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.

The design of the Heroult Furnace has undergone little alteration during the twelve years that have elapsed since the first English Patent was taken out, in 1900. This fact proves that Heroult's earlier experience in the manufacture of Aluminium and Ferro-alloys by aid of electric heat had been of service to him when the time arrived to design a furnace suited to the

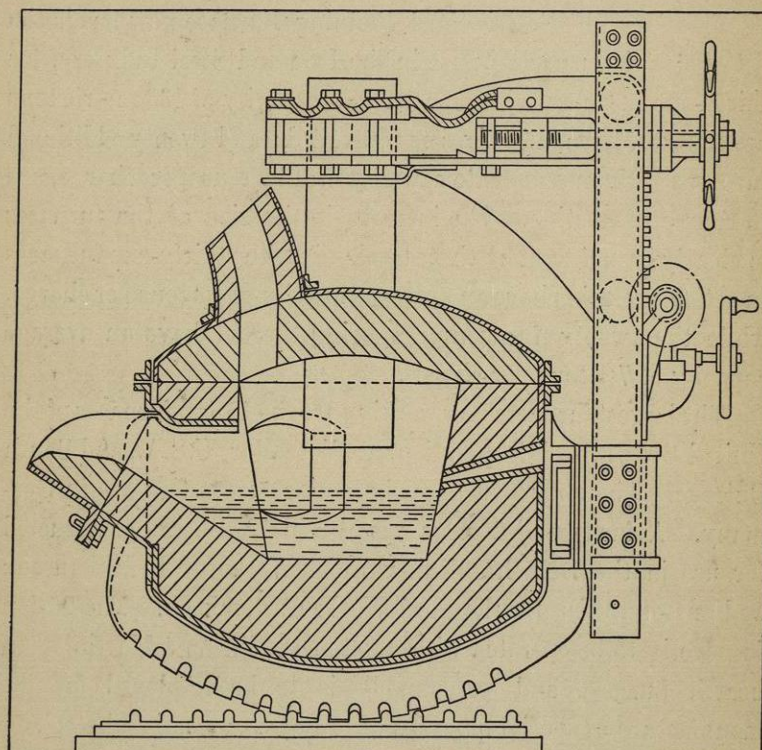

Fig. 19.—Heroult 3,000-kg. Furnace (early design).

special requirements of the steel industry. A paper read by Turnbull before the Niagara Falls Meeting of the American Electrochemical Company in 1909 contains interesting details of the gradual developments of the Heroult electric steel refining furnace (see *Transactions*, Vol. XV., p. 139). Figs. 19 and 20 show the original 3,000-kg. furnace with which the first trials were made at La Praz in 1899-1900; and Figs. 21 and 22 show

the 2,500-kg. furnace which was started in January, 1911, at Braintree, in Essex, for Messrs. Lake & Elliott. The changes in

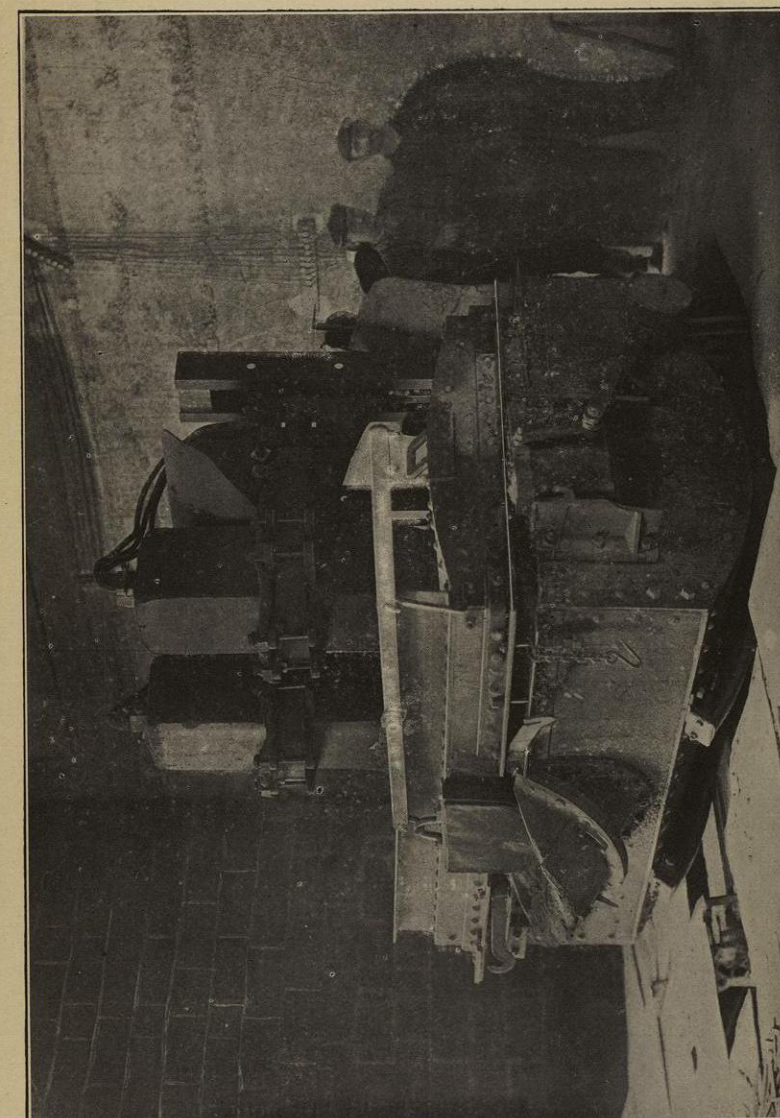

Fig. 20.—Heroult 3,000-kg. Furnace (early design).

design are slight and are hardly noticeable; the most striking being the change from square to round electrodes, and the location of the charging door at the back, instead of at the side of the furnace.

General Description of the Heroult Furnace.

