CHAPTER XI.

ELECTRIC SMELTING OF STEEL.

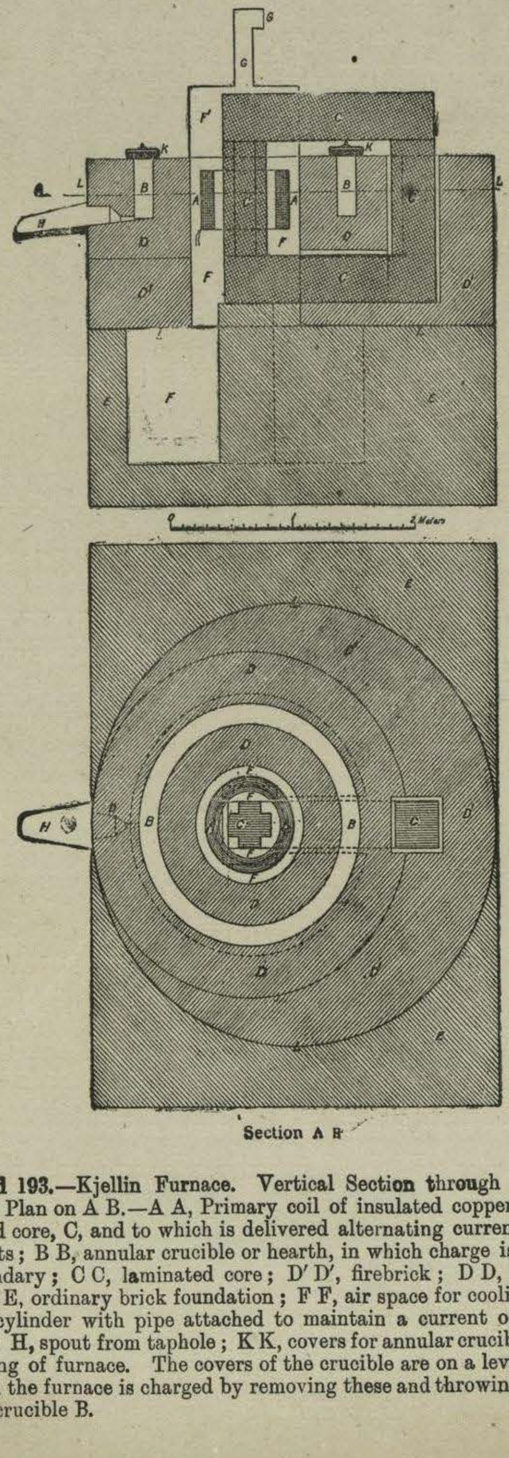
THERE are three distinct types of electric furnaces which are claiming the serious attention of metallurgists, and all three are now being employed to manufacture steel on what may be considered a commercial scale, although at present they are confined to the production of high-class Carbon and Special Steels from cold scrap, or to the refining of molten open hearth or Bessemer steel to produce steel of better quality. The three types of furnaces are (1) The Induction, (2) The Arc Resistance and Resistance, and (3) The Arc.

THE INDUCTION FURNACE.

This type of furnace is a large crucible in which the steel is melted by an induced current out of contact with any electrodes, completely protected from the action of any furnace gases, and practically protected from oxidation. It gives, from a metallurgical point of view, by far the nearest approach to the conditions of the crucible process, and provided the same care is taken in the selection of the raw materials, a finished product, equal in all respects to crucible steel, is obtained. The best known furnace of this type is the Kjellin furnace, which has been in operation at Gysinge, Sweden, since 1900. Figs. 192 and 193, taken from the Canadian Commission Report, are a plan and sectional elevation of this furnace. This furnace is in effect a step-down transformer, in which the contents in the hearth or crucible form the secondary circuit of the transformer. The furnace is of 225 H.P. capacity, and to the primary A A, Fig. 192, is delivered an alternating current of 90 amperes and 3,000 volts, which induces a current in the secondary B B of 3,000 amperes and 7 volts. The primary A A consists of an insulated copper wire wound round one leg of the laminated core C C C C, which forms the magnetic circuit. Where an alternating current is passed through the coil it excites a magnetic flux in the core, and the intensity of the current induced in the steel is then almost the same as the primary current multiplied by the turns of the wire in the primary coil. The tension of the current is naturally reduced in almost the same ratio as the intensity is increased. In this way it is possible to use an alternating-current generator of high tension, and to obtain a current of low voltage and great intensity in the furnace.

