erected during 1908. The following description of the latter furnace is taken from Dr. Haanel's report, prepared for the Canadian Government and published in 1909.

In general appearance this electric shaft furnace is unlike any hitherto constructed; being very similar in design to an ordinary blast furnace, in which the tuyeres are replaced by electrodes.

[A vertical section of the furnace is represented by Fig. 11.]

The height above ground level was about 25 ft. The melting chamber or crucible containing the electrodes was about 7 ft. high, and was of greater diameter than any other part. The shaft was about 18 ft. high; the lower end for about 4 ft. had the form of a truncated cone. The purpose of this design was to direct the charge into the crucible in such a manner that the electrodes, lining and descending charge should not come into contact.

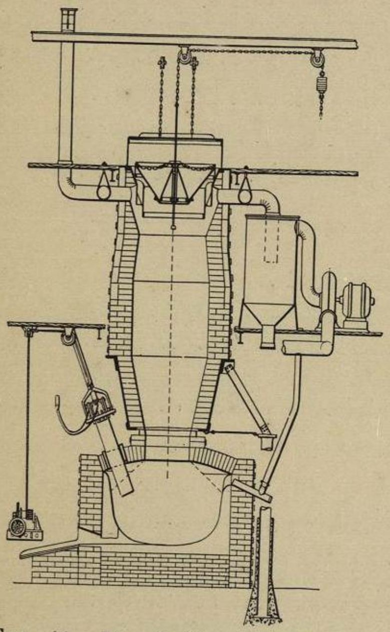

Fig. 11.—No. 2 Grönwall Furnace (vertical section).

This special feature of the design was introduced by the inventors after repeated experiments, and it is this isolation of the descending charge from the lining, at the point where the electrodes enter the furnace, that constitutes the particular economic advantage of the Gronwall design of furnace construction, since it tends to prevent the destruction of the lining.

For the purpose of cooling the brickwork used for lining the roof of the melting chamber, and thereby increasing its life, three tuyeres were introduced into the crucible (just above the melting zone), through which the comparatively cool tunnel-head gases were forced against the lining of the roof. These gases absorbed heat from the exposed lining of the roof and walls, and from the free surface of the spreading charge, thus effectively lowering the temperature.

Each electrode was built up from two carbons 11 ins. square and 63 ins. long, making the total cross section of the composite electrodes 11 ins. by 22 ins.

The water-cooled stuffing boxes, through which the electrodes entered the melting chamber, were provided with special devices (not shown in

the drawing) for preventing leakage of the gas under pressure within the melting chamber.

Fig. 12.—No. 2 Grönwall Furnace at Domnarfvet (external view).

Haanel carried out with this furnace a series of trial tests on December 27th, 28th, and 29th, 1908, the more important results of which are given below.

The ore used was Magnetite from the Grangesberg District, containing 63 per cent. metallic iron, 3·16 per cent. of silica and 2·34 per cent. phosphoric acid. Although the furnace was designed for a larger output, the low water supply would only admit of a power consumption during the trials of 400—450 kw. As regards yield, the average of nine tappings gave 1·87 tons pig-iron per e.h.p. year, but owing to the heat losses, due to heating up the furnace, and to an accident to one of the stuffing boxes, a yield of 2·44 tons obtained at the sixth cast was taken as the most reliable figure for the yield. This is equivalent to 2,675 kw. hours per ton (2,204 lbs.) of pig. It was believed however, that under more favourable conditions of work the power consumption could be reduced to less than 2,000 kw. hours per ton of pig, and Professor Von Odelstiern, of Stockholm, made the following estimate for a furnace producing 8,000 to 10,000 tons of pig-iron per annum :—

		s.	*d.*
Charcoal, ·27 ton at 33*s.* 4*d.* per ton . .		9	0
Power, ·30 e.h.p. year at 50*s.* . . .		15	0
Labour		4	2
Electrodes, 10 lbs. at 1½*d.* per lb. . . .		1	3
Repairs, etc.		6	3
	£1	15	8

This estimate did not, it must be noted, allow anything for the cost of ore, or for interest and depreciation of plant and machinery.

Following up the success attained with this smelting furnace at Domnarfvet, arrangements were made with the Trollhätten Water Power Co., to erect a larger plant at Trollhätten, the following being details of the scheme :—

Each furnace was to be of 2,500 h.p. capacity, and to produce 7,500 tons pig-iron per annum. Two furnaces were to be kept in operation and one in reserve. The ore used was to be Magnetite from Grangesberg, and to contain between ·40 per cent. and 1·9 phosphorus.