The Heroult electric steel refining furnace consists of a closed shallow iron tank, thickly lined with refractory materials, mounted

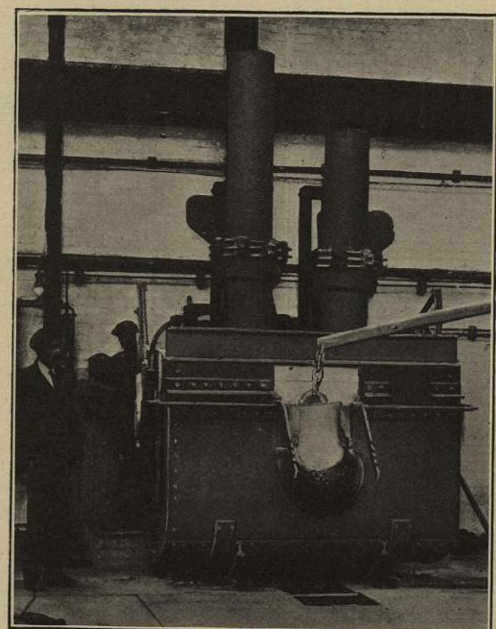

FIG. 21.—Heroult 2,500-kg. Furnace (latest design).

upon curved and toothed bars, which allow of the furnace being tilted and held by a rack at any angle for discharging purposes. Dolomite brick and crushed dolomite form the lining for the bottom of the furnace, and for those portions of the sides below the level of the metal; while magnesite brick and crushed magnesite are employed for the openings, and for the portions of the furnace exposed to the corroding action of the slags. The top of the furnace is built up of silica brick, as it is this portion which

suffers the most from the high temperature of the furnace operations.

As regards the source of heat, the earlier furnaces, of 3,000 kgs. capacity, were operated with direct current, two massive carbon electrodes, 65 ins. in length and 14 ins. square, well insulated from each other and from the furnace cover, being employed to carry the current into and away from the slag, resting on the charge of metal in the furnace. The carbons were supported by an insulated framework fixed to the back of the furnace, and could be moved either in a vertical or horizontal direction by a set of gears.

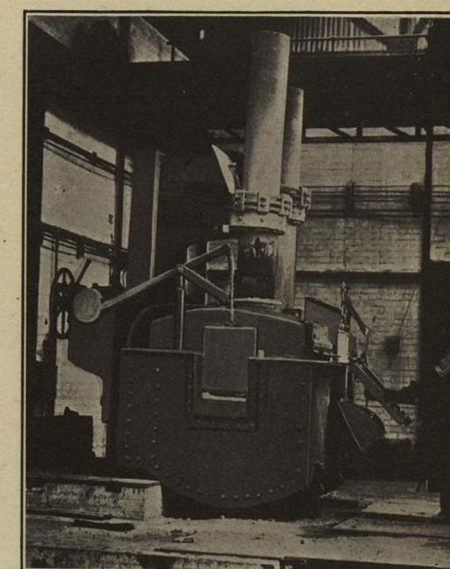

FIG. 22.—Heroult 2,500-kg. Furnace (latest design).

The method of operating these direct-current furnaces was to employ both arc and resistance heating for melting the charge of metal and for the after refining operation, the electrodes being raised just clear of the molten slag when the highest temperature was desired. Under these conditions of work two arcs were formed, one as the current entered the slag from the first electrode, and another as the current escaped from the slag by the second electrode. The heat of these two arcs, and that developed in the slag itself by the passage of the current between the point of ingress and egress, raised the slag to a very high temperature, which was transferred to the metal lying beneath it. Both oxidising and reducing effect could be obtained by varying the composition of the slag. The slag, it may be explained here, is employed in the Heroult refining process as a scavenging agent, the number of slags required to purify the metal depending upon the amount of impurities in the original charge, and upon the purpose for which the finished metal is required.

The use of an air-blast to produce an oxidising effect was abandoned very early in the trials of the Heroult furnace, and

Fig. 23.—General View of the Steel Works at La Praz, France.

iron ore is now used to produce an oxidising slag when this is required. Another change introduced into the methods of working is that the electrodes are never allowed to dip into the slag, and that arc-heating is therefore alone employed. The method of work with this early type of furnace was as follows:—

A charge of steel-scrap, pig-iron, iron ore and lime—in the requisite proportions and quantities—was placed in the furnace, and this was raised to the melting point by combined arc and resistance heating. The slag formed by the lime and silicates of

the ore rose and floated on the surface of the molten metal. The further heating of the charge occurred by allowing the electrodes