The furnace is basic lined, and steel of any required grade can be made exactly in the same way as in the ordinary crucible process (1) by melting blister bars of slightly higher "temper" than the steel required; (2) by melting selected blister bars of distinctly higher "temper," and "letting down" with the required percentage of low Carbon steel scrap; and (3) by melting best Swedish pig-iron with sufficient Walloon iron to give steel of the required "temper." Commercially, however, the method employed in Sweden is to use pig-iron and best Walloon scrap, and by this means any grade of steel from 0·1 to 1·5 per cent., or even higher Carbon, can be obtained.

In making dead soft steel it is necessary to melt Walloon iron practically alone, and for this purpose it is essential to have ample electrical power available to melt the charge rapidly, as otherwise the oxidising slag which



Section A B

Figs. 192 and 193.—Kjellin Furnace. Vertical Section through the Tap Hole and Sectional Plan on A B.—A A, Primary coil of insulated copper wire wound round laminated core, C, and to which is delivered alternating current of 90 amperes at 3,000 volts; B B, annular crucible or hearth, in which charge is melted and forms the secondary; C C, laminated core; D′ D′, firebrick; D D, Silica or Magnesite brick; E E, ordinary brick foundation; F F, air space for cooling primary; F′ and G, iron cylinder with pipe attached to maintain a current of air flowing round primary; H, spout from taphole; K K, covers for annular crucible; L L, cylindrical iron casing of furnace. The covers of the crucible are on a level with the working floor, and the furnace is charged by removing these and throwing the scrap and iron into the crucible B.

is liable to be formed, when present even in small quantities, will tend to produce wild metal.

In starting the furnace, a little molten pig-iron is poured into the circular trough B to form the secondary circuit, and at the finish of each heat, sufficient molten steel is left in the furnace to maintain this circuit. After tapping, cold pig and scrap are charged, and, as they gradually melt, fresh additions of scrap and pig-iron are made from time to time. The charging is done by removing the covers from the top of the annular hearth, and any accumulation of slag formed by oxide on the scrap is raked off the top of the molten metal and removed with iron bars in a pasty condition. The time taken to convert each charge varies from six to eight hours, according to the grade of steel required, the longest time being required for dead soft steel, as it takes longer to melt, and needs more time to get a sufficiently good tapping heat on the metal; consequently the consumption of energy will be greater in the case of low Carbon than high Carbon steel. Slight oxidation takes place during the operation, as materials which have an average composition of 1·4 per cent. of Carbon yield a steel with about 1·1 per cent., showing that about ·3 per cent. is oxidised during the working of the charge. This is probably due almost entirely to the rust on the scrap used, and not to atmospheric oxidation; and it is so slight as not to affect appreciably the oxidation of the impurities present, although Silicon may be to some extent removed.

The following may be taken as the average composition of the materials used and the steel produced :—

Materials Used.			Steel Produced.	
	Best Swedish Pig Iron (White).	Walloon Bar Iron.		Average Composition.
Carbon, . . .	4·400	0·200	Carbon, . . .	1·3 to ·50
Silicon, . . .	0·080	0·030	Silicon, . . .	0·200
Sulphur, . .	0·015	0·003	Sulphur, . . .	0·010
Phosphorus, . .	0·018	0·009	Phosphorus, . .	0·010
Manganese, . .	1·000	0·120	Manganese, . .	0·200
Arsenic, . . .	0·015	0·008	Arsenic, . . .	0·020
Copper, . . .	0·035	0·035	Copper, . . .	0·032
			Aluminium, . .	Nil.

The Carbon and Silicon in the finished steel are varied by regulating the charge, and by the addition of Silicon pig-iron; and by suitable additions, special steels or steel alloys of any composition can be made. Dead soft steel can also be made, and when the author was at Gysinge such a charge was made in his presence, the only difficulty being the removal of the slag, as there was no means of withdrawing it from time to time. In making the high Carbon steel, so little slag is formed that it can be readily removed from the top of the bath, and consequently no slag hole for withdrawing it had been provided, but with slight structural alterations to the furnace mild steel could be easily made.

Various modifications of the Kjellin induction furnace have been introduced during the last few years, amongst others the Frick and the Hiorth furnaces, but there is no new principle involved in either of these, and they vary only in detail from the original furnace at Gysinge, although both inventors claim considerable practical advantages for their furnaces. A 10-ton Frick furnace is working successfully at the Krupp Works at Essen.