Westphalian coke was to be used, costing 23*s.* 7*d.* at Trollhätten. Power was to be supplied at 31*s.* per h.p. year, rising to 41*s.* 4*d.* after ten years. The estimated capital required for financing the undertaking was £32,400, and the estimated cost of pig-iron 57*s.* 4*d.* per ton, leaving a margin between producing and selling price of 7*s.* 10*d.* per ton. The Swedish Association of Ironmasters provided the necessary capital, and the erection of one portion of the new plant was completed towards the end of 1910, at a cost of £17,700. The furnaces follow in their main lines of construction that erected at Domnarfvet, but they are much larger, and have four electrodes in place of three. Figs. 13 and 14 show a sectional elevation and external view of one furnace. The gases passing from the top of the furnace are trapped, and are then blown by means of a fan into the crucible. This double circulation of the gases has two objects: (*a*) to increase the heat of the charge of ore and coke in the shaft above, and to render it more ready for the reduction process, and (*b*) to cool the roof of the furnace and to lessen the danger of overheating and collapse.

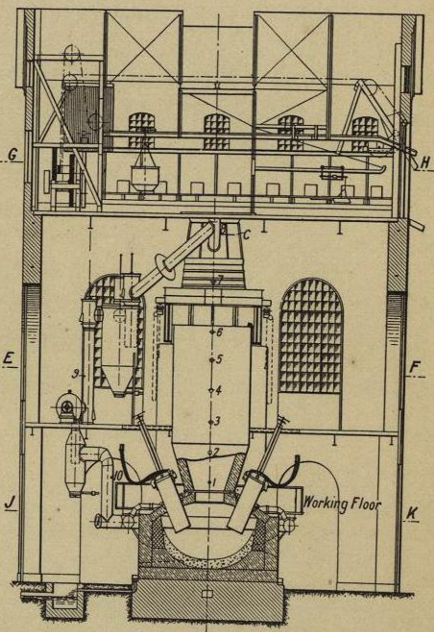

FIG. 13.—No. 3 Grönwall Furnace at Trollhätten (vertical section).

The electric power for this plant is obtained from the Swedish Government Electric Power Station at Trollhätten, and is obtained in the form of three-phase current, at 10,000 volts pressure, and 25 cycles. The furnace transformers are each 1,100 kw. capacity, with a guaranteed overload capacity up to 1,375 kw.

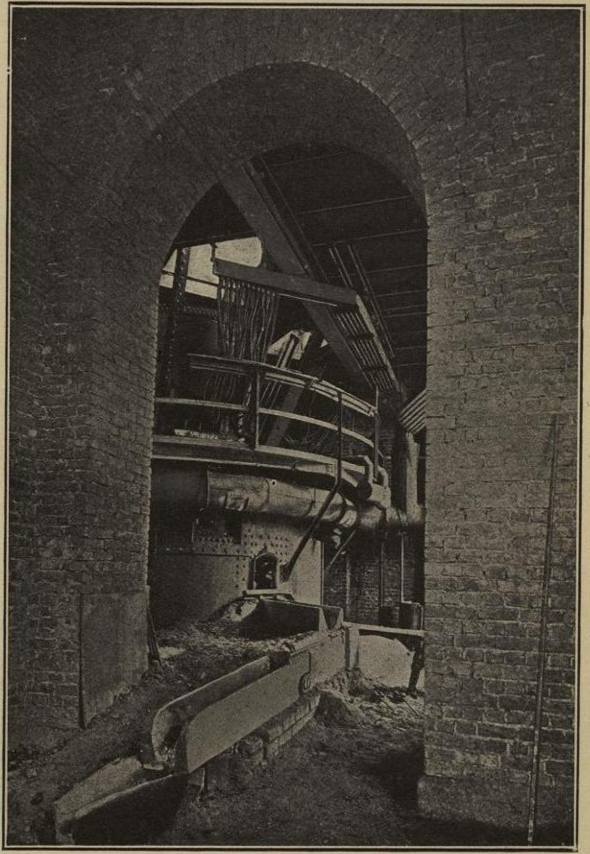

FIG. 14.—No. 3 Grönwall Furnace at Trollhätten (external view looking towards tap-hole).

Charcoal has replaced coke as the reducing agent for these furnaces, the average composition of this charcoal being moisture, 14·58 per cent., ash, 3·06 per cent., fixed carbon, 72·10 per cent., and volatile matter, 10·26 per cent. The molten metal is tapped as in ordinary blast-furnace practice, about 5 tons of pig-iron being obtained at each tapping of the furnace.

Later Trollhätten Operations.