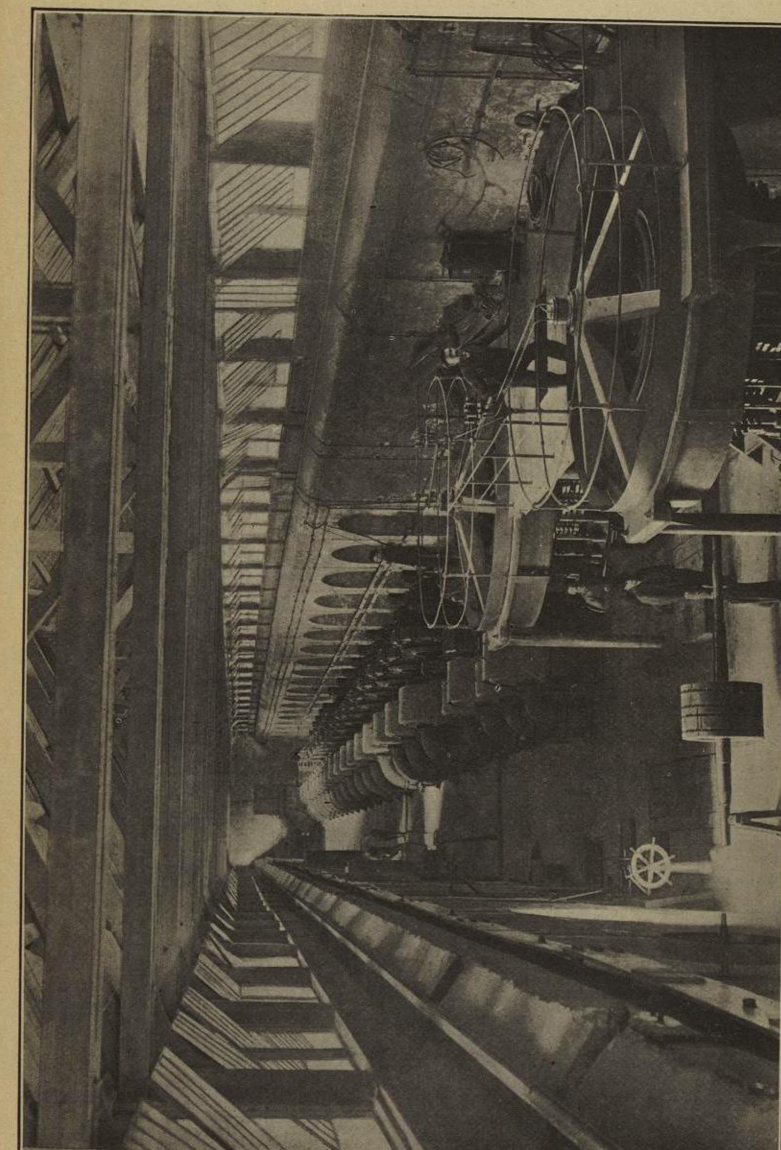

Fig. 24.—Interior of Power Station at La Praz, France.

to dip just beneath this slag, but not into the metal beneath it. Iron ore was then added to the charge to produce an oxidising slag. Under these conditions the impurities of the iron and steel scrap become oxidised and entered the slag. By pouring off this slag, therefore, and by renewing the materials which formed it once or twice, a very pure product could be obtained. The process was in reality a washing-out process, in which the slag acted as solvent. The fact that all the heating with this type of furnace occurred without any actual contact between the carbon electrodes and the metal also conduced to the purity of the product, since neither silicon nor carbon could enter into the steel from the electrodes. When the steel in the crucible had been raised to the requisite degree of purity by this washing-out process, a calculated amount of an iron alloy, high in carbon, was added, and the resultant steel (of known carbon contents) was tipped into the casting ladle.

Description of the 15-ton Furnace at Chicago.

The following details of the construction and methods of work of the 15-ton furnace at South Chicago are taken from a paper by C. G. Osborne, read before the Chicago Section of the American Electrochemical Society in January, 1911. They show that only slight changes have been found necessary in the Heroult furnace when worked with three-phase in place of direct current, and with charges of metal five times larger than those used in the early furnaces.

Upon a solid foundation about 5 feet above the ground-level, a stationary rack 8 feet 9 inches long is fastened. Upon this rack the furnace proper rests on a floating pinion, fastened to its shell by rivets. The arc of this floating pinion has a radius of 10 feet, and aims to give the furnace an angle of approximately 29° when tilted over to its full extent.

Attached to the extreme back of the furnace is an 18-inch plunger with a 4-foot stroke, working in a cylinder attached to an hydraulic pipe line of 500 pounds pressure to the square inch. This gives a lifting power, approximately, of 45 tons. The balance of the furnace is so arranged that the equilibrium is never upset, and therefore to return to the horizontal position merely requires the releasing of the pressure,

and the furnace returns of its own weight. It will be noted that the floating pinion and rack requires some provision for the forward position of the furnace when tipping. This is taken care of by having a movable cylinder, pivoted at both the top and bottom, which allows the cylinder to follow the motion of the furnace.

The furnace shell is built up of plate steel, 1 inch in thickness, riveted together. The outside horizontal cross-section plan is approximately that of a complete circle of 13½ feet in diameter, with two flattened portions situated at the front and back respectively.

On the bottom of the furnace, within the 1-inch plate, and next to it, one row of magnesite brick (laid the 4½-inch way) is placed across the flat portion. The side walls of the furnace are vertical and consist of two rows of magnesite brick, laid the 9-inch way, giving a thickness of 18 inches of magnesite brick. These solid magnesite brick walls extend up to the furnace roof. The bottom of the furnace consists of dead-burned Spaeter magnesite to a depth of 12 inches at its thinnest point, which is, of course, at the extreme centre. From this thinnest point the bottom slopes gradually upwards so as to form a portion of a sphere 7 feet 2 inches in radius. The furnace bottom was made in the following manner: Dead-burned and carefully ground Spaeter magnesite was mixed with basic open-hearth slag, in the proportion of four of magnesite to one of open-hearth slag. To this mixture, sufficient tar was added to make the mass sufficiently plastic, to be tamped into the furnace in the usual manner. The entire depth of the bottom was tamped in this way. Next, the furnace was filled with wood, dried out for about forty-eight hours, and then filled with coke, and the electrodes lowered and the current turned on. In this way the bottom was fluxed into place.

The furnace roof is of silica brick 12 inches in thickness, and is "sprung" from a movable ring. This ring is fitted with a top and bottom angle iron to take a skew-back brick, and from this the arch is spanned across the 10-foot interior of the furnace with an 8-inch rise. The bricks are set in circles parallel to the steel ring, the usual wooden wedges being placed here and there, to take care of the subsequent expansion of the brick. Holes for the electrodes are left in the roof by means of templates, and the bricks are held in position around these holes by lateral pressure.

There are five doors, two on each side of the furnace, and one in front over the pouring spout. These doors are of cast-iron, lined with clay brick, laid the 4½-inch way. They work in the usual groove arrangement and are operated by steam pressure of about 150 pounds. The front door over the pouring spout is an exception to this, being operated by hand with a counter-balance.