One great disadvantage of the Kjellin type of furnace from a practical point of view is the narrow ring channel forming the hearth of the furnace, and this is especially so for furnaces of comparatively large capacity. This form of furnace offers difficulties in charging, repairing, &c., and if refining has to be done by very basic infusible slags, it is difficult, if not impossible, to maintain these slags sufficiently hot, and consequently fluid, to do the necessary work, as the induced currents prefer the path of least resistance—namely, that of the metallic base. Further, the power factor of these furnaces is always low, and although this may be improved by reducing the frequency of the alternating current, it has been found that such an unusually low frequency is required for large furnaces that very expensive generators are necessary. However, furnaces up to 10 tons capacity are in successful operation. These various disadvantages, both metallurgical and electrical, have been largely overcome by the designers of the Röchling-Rodenhauser furnace, which may be regarded as a combination of an induction and resistance furnace.

Like the Kjellin induction, the Röchling-Rodenhauser furnace, Figs. 194 and 195, is essentially a transformer with a single primary winding A round both iron cores H of the transformer. The secondaries are two in number, one is the molten bath in form of an 8, the channel D between the two cores being very broad. The other secondary is the copper winding B, which is connected with the metal plates E. These metal plates are inserted into the furnace walls F in such a way that the currents pass from the winding B through the plates E, and through the mass G of highly refractory electrolytic conductors (of the same nature as those used as filaments in the Nernst lamp) to the molten mass D. In this way the molten mass D is subjected to a double heating effect, one direct by induction and the other from the currents passing between the opposite sets of electrodes E. The direction of the currents in the bath at a certain moment is indicated by arrows in the illustration.

In order to protect the windings against the effect of high temperatures, thin-walled copper cylinders are provided, through which is conducted an air blast passing out of the tubes N_1N_2. The transformer iron contains ventilation slits H. These methods of cooling have been found to be perfectly sufficient during several months' operation.

The charging door is at one end of the furnace, the tapping door at the other end. On account of the method of operation of the furnace the molten charge is kept in sufficient circulation so that all manual operations are restricted to taking care of the right formation of slag and to the tapping of the metal. As shown in Fig. 196, the whole furnace is built as a tilting furnace.

The latest development in connection with this furnace is its operation by a three-phase instead of a single-phase current, which enables a 15-ton furnace to be operated with a frequency of 50 periods instead of 25, and standard three-phase generators to be used instead of specially constructed expensive generators. Figs. 194, 195, and 196 show this furnace in sectional elevation and plan. It is claimed that a special feature of this furnace is the rotation of the charge due to the presence of a rotatory field, as in an induction motor, which insures an automatic circulation in the bath. The furnace is, like the Kjellin furnace, basic lined, and is being used almost exclusively for refining molten steel made in Bessemer or open-hearth process, although, provided it is started with a small quantity of molten metal, there is no reason why cold scrap and pig should not be charged.

When starting with cold scrap rings of metal embedded in scrap turnings, &c., are placed in the furnace, and the current switched on; the rings soon become heated, and heat the surrounding material, so that the entire charge melts rapidly.

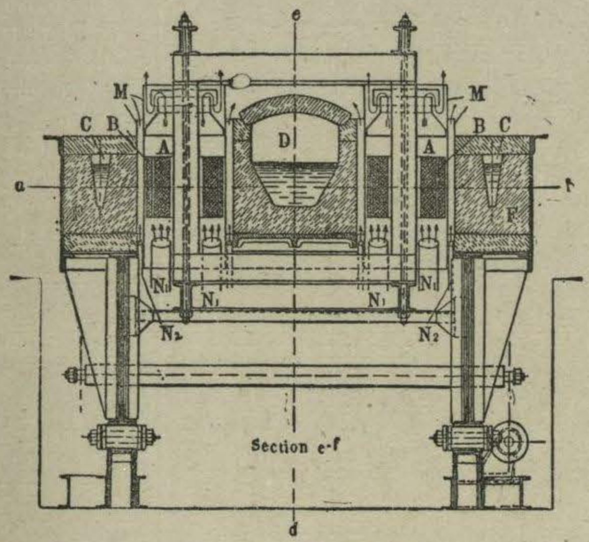


Fig. 194.—Sectional Elevation of Röchling-Rodenhauser Furnace.