Over 3,000 tons of pig-iron have been produced at Trollhätten since the first furnaces were started in November, 1910, and the metal is stated to be of exceptionally good quality, containing only small percentages of sulphur and phosphorus.

The following additional details of the work of the first Trollhätten furnace from August, 1911, to March, 1912, were contributed by Messrs. Leffler and Nyström to a meeting of the Swedish Ironmasters at Stockholm in May, 1912 (see *Metall. and Chem. Engineering*, July, 1912). During the summer of 1911, the furnace was closed down for alterations and repairs, costing £3,150. The four square electrodes were exchanged for six round ones, and a new gas circulation system was installed for the better drying of the gas returned to the furnace. The cooler acts on the condenser system, and requires 100 litres of water per minute to reduce the temperature of the gas, so that its moisture content is reduced from 4 gms. per cubic meter to 0·5 gm. All the electric pig-iron furnaces now being built and operated in Sweden and Norway are provided with this condenser, in order to avoid returning moisture to the smelting zone of the furnace. The round form of electrode was used (with screwed and tapped ends) in order to avoid formation of butts. The dimensions at first were 22 ins. × 60 ins., and later were increased to 24 ins. × 72 ins. For the 215 days which the furnace was run during the above period, the average net consumption of electrodes was 5·18 kgs. per ton of pig-iron produced, or ·518 per cent. of the iron. It is hoped that as the efficiency of the furnace is improved this consumption of electrodes may be reduced to 4 kgs. per ton. The smaller electrodes were manufactured by the Planiawerke, at Ratibor; the larger ones by Messrs. Siemens and Halske, at Lichtenberg. As regards ore used, various hæmatites and magnetites were employed, varying in composition as follows:—

Iron	42·00 per cent.	up to	68·95 per cent.
Silica	3·42 ,,	,,	28·46 ,,
Sulphur	·001 ,,	,,	·138 ,,
Phosphorus	·002 ,,	,,	·055 ,,

The method of restarting the furnace was as follows:—

Half a ton of scrap-iron and ½ ton of limestone were put on the hearth; on this was placed one ton of dry coke; over this a mixture of 3 tons of castings, 1·2 tons of coke, and 3½ cwts. of limestone. This filled the crucible up to the electrodes. Eight cwts. of broken electrodes were then scattered on top to give electrical connection between the electrodes. On the top of this were placed regular charges of ore, fuel and limestone. According to Richards (see issue of *Metall. and Chem. Engineering* for July, 1912), the best figures were obtained in September, 1911, when a yield of 4 tons of iron per e.h.p. year was averaged over a period of one week.

It is expected, however, that an output of 5 tons per e.h.p. year will be obtained with larger furnaces and more efficient control of the electrical reduction process. The metal produced in this furnace is really pig-steel, since it contains 97—98 per cent. iron and only 2—3 per cent. impurities. This improvement in the composition of the metal has followed the cutting down of the coke supply of the furnace to the minimum required for reducing the oxide of the iron ore to the metallic state. It has been discovered that the electric iron furnace, worked under these conditions, has an increased output of a purer metal than when worked as formerly, with an excess of coke. The steel refining furnace also is found to produce *more steel*, and at a less cost, when supplied with the product of the electric iron furnace than when using ordinary pig-iron, and this discovery has been the most notable reason for the success of the new Swedish Electric Iron Industry. The following figures show the best average so far, for one month's continuous work (September, 1911) of the Trollhätten furnace:—

TABLE III.

Pig-iron produced, tons	537·9
Quantity of slag, tons	88·9
Iron in the ore, per cent.	67·65
Iron in the ore and lime, per cent.	65·02
Quantity of slag per ton of iron, kgs.	165
Charcoal used per ton of iron, kgs.	339·9
Average load, kw.	1,407
Average power, h.p.	1,913·5
[1] Current used per ton of iron, kw. hours	1,749
[2] Iron produced per kw. year, tons	5·01
Iron produced per h.p. year, tons	3·68
Average CO_2 contents in gas, per cent.	29·27
C per cent.	3·64
Si ,, ,,	0·36
Mn ,, ,,	0·40
S ,, ,,	0·009
P ,, ,,	0·018

Since the furnace was restarted, there has been considerable variation in the results obtained, owing to the trials that have been made with different kinds of ore and with different proportions of concentrates.

The above figures, however, are typical of the results obtained, under regular and normal conditions of work.

Four large electric pig-iron furnaces of similar design were expected to be in commercial operation in Scandinavia early in 1912, located at Domnarfvet and Hagfars, Sweden, and at Tyassaa, Norway. The largest of these is at Tyassaa and has a power capacity of 3,500 kw.