The three electrodes are lowered through the roof in the form of an equilateral triangle, each side of which is 5 feet 2 inches in length, the apex of this triangle pointing directly towards the back of the furnace. The center of this triangle coincides with the center of the furnace roof. There are three separate holders, one for each electrode. Each holder

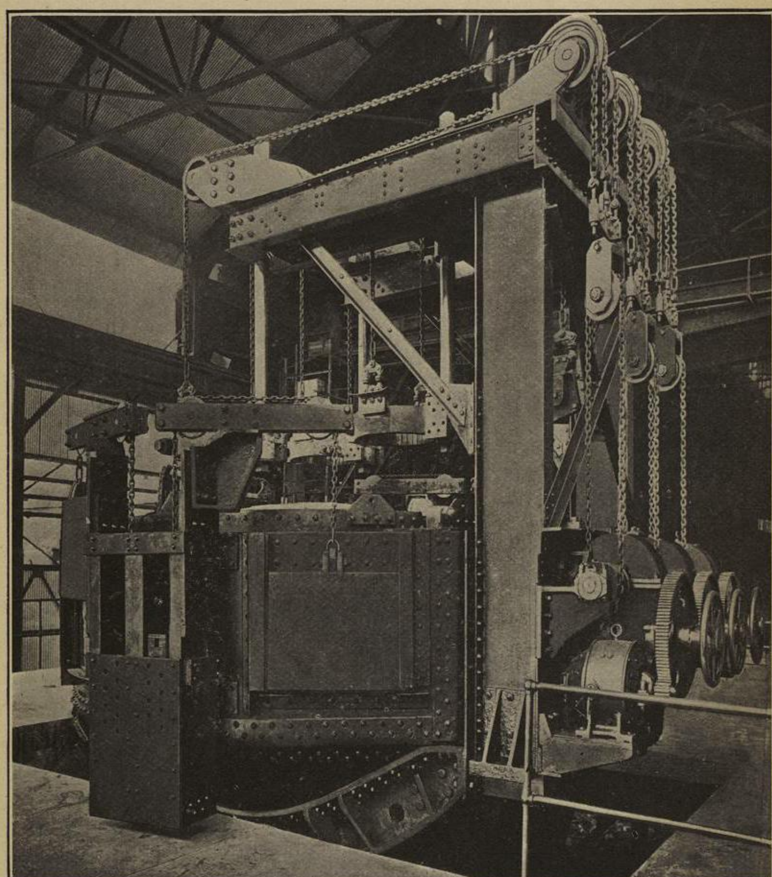

FIG. 25.—Heroult 15-Ton Furnace at Worcester, U.S.A.

is constructed of a solid water-cooled copper casting, bolted directly to the bus-bar. In front these holders are split, and are joined with a right and left screw which enables the holder to be opened or closed at will. The holders are designed to carry a 24-inch electrode, but by means of contact blocks any smaller-sized electrode can be employed. The electrodes used early in June, 1911, were 14-inch square carbon

electrodes manufactured by the National Carbon Co., of U.S.A., and a cooling box through which water was kept in constant flow, was placed round the electrode. This box rested on the roof of the furnace, and movable plates were set in position round it and the electrode, to make a gas-tight joint.

The weight of the electrodes is supported by the chains which extend over pulleys, to the drums at the back of the furnace. The electrodes are kept in alignment by vertical guides, and are regulated by individual motors placed at the back of the furnace. The regulation may be either by hand, by controllers, or by an automatic device.

The operating platform of the furnace is raised about 9 feet from the ground level. Around the furnace on this platform, at convenient points, bins are placed for storing the miscellaneous fluxing materials used in furnace operations. The front part of the furnace platform is cut out to allow a ladle to be hung in position, when the furnace is tapped, and for any miscellaneous work in the pit.

The pouring platform is 30 feet long, and is sufficiently large to admit eight moulds to be placed in position for pouring.

The power for the furnace is generated by dynamos having as prime movers,—reciprocating gas-engines, reciprocating steam-engines, also high-pressure and low-pressure turbines. It is three-phase in character, and is generated at 2,200 volts and 25 cycles. The cost of this supply is half a cent. per kw. hour as measured at the meters. At the electric furnace it is stepped-down by means of three 750-kw. transformers, to the voltage of the furnace. These transformers are so arranged with switches, that the primary turns may be altered to give secondary voltages of 80, 90, 100, or 110 volts, as desired. Ordinarily 90 volts is used.

The entire building is spanned by a 50-ton crane. The normal operation of the furnace is as follows :—

Ordinary Bessemer pig-iron is full blown in a 15-ton Bessemer Converter, in from eight to twelve minutes. It is then poured directly from the Bessemer vessel into the electric furnace transfer ladle, and is drawn to the electric furnace building, a distance of about a quarter of a mile. This requires about five minutes, and, as a precaution against the possible formation of a skull in the ladle, the Bessemer charge is blown about 1,500 pounds of scrap "hotter" than in ordinary Bessemer practice.

Immediately the ladle is received at the electric furnace it is picked up by the crane, slightly tilted, and the silicious slag is completely cleaned off by hand-rabbling. The metal is now ready for charging. To do this, the ladle is merely turned over on its trunnions, and the metal is poured into a spout through which it flows to the furnace.

The operation of cleaning off the slag and charging occupies from five to ten minutes. As the metal is being poured the furnace men shovel iron oxide and lime into the furnace through the working doors. The electrodes are then lowered and the current is turned on.