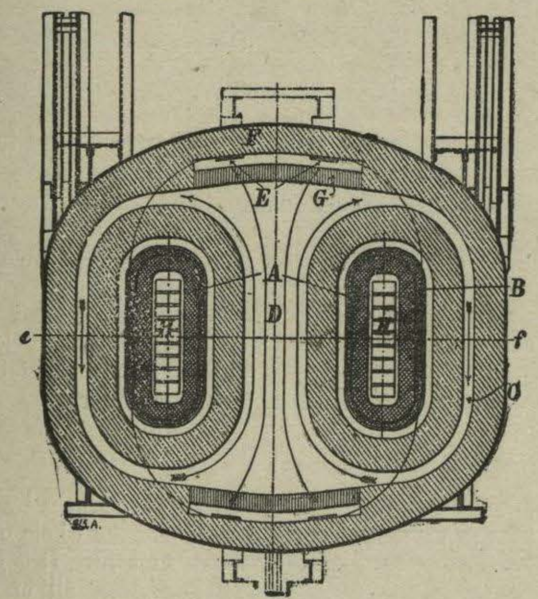


Fig. 195.—Sectional Plan of Röchling-Rodenhauser Furnace.

From the practical metallurgical standpoint, this furnace has many advantages over the Kjellin furnace, as materials can be readily charged into the wide portion of the hearth. Sufficient heat can be obtained to maintain a fluid slag for refining which can be readily poured or raked off the surface of the metal, and the metal itself when the charge is finished can be poured into a ladle. The central chamber or main hearth is also readily accessible for repairs, as these can be effected from either end through the doors provided. In working a heat either cold scrap or molten steel is charged into the furnace with suitable additions of lime and oxide, and when these are completely melted the slag is poured off, and further additions of lime and oxides added to form a new slag and complete the refining; if necessary this operation can be repeated until metal of the required degree of purity is obtained.

Although cold scrap can be used, the furnace is far better adapted for refining molten metal, and it is in this direction that it may be expected to do the best work. When refining molten metal the amount of energy consumed will vary from 120 to 300 kilo-watt hours, according to the degree of purification required.

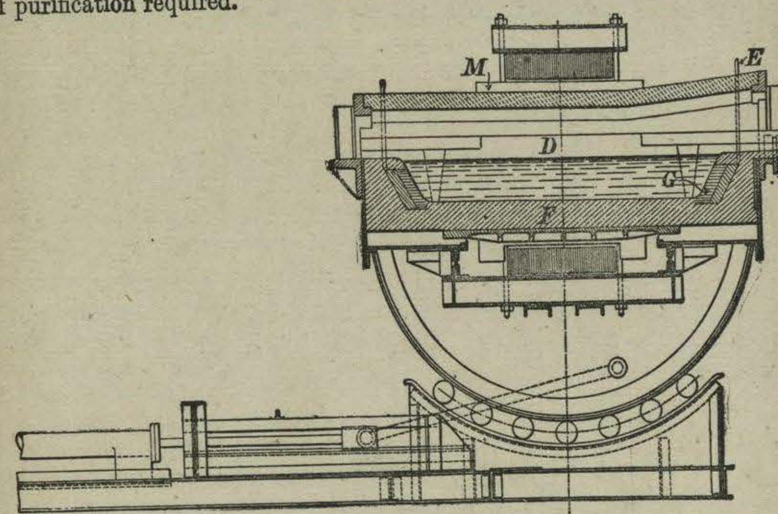


Fig. 196.—Röchling-Rodenhauser Furnace. Section through centre of bath.

A furnace at Völklingen has been in operation for some time refining molten metal from a basic Bessemer converter, and others have been erected in different parts of the Continent.

A very similar furnace somewhat modified in respect to electrical details has been designed by Hiorth, but the difference from the metallurgical standpoint is so slight that no detailed description is necessary.

THE ARC RESISTANCE FURNACE.

In this type of furnace the heat is generated largely by the arc, and, to a smaller extent, by the resistance offered by the whole or a portion of the furnace charge to a very powerful electric current. It is represented by the Héroult, Keller, Girod, and Grönwal furnaces, all of which are in commercial operation.

THE HÉROULT PROCESS.