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[1] According to instruments at the furnace.

[2] Estimated on the basis of 8,760 kw. hours per kw. year.

In concluding this review of the present position of electric iron ore smelting in Sweden, it may be pointed out again that the conditions in that country and in Norway, for the successful development of the process, are probably more favourable than in any other part of the world.

High grade iron ore is abundant, and electric power developed from large waterfalls, is remarkably cheap. The country has no deposits of coal and the native iron industry has been dependent, therefore, on charcoal made by carbonisation of the timber, with which the lower sides of the valleys and mountains are covered. To replace two-thirds of the charcoal required by the ordinary process of iron smelting by electric power is therefore a most profitable substitution.

The future of the electric iron smelting industry in Scandinavia ought therefore to be assured, and its gradual development will be of enormous importance to the industrial progress of Sweden and Norway.

(b) The Trials at Heroult, Shasta County, California.

The only other locality where, at present, similar conditions prevail is California. No coal beds are known to exist in this strip of the western border of the United States, and the selling price of pig-iron and steel is very high, due to the heavy freight charges from the Eastern States and from other centres of the iron and steel-making industry. For this reason, the further trials of the Heroult iron smelting furnace and process in America were transferred from the "Soo" to Shasta County, California, where a cheap and plentiful supply of power was combined with the other requisite conditions for the development of a successful electric iron smelting industry.

The trials at Heroult, on the Pitt River, California, were initiated by Mr. H. Noble, President of the Northern California Power Co., who was anxious to find an outlet for some of the surplus power produced by their generating plant. M. Heroult was therefore retained by Mr. Noble early in the year 1907 to

design and erect a furnace for smelting the iron ore produced by the Shasta Iron Co. at that place.

The following description of the furnace, as erected, was given by R. L. Phelps, in an article contributed to *The Mining and Scientific Press*, July 20, 1907.

The smelter itself was elliptical in form, with one compartment, standing about 5 ft. high, made of heavy sheet-steel and lined inside with the best magnesite brick. The bottom of the furnace was formed of heavy cast-iron plates, with a covering of tamped carbon to form the neutral point of the circuit. The bottom plates were insulated from the upper parts of the furnace with asbestos.

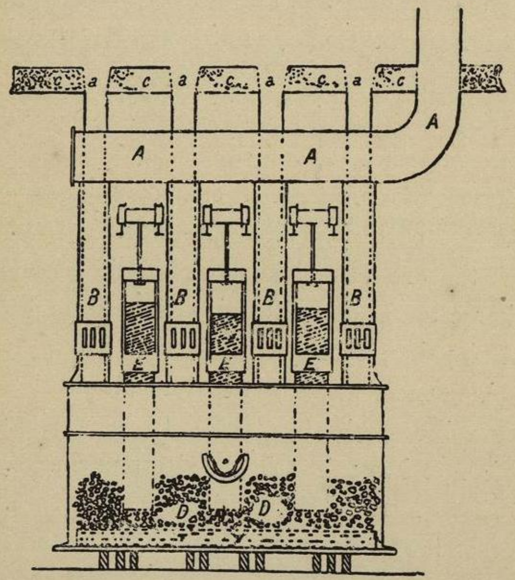

Fig. 15.—No. 3 Heroult Furnace, at Shasta, California.

A tap and trough were provided on one side to draw the molten pig-iron on to the moulding beds. Through apertures in the top cover of the furnace the three carbon electrodes were introduced. These carbons were 18 by 18 by 72 ins. and were made in Sweden. They were fastened by wedges to a copper holder, which was water-jacketed, and by mechanical means were lowered and raised from the furnace when necessary. Four combination charging and draft tubes were placed on the top cover of the furnace. The tubes consisted of an inner tube made of steel and an outer tube made of cast-iron, so as to leave an annular space large enough to serve as a conduit for the gases that were generated. Bunsen burner slots were provided in the base of each tube to allow enough oxygen to enter, in order to complete the combustion of the gases liberated from the charge. The burning of these gases in the annular space heated the charge as it was fed through the inner tube to the furnace, thus delivering the charge hot instead of cold. The furnace was designed to utilise 1,500 kw. in the form of three-phase current at 50 volts and 60 cycles.

The charge was composed of charcoal, limestone and ore. The charcoal was burned in kilns close to the plant. The heat for smelting the ore was obtained from the resistance of the slag and charge to the current as it passed from the electrodes to the neutral point; consequently, at the start, the electrodes were in slight contact with the neutral bottom of the furnace. As the charge became heated the electrodes were drawn out of the molten iron and remained in the slag and charge.