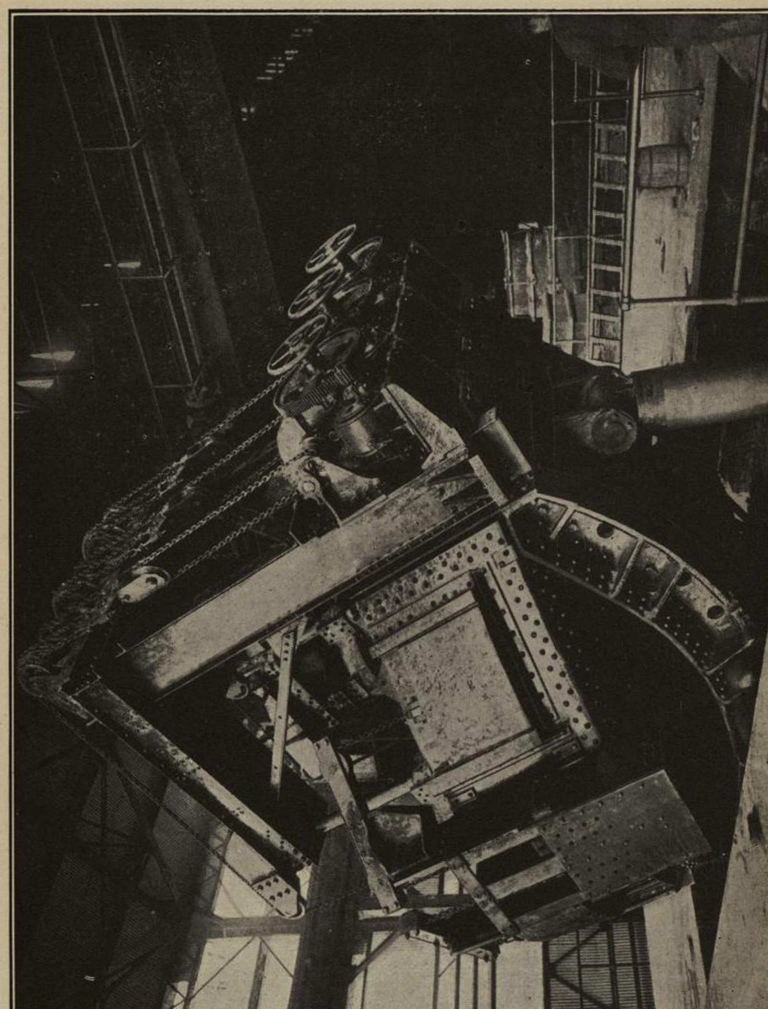

FIG. 26.—Heroult 15-Ton Furnace at Worcester (tipped for discharge).

A basic oxidising slag is first produced; this removes the phosphorus. In about thirty minutes this slag has served its purpose; the furnace is tilted slightly forward and the slag is removed in from five to ten minutes as before, by hand-rabbling. The recarburiser is now added.

On the bare surface of the oxidised metal lime is then quickly spread, with sufficient fluorspar to keep the mass fluid. In about fifteen minutes this lime is melted, and coke dust is thrown on to the slag beneath each of the three electrodes. Under the influence of the electric arcs calcium carbide is produced in gradually increasing quantities. As soon as this position is reached, a neutral if not actually reducing atmosphere has been obtained. From this point to the finish, there is practically a dead-melt in a reducing atmosphere. The slag at this stage of the process is fluid and highly basic. If a sample should be taken and water be added to it, the resultant acetylene gas, from the well-known calcium carbide and water reaction, is of sufficient quantity to light and burn for half a minute.

Tests are now taken to show the condition of the steel. A small cylindrical test piece is poured and is forged to a round pan-cake shape under a steam-hammer located at the furnace. If this forged sample shows by its appearance a satisfactory condition of the metal, the bath is tapped. If not, further refining is necessary.

To tap the furnace, the electrodes are raised from the bath, the ladle is swung by a crane under the pouring spout, and the tilting lever is then pulled forward. The pouring is done through a $1\frac{1}{2}$ inch nozzle into moulds of varying sizes.

A typical furnace charge sheet is shown in Table V.

TABLE V.

Electric Furnace Charge Sheet, Illinois Steel Co., South Chicago.
Material used.

	Pounds.
Converter-blown metal	30,000
Scale	700
Ferro-manganese, 80 per cent.	200
Ferro-silicon, 10 per cent.	60
Ferro-silicon, 50 per cent.	80
Recarboniser	130
Fluorspar	400
Coke dust	200
Lime, first slag	600
Lime, second slag	600
Dolomite	400
Magnesite	25

TABLE V.—*continued.*

Time Required for Electric Furnace Operation.

	A. M.
Tapped previous heat	7 : 00
Metal ordered for	7 : 15
Metal received	7 : 15
Began fettling	7 : 17
Current on	7 : 27
Slag-off, began	8 : 00
Slag-off, finished	8 : 11
Tapped	8 : 48
Time of heat	1 hour, 21 minutes

It will be seen from this table that it takes from $1\frac{1}{2}$ to 2 hours to complete a heat, according to the grade of steel produced.

What is actually done in the electric furnace at the South Chicago Works of the Illinois Steel Company, is to take oxidised blown metal, and to produce deoxidised steel, low in sulphur and phosphorus and (within reasonable limits) of practically any analysis required by the consumer. The steel charged has approximately the following analysis:—

Carbon, ·05 per cent. to ·10 per cent.; Sulphur, ·035 per cent. to ·070 per cent.; Phosphorus, ·095 per cent.; Manganese, ·05 per cent. to ·10 per cent.; Silicon, ·005 per cent. to ·015 per cent.

This furnace has produced high-grade alloy steels, high-grade carbon steels, and ordinary steels, and according to Osborne has operated on a greater variety of products than any other electrically-heated furnace in the world.

As to the mechanical tests of the steel made by the Heroult electric process at South Chicago, the following data were obtained at the mechanical testing plant of the Illinois Steel Company:—Elastic limit, 35,000—47,000 lbs. per square inch; tensile strength, 60,000—70,000 lbs. per square inch; elongation, 25 to 30 per cent.; reduction of area, 43 to 60 per cent. As to the difference between this electric steel and acid open-hearth steel, it was stated that the same tensile strength was obtained with the electric steel with lower carbon tests than with open-hearth

steel. For example, a ·10 per cent. carbon electric steel averages the same tensile strength as a ·15—·17 per cent. carbon acid open-hearth steel.