The Héroult furnace is a tilting furnace similar, as regards the tilting section, to the Wellman or Campbell furnace, and lined with basic material. Two electrodes pass through the roof, and a water-jacket

surrounds them supported upon the roof. An alternating current of about 4,000 amperes at 110 volts is used for a 3-ton furnace, and the intensity of the current passing through the bath of steel is regulated by raising or lowering the electrodes. This may be done by hand, or by a specially designed automatic regulator, which controls separately the position of each electrode by means of a small motor placed at the back of the furnace, and geared to the mechanism supporting the electrodes. The motor is controlled by electric mechanism actuated by variations of the voltage or current below or above certain defined limits. At the ends of the furnace, where the gas ports are in the ordinary Wellman furnace, are charging doors, and in front is a movable door over the pouring spout. In starting the furnace

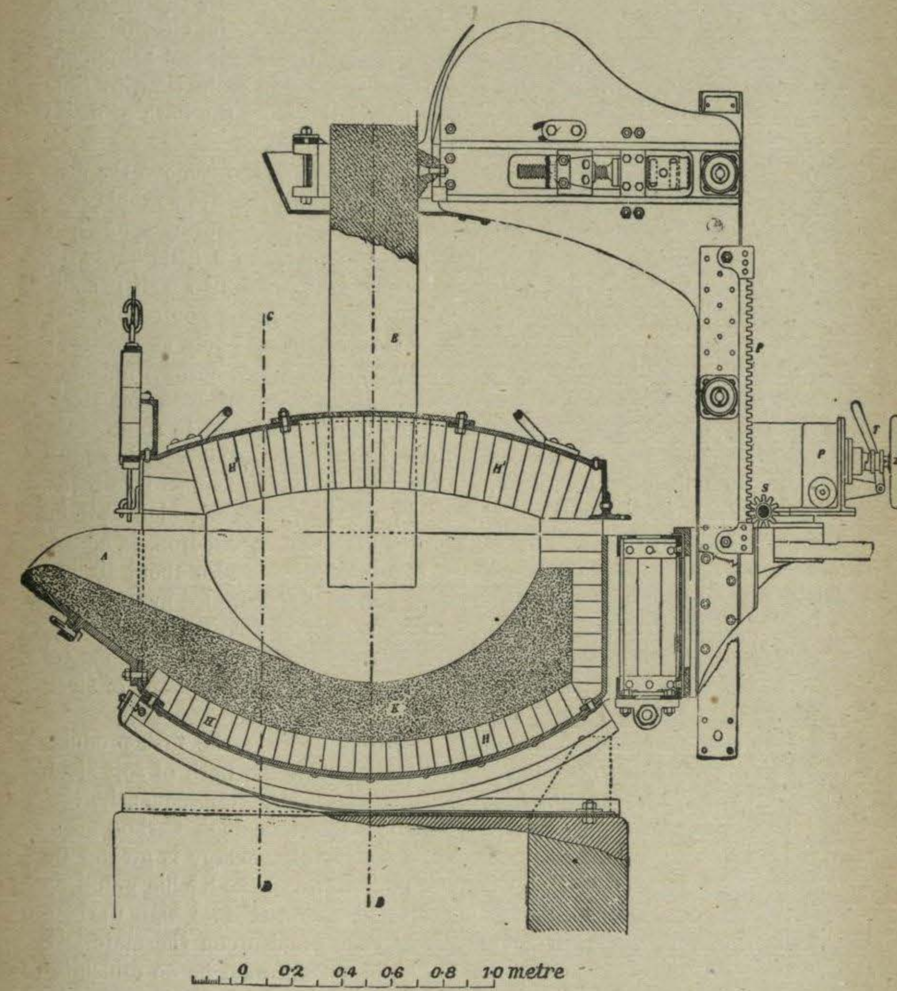


Fig. 197.—Vertical Section through the Pouring Spout of the Héroult Furnace at La Praz.—A, Pouring spout; E, suspended electrode, of which there are two passing through roof; H, basic or burnt Dolomite bricks; H′, Silica bricks of roof; K, rammed basic material; P, motor for driving automatic regulator; T, lever for throwing motor, P, out of action; Z, hand-wheel operating pinion, S′, for regulating electrodes by hand; R, rack gearing with S, by which electrode is raised or lowered. An alternating current at 110 volts is used.

for melting and refining some lime and iron ore are first placed upon the furnace bottom, and then miscellaneous wrought iron and steel scrap, such as old bolts, plate cuttings, &c., are charged into the furnace, and the electrodes are lowered sufficiently to establish an electric circuit, the current passing between the electrodes and the charge. At first, before the iron is melted, the electrodes are generally in contact with it, and numerous small arcs and high resistance contacts are formed between the pieces of metal, which largely absorb the energy of the current. The resistance of the charge varies greatly during this period, violent fluctuations of the current taking place owing to the continual change in contacts and disruption of circuits, but gradually, as the metal melts and an arc is established between each of the electrodes and the molten bath, the greater part of the energy is absorbed by these two arcs. When the bath is melted, the electrodes are kept just above the surface of the slag, the width of the air-gap being controlled by the regulator. Iron ore and lime are added from time to time exactly as in the ordinary open hearth process, and when the bath of metal and slag is completely melted the current is switched off.