Fig. 15 shows a sectional elevation of the furnace.

The cost of the ore was estimated at 6*s.* 3*d.* per ton, and of power 50*s.* per e.h.p. year, with charcoal at less than 4*s.* 6*d.* per ton.

It was estimated, therefore, that it would be possible to produce pig-iron at a cost of 67*s.* 3*d.* per ton or under, assuming that 1 ton could be produced with an expenditure of 2,700 kw. hours.

This furnace was first put into operation on July 4, 1907, and it was hoped that a production of 24 tons per day would be speedily attained. For various reasons these expectations were not fulfilled, and the output never exceeded 11 tons of pig-iron per day.

According to Elwell, it was found impossible to run the furnace for any length of time, as the electrodes were exposed to the air and were consumed rapidly, and the heat from the open furnace top was so unbearable that the men refused to work. The experience gained in this first trial, however, was utilised in the plans for a second furnace, which was erected to the designs of Professor Dorsey Lyon, of Stanford University. The new furnace was smaller than the first, being of 160 kw. capacity,

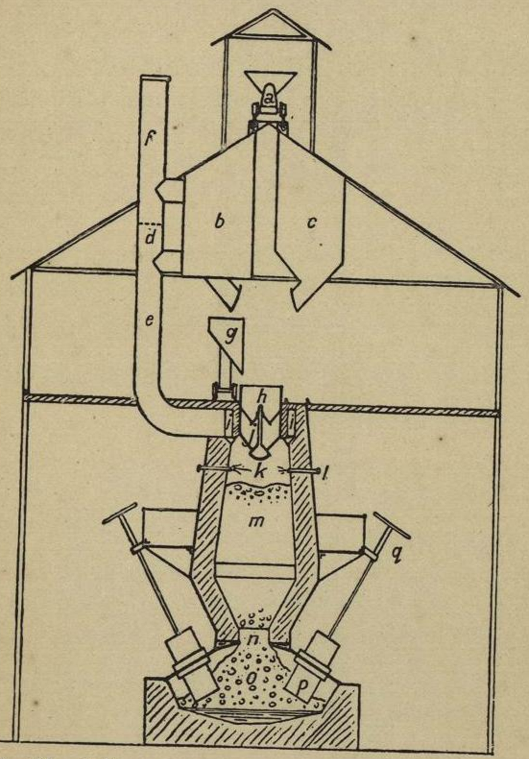

FIG. 16.—No. 1 Lyon Heroult Furnace, at Shasta, California.

and was designed to run with 4,000 amperes at 35 volts single-phase current. The furnace stack was built of concrete and was 29 ft. in height. The crucible was lined with firebrick, and was water-cooled, the electrodes being fixed in its walls. The charge of ore, lime and charcoal was preheated in the stack before reaching the zone of fusion in the crucible between the two electrodes, which were fixed 24 ins. apart. The new furnace was heated up early in 1908, and was run experimentally for a period of forty days, the lowest figure obtained in the trial runs being 3,066 kw. hours per ton of pig. The output of the furnace was 2,400 lbs. per day of twenty-four hours. It was hoped to reduce this power consumption with a larger furnace capable of longer continuous runs, and plans for a 1,500 kw. furnace of similar design, but to employ three-phase current, were next prepared.

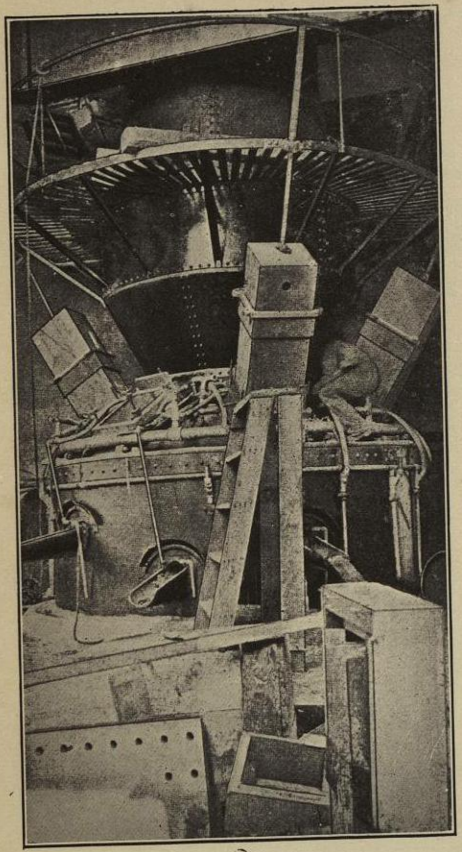

Fig. 17.—No. 1 Lyon Heroult Furnace: (1,500 kw.), at Shasta, California.