In the course of the discussion on *Osborne's* paper, it was stated that at South Chicago ferro-silicon was employed in finishing rail steel, but was not used in an ordinary way for deoxidising purposes. There was found to be less loss from segregation in the ingot with electric steel than with open-hearth steel; this is ascribed to its greater density and to its greater freedom from occluded gases. The furnace required 1,950 kw. to operate it. Of this total 750 kw. was necessary to maintain the 15-ton charge at the proper temperature for the refining operation (to balance radiation and other heat losses), while the full power was only employed when the charge was being heated up. The furnace was not run continuously, and on restarting after cooling down at week-ends and at other times, it was prepared for its charge of molten metal, by the use of coke and of an electric current, or by the aid of oil burners.

No costs figures have been published for the operation of either the South Chicago or Worcester 15-ton furnace, and only a few detailed figures for the power consumption have been given to the public. Assuming that the average power used per charge at South Chicago is 1,350 kw. and that the average time per charge of 30,000 lbs. is 80 minutes, the results would show 119 kw. hours per ton of 2,000 lbs. The figures given in Tables VI. and VII., from an unsigned article appearing in the issue of *Metallurgical and Chemical Engineering* for April, 1910, support this estimate of the power consumption of the South Chicago furnace, when working under normal conditions, with molten metal from the Bessemer Converter. This method of working, it may be noted, is covered by the U.S.A. patent No. 934247 of Sept. 1909 in the name of A. R. Walker.

Table VI. gives the power consumed when refining metal high in phosphorus and sulphur, while Table VII. gives the corresponding figures for a metal low in phosphorus.

TABLE VI.

Net weight charged. Lbs.	Kw. hours used.	Time.
29,000	2,000	1 hour 20 minutes.
28,200	2,300	1 „ 35 „
28,200	2,500	2 „ 15 „
28,000	2,200	1 „ 30 „
26,600	2,100	1 „ 15 „
26,000	2,200	1 „ 40 „
25,700	2,900	2 „ — „
23,000	2,500	1 „ 35 „
28,000	2.400	1 „ 35 „
27,000	2,300	1 „ 35 „
27,400	2,700	1 „ 45 „

TABLE VII.

Net weight. Lbs.	Kw. hours.	Kw. hours per metric ton.
28,000	1,400	110·0
27,600	1,700	135·5
27,000	1,400	114·1
28,000	1,000	78·5
28,000	1,300	102·1
28,400	1,300	100·8
27,800	1,000	79·2
27,600	1,500	119·5
28,100	1,200	93·9

The average energy consumption of the eleven heats recorded in Table VI. was 88·4 kw. hours per 1,000 lbs. net weight, or 194·5 kw. hours per net metric ton; while the average energy consumption of the nine heats of Table VII. was 47·2 kw. hours per 1,000 lbs. net weight, or 103·8 kw. hours per net metric ton.

Concerning the composition and reliability of the steel made at the South Chicago furnace, the following figures (Table VIII.) may be quoted from the same article.

The first line, marked "Specification" gives the desired specified composition of the steel; while the following lines marked "Analysis," give the analyses of the steel produced in eight successive heats:—

TABLE VIII.

—	C	S	P	Mn
Specification: Axle steel .	0·35 to 0·45	0·03	0·03	0·37
Analysis:				
30,000 lbs. .	·45	0·032	0·031	0·49
29,000 „ .	·37	·028	·033	·42
30,000 „ .	·38	·028	·026	·40
30,000 „ .	·35	·031	·037	·38
30,000 „ .	·41	·030	·039	·37
30,000 „ .	·48	·025	·032	·41
30,000 „ .	·42	·030	·027	·44
30,000 „ .	·35	·030	·028	·34

The cost of repairs is stated to be low, and is given by the same writer as follows:—

A silica roof costs \$60; if it lasts for 129 heats the cost of the roof per ton treated is about 3 cents. The 10 lbs. of dolomite at \$6 per ton, required for repairing the lining per ton of steel, costs also about 3 cents. Hence, the total cost of repairs of the furnace proper, is approximately 6 cents per ton.

Campbell in a recent paper, states that the cost of repairs to the roof in the latest type of Heroult furnaces is about $2\frac{1}{2}d.$ per ton of steel produced. This is higher than the American figures.

The consumption of electrodes is given as 6 lbs. per ton of steel, this figure applies both to graphite and to amorphous carbon electrodes.

Considerable space has been devoted in this Chapter to a description of the methods of work and results obtained with the Chicago furnace, on account of the size and importance of this installation, and also because of the full particulars that are available concerning it.

The Worcester Furnace.

No detailed figures have been published for the power consumption or for the repairs costs of the 15-ton Heroult furnace installed at the works of the American Steel and Wire Company, at Worcester, Mass. It is known, however, that this furnace, which has been operating since January, 1910, is in some respects more easy to work than the Chicago furnace, and that as it is charged with Talbot open-hearth steel already largely dephosphorised, the time of the heats is shorter, and the specific energy consumption is less (see Table VI.) than that of the earlier erected furnace. The steel produced at Worcester was employed originally for the manufacture of the wire billets used for the finer varieties of wire. It was stated, however, in a recent discussion, that this steel had not been found as suitable for wire making as the steel billets formerly used, and doubtless some other product is now being made in the Worcester furnace. Fig. 25 shows the 15-ton Worcester furnace, and Fig. 26 the same furnace tipped for discharging.

Other specially interesting installations of the Heroult furnace will now be dealt with briefly.

Other Installations.