The furnace is then tilted, and the slag poured off; to remove the slag completely, the surface of the metal is skimmed with an iron rabble, the slag being raked off the bath through the door over the pouring spout. A new slag is now formed by adding lime and fluorspar and a little ore, with sufficient sand to give fluidity, and the current switched on to melt it completely. After the slag has been melted for some time, it is poured off, and the surface of the bath again raked to remove it as completely as possible; further additions of lime, fluorspar, &c., are then made to form a finishing slag, to remove the last traces of impurity. In the case of dead soft steel, after the slag has been poured off, from 1·0 to 1·5 lbs., and in some cases as much as 2 lbs. of 80 per cent. Ferro-Manganese per ton of steel is added in the furnace, and the metal is poured into the ladle and teemed into ingot moulds, a little Aluminium being added in the ladle. When high Carbon steel is required "carburite," a mixture of pure Carbon and iron, is added until the required degree of carburisation is obtained, and also about 10 lbs. of 12 per cent. Silicon pig per ton of steel. The bath is sampled in the usual way with a spoon ladle, and when the furnaceman is satisfied with his sample the metal is poured into the ladle and teemed. The time from charging to tapping varies from about six to eight hours, according to the grade of steel required.

It will be noted that when starting with scrap iron the first product obtained is soft steel; to produce high Carbon steel, the bath of soft steel first obtained has to be carburised by suitable additions. Consequently, the metal has to be kept longer in the furnace to produce high Carbon steel than low Carbon steel, and the consumption of electric energy is greater in the former case than the latter. This is just the reverse of the Kjellin practice, where it takes longer to produce dead soft steel than it does high Carbon steel. The method of working, however, depends more upon the materials commercially available than anything else, and there would be no difficulty in making high Carbon steel without recarburising by melting down a suitable mixture of pig and scrap in the Héroult furnace; and, on the other hand, pure scrap could be melted down in the Kjellin furnace and recarburised by suitable additions at the end of the operation if desired.

The amount of energy required for melting and refining cold scrap to produce 1·00 Carbon steel varies from 700 to 1,000 kilo-watt hours, according to the capacity of the furnace. About 110 tons of scrap are required to produce 100 tons of ingots. The cost of repairs and renewals, when melting and refining cold scrap, including roof and basic and acid refractories, varies from 3s. 6d. to 5s. 6d. per ton, according to the price of materials in different places, and the output of the furnace. A Héroult furnace at La Praz of 2·4 tons capacity made twenty consecutive heats, melting and refining common scrap at the rate of about four heats per twenty-four hours, of which five hours ten minutes was the average duration of the heat, and the average intervals for fettling and charging were forty minutes. The yield of ingots was 94 per cent. of the rough scrap charged, and the consumption of electricity was 765 kilo-watt hours per ton.

Recently there have been considerable developments in the direction of the refining of molten Bessemer or open hearth steel, the steel being conveyed to the furnace in a ladle and subjected to a refining by addition of suitable fluxes, one or more slags being made according to the degree of purification required. The energy consumed under these conditions varies from 120 to 300 kilo-watt hours per ton of steel produced, according to the quality of steel required. In the case of five consecutive heats at one of the furnaces used by the United States Steel Corporation for refining steel from an acid Bessemer converter which was high in Phosphorus and Sulphur, the consumption was 172 kilo-watt hours per ton, and when producing the same quality of finished steel from open hearth metal low in Phosphorus the consumption of energy fell to 111 kilo-watt hours. The cost of refractories, renewals, &c., is very considerably reduced when molten metal is used instead of cold scrap. The Silica brick roof is stated to last from 100 to 150 heats, and the total cost not to exceed sixpence to one shilling per ton, according to capacity, &c., of the furnace.