Fig. 16 shows a sectional elevation and Fig. 17 a general view of the exterior of the 1,500 kw. furnace ultimately erected, and put into operation in the autumn of 1909. The following description of the working of the furnace is taken from a paper read by Professor Lyon before the Niagara Falls meeting of the American Electrochemical Society in that year:

> In the operation of the furnace the ore, with its proper proportion of fluxing materials, is fed into a preheater (b) wherein it is dried and heated. The heat for the preheater is derived from the products of combustion from the combustion chamber (k) at the top of the stack, which is let into the base of the preheater through a flue (e). This communicates with an annular chamber surrounding the top of the stack, and with the production chamber through openings or ducts (l).

> A scale car (g) runs upon a circular track round the top of the stack, and alternately receives a charge of ore and flux from the preheater (b) and a weighed charge of carbon from the carbon hopper (c), these charges being delivered alternately by proper mechanism into the body of the furnace.
>
> In the operation of the charging device a charge of ore and flux is first dropped into the upper portion of the hopper, the bell (h) being closed, and after the charge is properly distributed about the hopper the bell (h) is lowered so as to permit the charge to pass into the lower compartment of the hopper, the upper bell being then closed and the lower bell (j) opened, so as to permit the charge to pass into the stack. The charge of carbon is then fed into the furnace through the charging device in the same way.
>
> The electrodes, six in number, are arranged equidistantly around the furnace. The electric current passing through the ore lying between them melts the charge, and the molten metal and slag are collected in the crucible, from which they are drawn as in ordinary blast-furnace work.

On July 21, 1910, a party of American steel-makers and engineers visited the plant of the Noble Electric Co., at Heroult, and witnessed this furnace in operation. The furnace at that date had been running without a hitch for some time, and had produced several hundred tons of pig-iron, but no figures were given to the visitors for the power consumption per ton of pig.

The furnace was tapped every six hours and produced 5 tons of iron at each tapping, or 20 tons per day. A wood carbonising plant had been erected in close vicinity to the smelter, and wood alcohol, acetic acid, tar and creosote oils, were being obtained as by-products of the charcoal manufacture. The operation of the 1,500 kw. furnace had proved so successful that the erection of five more furnaces of similar design at a cost of £62,500 had been decided on, and the progress of the trials from the experimental to the commercial stage was considered to have commenced. Since that date but little information has been published concerning the progress of this Smelting Works at Heroult. One of the difficulties that this plant has had to contend with is the shortness of water supply during the summer and autumn months of the year, and the consequent inability of the Northern Californian Power Co. to supply sufficient power to run the Smelting Works continually. According to the estimate made by Mr. McBennie, before the larger furnace was started up, the cost of production was expected to be in the neighbourhood of 62*s.* 6*d.* per ton. Freight charges to San Francisco were expected to add about 12*s.* 6*d.* per ton to the cost of the pig-iron delivered at the foundries in that city. As pig was selling at that date at San Francisco at 96*s.* to 108*s.* per ton, the margin for profit and incidental expenses appeared to be sufficient to assure the success of the electric iron-smelting industry on the Pacific coast.

As already stated, detailed figures for the output of these furnaces (similar to those given for the Trollhätten furnace) have not so far been published, and the cost of running the smelting plant at Heroult, California, is only known to the officials of the Company. Assuming that four of the six furnaces are now operating continuously, with two laid off for repairs, the output of pig should be 80 tons per day of twenty-four hours, or 500 tons per week.

D. A. Lyon and F. C. Langenberg have published recently (*Metall. & Chem. Engineering*, August 1912), an investigation of the pig-iron produced by the Noble Electric Steel Co. at Heroult, which proves that this metal is practically free from phosphorus, sulphur and manganese, and is, therefore, eminently suitable for use by the foundry workers on the Pacific coast of U.S.A. The following is their analysis of this pig-iron :—

Silicon 3·64 per cent.
Sulphur nil.
Phosphorus ·02 per cent.
Combined Carbon nil.
Total Carbon 3·58 per cent.
Manganese nil.

(c) Other Reduction Furnaces.—The Frick and Chaplet Furnaces.