At the Stahlwerke of Richard Lindenburg, at Remscheid-Hasten, in Germany, two furnaces of 2,500—3,000 kgs. capacity are producing tool and gun steels from molten steel, charged from a Wellman tilting open-hearth furnace. According to Eichoff the method of work at this plant is as follows :—

From a Wellman tilting open-hearth furnace $1\frac{1}{2}$ to 2 tons of liquid steel, partially purified, are poured into the electric furnace, care being taken to hold back the slag. The bath is covered with an oxidising slag, and the current is turned on. After the lapse of one-half to three-quarters of an hour this first slag is carefully drawn off, the clear bath is covered with a weighed amount of carbon, and a fresh amount of slag, free from oxides, is charged. This slag is melted after twenty minutes, and then, through the action of the arc upon the slag, it is thoroughly deoxidised, calcium carbide being formed. In this manner the bath is completely protected against access of air. The charging of the neutral slag cools the bath so much that the greater part of the protoxide of iron is reduced by the layer of carbon. A certain quantity of manganese ore is also charged with the neutral slag. This too is reduced and destroys the last small balance of the protoxide of iron. When the slag has become quite white, a sample of the steel is taken and its carbon content is determined. A mixture of iron and carbon, accurately calculated, is added, and when dissolved, the necessary addition of manganese and of ferro-silicon is charged, to produce the desired quality. The steel is then tapped. So far as phosphorus is concerned, the analysis of the steel in a well-managed charge fluctuates between 0·003 and 0·005 per cent., while sulphur ranges from 0·007 to 0·012 per cent. As a rule, carbon, manganese and silicon can be accurately kept within limits of 0·03 to 0·05 per cent. The elimination of the sulphur takes place during the last stage of the process, and seems to be due to the fact that a much more basic slag can be used in the electric process, on account of the much higher temperature available. When the steel is taken in a highly oxidised condition from the Wellman furnace it carries about 0·01 per cent. of phosphorus, and may be directly covered with carbon and the neutral slag. This makes it possible to finish a charge in one and a quarter hours, with a power consumption of 200 kw. hours per ton of steel.

The steel produced under these conditions, according to Eichoff, may be kept for hours under a neutral slag without changing its quality, and a part of the heat may be cast, and the balance be worked over to another grade, a convenience which is of great importance to steel-founders. The steel may also be allowed to chill, and may then be re-melted without affecting its quality.[1]

Heroult Furnace at a Foundry in Essex, England.

An installation of a different character is that recently completed at the steel foundry of Messrs. Lake & Elliot, at Braintree, in Essex, England, where castings for the motor trade are the chief speciality. This plant is of special interest, not only because it was the first works in England where an electric furnace was employed solely for foundry work, but also because it is located in a district where cheap power is unobtainable. Messrs. Lake & Elliott have therefore been compelled to generate their own power.

The generating plant consists of a gas-producer, of a Westinghouse gas-engine, and of a single-phase alternator.

[1] *Electrochemical and Metallurgical Industry*, February, 1907.

The gas-engine is of the vertical tandem type, with 8 cylinders, and is capable of giving 450 b.h.p. continuously, and 500 b.h.p. for periods of half an hour. The alternator has a capacity at normal full-load, of 300 kw. at a pressure of 110 volts. The current is single-phase alternating, and the periodicity 25 cycles per second. This alternator is directly coupled to the gas-engine.

The furnace is of 2 tons capacity, and is of the standard

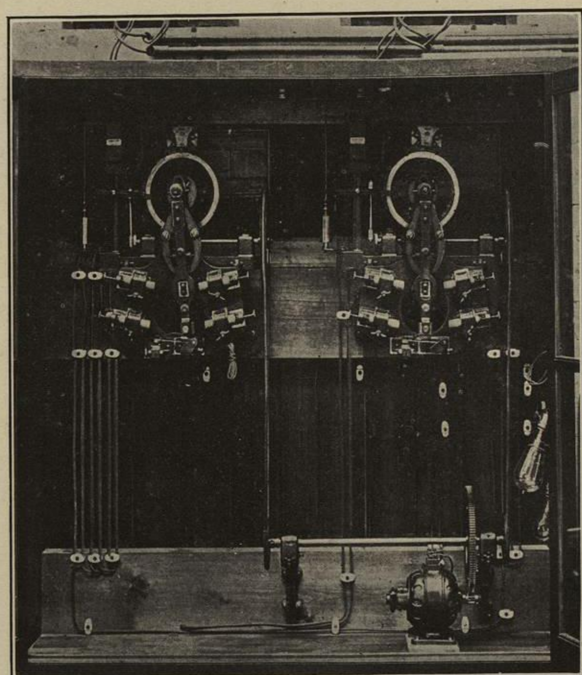

FIG. 27.—The Thury Regulating Apparatus at Braintree, Essex.

single-phase Heroult type, using two electrodes. Figs. 21 and 22 show views of the furnace. The furnace rests on a concrete foundation, 2 ft. 6 ins. above the level of the foundry floor. When skimming-off the first slag, the middle part only of the platform is raised, and a shallow bogie is run in beneath it. When the slagging is finished, this bogie is run out again. It will be seen that this bogie, when in position for receiving the slag, rests on a sliding platform, which is pushed back when

the furnace is ready for tapping, thus allowing room for the ladle.

The case for the automatic regulators, which are of the Thury type (see Fig. 27), and are used for maintaining the arcs at a constant length, is built into a wall between the engine-room and the foundry, so that the regulators are accessible both by the foreman melter in the foundry, and by the electrician in the engine-room. The furnace is tilted electrically, a motor of 5 h.p. being employed. The control of the tilting mechanism is placed immediately in front of the furnace.

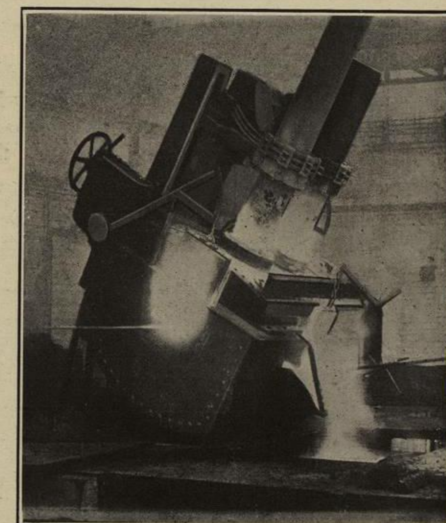

FIG. 28.—The Braintree Heroult Furnace (discharging).

The method of working the furnace is that usually employed when melting and refining scrap in a Heroult furnace. The scrap employed is a mixture of horse-shoes, castings, and foundry scrap, together with boiler-punchings and miscellaneous heavy steel-scrap of small dimensions.