The following may be taken as a typical analysis of the steel produced, the Carbon being varied as required:—

Carbon, ...	0·060 to 1·700
Silicon, ...	0·080 to 0·180
Sulphur, ...	0·013 to 0·022
Phosphorus, ...	0·009 to 0·012
Manganese, ...	0·140 to 0·270
Arsenic, ...	trace to 0·09
Copper, ...	trace

The arsenic and copper will vary with the percentage present in the raw materials used, as these impurities are not removed during the working of the charge. From a number of analyses made of Héroult and Kjellin steels by the author for the Canadian Government Commission from the centre, the top, and the bottom of different ingots, both steels were shown to be of very regular composition, and remarkably free from the segregation of impurities. The mechanical properties of both steels were extremely good, and when forged into tools and compared by series of trials in the lathe with the best crucible tool steel of similar content of Carbon, they gave results in every way equal to their more costly competitor. The above results have been fully confirmed by further experience, and now there are a number of these furnaces, both in Europe and England and America, either in operation or in course of erection.

Special steels, or high-speed tool steels, are now being made commercially in the Héroult furnace, and there is no reason why such steels should not be satisfactorily and economically produced in this and other electrical furnaces.

THE KELLER PROCESS.

The original furnace employed really consisted of two furnaces at different levels, one fixed and one tilting. When working pig and scrap, the materials were melted and partially refined in the upper furnace, and then tapped into the lower tilting furnace, where the charge

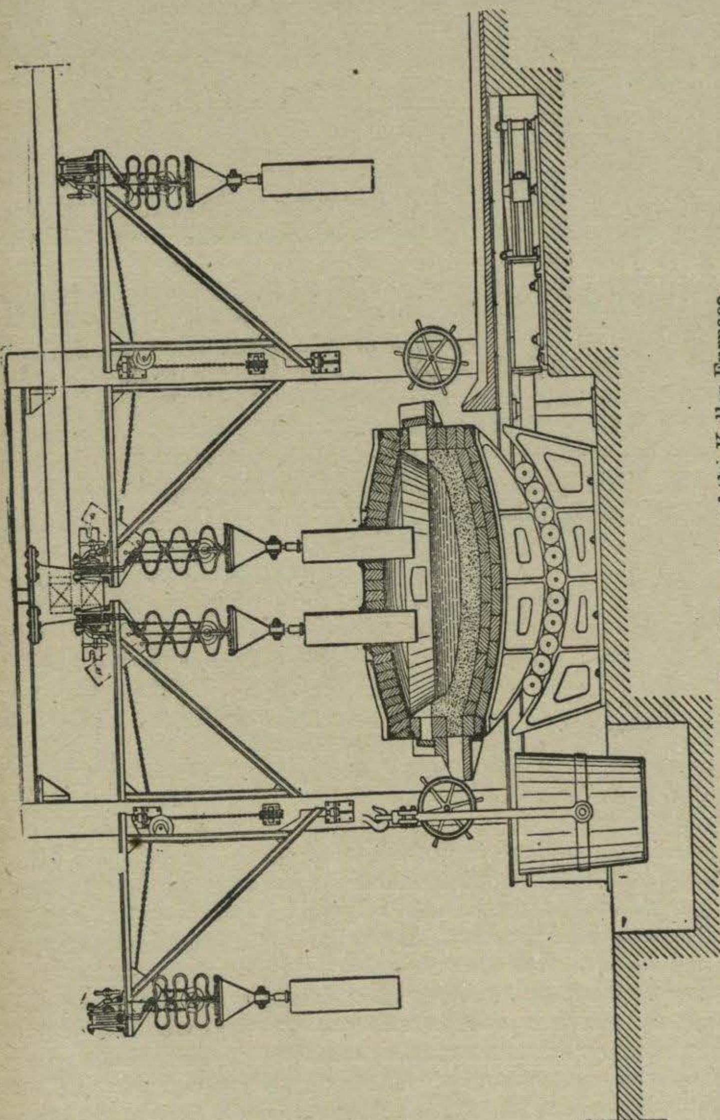


Fig. 198.—Sectional Elevation of the Keller Furnace.

was finished. Care was taken that the slag from the melting furnace did not pass into the finishing furnace with the metal. When working scrap charges, the preliminary refining furnace was dispensed with, and the scrap was melted direct in the tilting furnace; this latter furnace was mounted on trunnions, and could be tilted in either direction. Instead of having a spout, it had a tap hole at one end, and not in the centre of one of the

longer sides, as is usual in open hearth furnaces; at the other end was a slag hole. The metal was tapped out in the usual way, the furnace being tilted to drain all the metal off. During the working of the charge, slag was poured off several times from the slag hole at the opposite end to the taphole by tilting the furnace in that direction; the furnace was basic lined.