With regard to other types of electric furnaces that have been designed for the smelting of iron ore, only two demand notice :—*The Frick* and the *Chaplet* Reduction Furnaces. Fig. 18 shows a Frick furnace, in sectional elevation, designed to utilise 2,000 kw. and to produce 25 tons of pig-iron per day of twenty-four hours. Although a description of this furnace was published by E. Haanel in 1910 (Bulletin 3, Canadian Department of Mines), with detailed figures of the power consumption and working costs, the Frick furnace does not appear to have been operated upon a commercial scale. Its chief interest now lies in its relation to the more successfully operating furnaces in Sweden and California. It may be pointed out, however, that the Frick Smelting Furnace consisted of the following parts :—

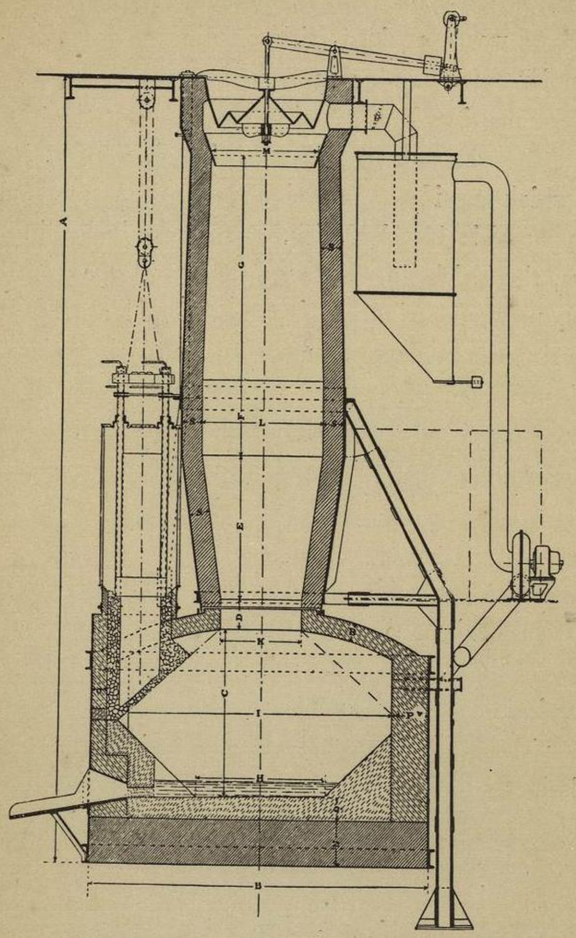

FIG. 18.—Frick Reduction Furnace (sectional elevation).

(1) A wide circular reaction and melting chamber, covered with a vault-like roof. (2) One central feeding shaft, into which the ore and one portion of the reduction coal were fed, in a manner similar to that used for an ordinary blast-furnace. (3) Two or more smaller shafts, for the introduction of the electrodes. These latter shafts were provided with openings, through which the other portions of the reducing agents, coke or charcoal, were fed. The Frick Smelting Furnace also provided for the return of a portion of the waste gases to the smelting chamber of the furnace, an idea which is said to have originated with Harmet and to have been supported in 1905 by Frick. In many of its leading features, therefore, the Frick furnace was the prototype of the larger furnaces, now operating at Trollhätten and at Heroult. The theoretical power consumption, according to the calculations of Frick, lies between 1,300 and 1,650 kw. hours and the practical power consumption between 1,743 and 2,020 kw. hours per ton of pig, according to the purity and dryness of the mixing materials used. It is assumed in these calculations that an ore containing 57 per cent. Fe is used as raw material.

The *Chaplet Furnace* has been operated by the French company la Neo-Metallurgie at their steel works at d'Allevard, Isère. The furnace is of the arc type, and the current enters through one or more vertical electrodes, and leaves through one or more side channels; these are connected with the main bath by horizontal channels below the level of the bath. The slag is charged first, then the ore to be reduced, mixed with carbon in proper proportions. The reduction commences under the action of the arc, the reduced metal filters through the slag and collects on the bottom. The furnace works in a similar manner to a small blast-furnace, in which there is also a separate reducing and fusion zone. The slag contains in normal operation, less than 8 per cent. iron oxide. The charge used is a mixture of hæmatite ore and dried powdered charcoal. Dried hæmatite briquettes and wood charcoal, and mixtures of carbon and hæmatite in the form of powdered dust, also have been tried.

Further details of this furnace, which has received trial only in France, will be found in an article by G. Arnou (see the *Revue de Metallurgie*, December, 1910.)

3.—Comparative Yields and Costs.

Taking the figures given in the course of this chapter, and bringing them to a common basis of comparison, we have the following table of comparative yields and costs, the power consumption being expressed as kw. hours, and the cost in £ *s*. *d*. per ton of 2,204 lbs. of pig-iron produced.

TABLE IV.