The furnace is served by a 5-ton overhead electrically driven crane. Steel from the furnace is received in a 2-ton bottom teeming ladle (Fig. 28) the actual casting being performed through the intermediate use of hand-shanks, and in the case of the larger castings, by direct casting from ladle. By the use of a bottom-teeming ladle, a ready method is obtained of delivering small and intermittent quantities of steel, free from slag, both to shanks and to moulds.

The steel made is, of course, exclusively dead-soft, testing between ·10 and ·15 per cent. carbon, with manganese and silicon varying slightly, according to the special mechanical properties required. Owing to the refining power of the electric furnace, the sulphur and phosphorus are extremely low, being together less than ·03 per cent.

As a result of the absence of sulphur, the proportion of cracked castings is reduced to a minimum. Cracking or tearing is generally due to contraction over large surfaces. The size, shape and condition of cores will frequently not permit the necessary shrinkage to take place; this sets up stresses in the steel which are sufficient to cause rupture. For case hardening, the Braintree steel is quite equal to the best crucible steel of the same carbon contents.

Other Heroult Furnace Installations in England.

Furnaces of similar size and capacity have been in operation at Messrs. Edgar Allen's, at Messrs. Vickers, and at Messrs. Thomas Firth & Sons, Sheffield, since 1910; and an 8-ton furnace in 1912 was in course of construction at Messrs. Vickers' works. At Messrs. Edgar Allen's Foundry molten steel from an open-hearth furnace is employed for charging the electric refining furnace, while at Messrs. Thomas Firth & Sons, and Vickers', cold scrap is used.

The most important development of electric furnace work in England is that at the Skinningrove Iron Company's Works, at Carlin How, Yorkshire, where the erection of a 15-ton furnace is planned. This furnace will be operated entirely by electricity generated from the waste-gases of blast-furnaces and coke-ovens, and will produce a high quality of rail-steel, from metal run into it from a Talbot melting furnace. The cost of electrical power at this plant is expected to be about ·25*d*. per kw. hour, or about the same as that of the Chicago plant, which is also operated by gas-power.

As regards the power consumption of the smaller type of Heroult furnace, when melting and refining steel scrap, the

following figures, showing the work of the 2½-ton experimental furnace at La Praz, France, for the week ending December 24th, 1911, have been placed in the writer's hands by the Société Electrometallurgique, Francaise, who own and control the Heroult patents.

TABLE IX.

OUTPUT OF ONE 2½-TON HEROULT ELECTRIC FURNACE AT LA PRAZ, FRANCE.

MELTING AND REFINING SCRAP STEEL WITH TWO SLAGS.

Week ending December, 24th, 1911.

Hours worked, 126.

No. of heats, 26.

Average hours per heat including all repairs and charging. } 4 hours 51 minutes.

	Tons.	Cwts.	Qrs.	Lbs.
Total weight teemed,	62	14	2	6, or 140,510 lbs.

Shortest heat, 3 hours 10 minutes.

Lowest power consumption at furnace, 459·2 kw. hours per 1,000 kgs.

Average power for week at furnace, 528 kw. hours per 1,000 kgs.

Percentage of clean ingots	93	per cent.
„ „ scrap	3	„
Oxidation, etc.	4	„

Note: The last heat was the 107th heat made with the same roof, and this was apparently fit for 10 more heats.

Making allowances for the difference in the time taken to refine each charge of metal, these figures represent a larger power consumption than the corresponding ones for the South Chicago furnaces, and the economy of installing large furnaces, heated by three-phase current becomes manifest. In order to obtain the higher efficiency and other advantages of three-phase current generators, small furnaces are being adapted for this method of working, and the Königliche Ungarische Staatseisenwerke, at Diosgyor, in Hungary, are now installing a 2,000-kg. furnace of this type.

The 8-ton Heroult furnace erected in 1912 at Messrs. Vickers' Works, Sheffield, is also of the three-phase type, and the last report received by the author states that this furnace is giving excellent results.

Further Developments of the Heroult Furnace.

The future developments of the Heroult Electric Steel Refining furnace and process would appear likely to be in the direction of utilising three-phase current for all sizes of furnace, and, where large installations are concerned, of employing metal from Open-hearth Furnaces or from the Bessemer Converter, as raw material for the final operation.

Over one-half of the large Heroult furnaces now operating are using molten metal from Martin, Wellman or Talbot furnaces for charging purposes, and in the writer's opinion this method is likely to become generally adopted.

CHAPTER V

THE GIROD ELECTRIC STEEL REFINING FURNACE

The total number of electric steel refining furnaces of the Girod type in use on May 1st, 1912, according to figures supplied by M. Girod, was fifteen, with an aggregate capacity per charge of 66 tons, while five additional furnaces, having an aggregate charge capacity of 20 tons, were under construction. Since the larger number of the furnaces are working with cold scrap, etc., and are producing steel for fine castings and for guns and projectiles, only three heats can be made per twenty-four hours; and the total daily output of the fifteen furnaces in operation in 1912 was 225 tons of fine steel.

The largest furnaces yet constructed or operated are of 12 tons capacity. The fact that of the five furnaces under construction in 1912 only one was of 8 tons capacity and the others were of 2, 3 and 4 tons, would appear to indicate that the Girod type of furnace yields the highest efficiency and best results in the smaller sized units.

The most notable installations of the Girod furnace are to be found at the Forges et Aciéries Électriques Paul Girod, at Ugine, in Savoie, where six furnaces are at work (two of 12 tons); and at the works of Fried Krupp, at Essen, where one 12-ton furnace is in use. A complete list of the twenty furnaces operating or under construction is given in the Appendix. The 12-ton furnaces are charged with cold scrap, and are worked chiefly to produce the special steels required for guns and projectiles. Only at the Gütehoffnungshütte, at Oberhausen, at the Oberschlesische, Eisen-Industrie, at Gleiwitz, and at the Usines Pontiloff, at St. Petersburg, is molten metal employed for charging the Girod furnaces.