Process and Furnace.	Locality.	Power. Kw. hrs.	Estimated cost. £ *s*. *d*.	Remarks.
Stassano .	Darfo . .	2,866	3 15 0	Power at £1 16*s*. 6*d*. per e.p.h. year. Steel produced not pig-iron.
Keller .	Livet . .	2,589	2 13 0	—
Heroult .	Sault Sainte Marie.	1,620	2 9 0	Power at £2 4*s*. 7*d*. per e.p.h. year. Ore 6*s*. per ton.
Grönwall	Domnarfvet .	1,957	2 4 3	Estimate based on early trials. Power at 50*s*. per e.h.p. year.
Grönwall	Trollhätten .	1,735	2 17 4	Actual results obtained at Trollhätten, Sept. 3rd, 1911.
Heroult .	Shasta Co., California.	—	3 2 6	Power at 50*s*. per e.p.h. year. Ore at 6*s*. 3*d*. per ton.

Comparing the latest figures for power consumption with those obtained by Stassano and Keller in the early trials, a notable reduction of 33 per cent. is observed, and it is quite possible that with larger furnaces, and with further reduction of radiation and other avoidable heat losses, the power consumption may ultimately be brought down to 1,500 kw. hours per ton of pig-iron. The attempts made at Trollhätten to obtain a better utilisation of the reducing power of the carbon, by returning the gases which pass from the top of the shaft into the melting and reducing zone of the furnace, have resulted in an increase of the CO_2 percentage to over 29 per cent., and it may no doubt be possible to still further utilise the reducing power of the carbon monoxide gas, which still escapes with the exit gases. But even when the power consumption has been reduced to 1,500 kw. hours per ton the electric iron smelting furnace will still be unable to compete with the ordinary blast-furnace methods of producing pig-iron, except under the most favourable conditions, as at Trollhätten and at Heroult. As pointed out in the introductory extract, from the author's book of 1907, the modern blast-furnace, when worked under the best conditions, only requires 16 cwts. of coke per ton of pig, and of this total 6¼ cwts. are required to reduce the ore to the metallic state. This amount of charcoal or coke has to be provided for by either process. The saving in coke by the adoption of electric heating can therefore only amount to 9·5 cwts. per ton of pig, costing at the present market price, in localities near the coal mines, 8*s.* 4*d.* to 10*s.* 5*d.* Now, if 1,500 kw. hours can be obtained for 10*s.* 5*d.* it signifies that the e.h.p. year must be sold for between 33*s.* 6*d.* and 41*s.* 8*d.*, and there are, as already stated, exceptionally few hydro-electric stations that can produce or sell electric power at this figure. The electric process is also further handicapped by the cost of the carbon electrodes, an item of expenditure which has no counterpart in the ordinary blast-furnace procedure.

Though the electric iron smelting processes may therefore make headway in those localities, where all the conditions favour their development, and where the price of ordinary pig-iron is artificially increased by freight charges—they are unlikely to undergo extension or development, in other lands or localities, so long as cheap supplies of coal and coke are available for the ordinary blast-furnace process of manufacture.

CHAPTER IV

THE HEROULT ELECTRIC STEEL REFINING FURNACE

The Heroult Electric Steel Refining Furnace now heads the list of electric furnaces in use in the Iron and Steel Industry, for thirty-one furnaces with an aggregate capacity of 133 metric tons per charge, have already been installed; and twenty additional furnaces with an aggregate capacity of 143 tons per charge, are in course of erection. The increase in the size of the furnaces is clearly brought out by these totals, since the thirty-one furnaces in active operation have an average capacity of 4·3 tons per charge, while the twenty furnaces now being erected have an average capacity of 7·1 tons per charge.

The largest furnaces now working are the 15-ton furnaces of the United States Steel Corporation, at Worcester, U.S.A., and South Chicago. The largest furnaces in course of erection are in Germany. A furnace of 25 tons was also in 1912 being constructed for use in the Deutcher Kaiser Steel Works at Brückhausen; and one of 22 tons for the Steel Works at Rombach. The 25-ton furnace is to be operated with molten steel from a Martin open-hearth furnace, and presumably is to be employed for the manufacture of special qualities of rail or constructional steel.

The furnaces which are working on cold scrap yield on the average four heats per day of twenty-four hours; those taking molten metal yield fifteen heats per day. The daily aggregate output of the thirty-one furnaces in active operation on this basis is 1,489 tons per day of twenty-four hours, a total which will be more than doubled when the furnaces now in course of erection are placed in service.

A complete list of the Heroult Furnaces in operation or in course of erection in January, 1912, is given in the Appendix.