The electrodes passed through the roof and were regulated by hand, and the charge was melted down with lime and ore additions exactly as in the Héroult process, the slag being poured off and a new slag formed two or three times during the operation; the details of working being the same as in the Héroult process, it is not necessary to repeat them.

Since the original furnace was erected the design has been considerably modified, the latest type erected at the Holtzer Steel Works, Unieux, France, being mounted on rollers for tilting. The body of the furnace is circular, and there are four electrodes mounted on movable supports independent of the furnace, so that they can readily be removed and replaced when necessary. The electrodes pass through the roof of the furnace, and two electrodes in parallel are coupled to each pole. The current is regulated by raising or lowering the electrodes by motors, and each electrode can be manipulated independently. This particular furnace is used for refining molten metal, but it is equally well adapted for the use of cold scrap. Fig. 198 shows the general design of this furnace and method of supporting the electrodes.

Steel of any Carbon content from 0·08 to 1·5 per cent. or higher, and extremely low in Sulphur and Phosphorus, can be made. From a metallurgical standpoint, the process is identical with the Héroult process, working under similar conditions, and the same high quality of products can be obtained.

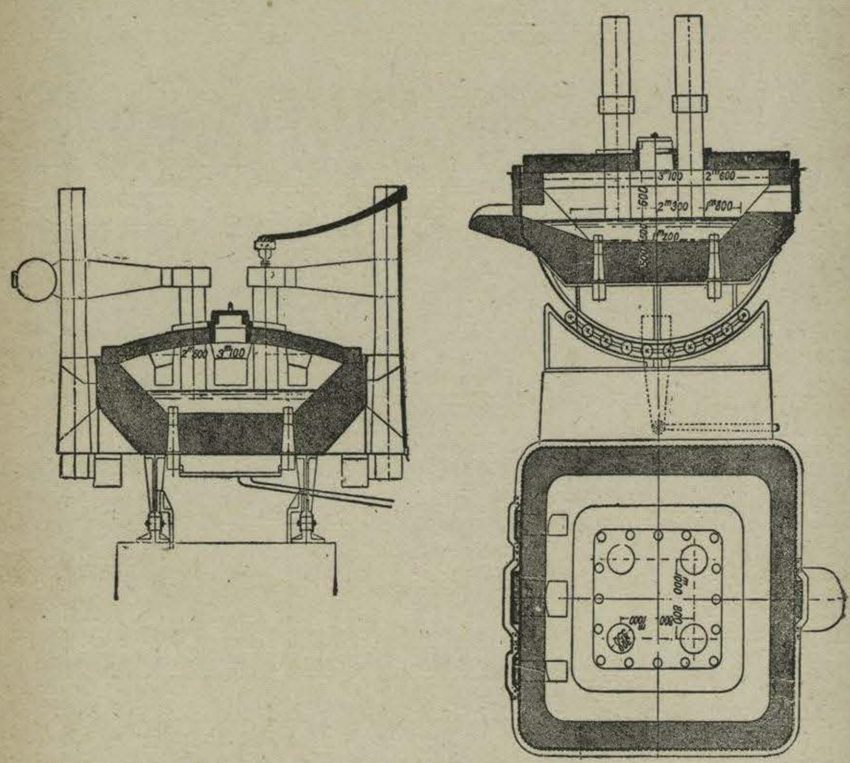
THE GIROD FURNACE.

A sketch of this furnace is shown in Fig. 199, and in general construction it is very similar to the Héroult furnace, but it differs in that the electrodes passing through the roof are of like polarity, and pole pieces of soft steel embedded in the hearth of the furnace and in direct contact with the molten metal form the negative electrode. The current enters by the upper electrodes, forms an arc between itself and the bath, traverses the bath, and passes out through the lower pole pieces. These lower pole pieces have a cavity about 6 inches deep on their lower ends, which are water-cooled, and notwithstanding the fact that the upper ends in contact with the bath become molten, not more than a few inches are said to wear away during several months' work.

In small 2-ton furnaces a single electrode through the roof is used, but in larger furnaces several electrodes may be used, but whatever their number they are all mounted in parallel and connected with the same terminals of the machine, the other terminal being connected with the metallic pole pieces.

At the Oehler Works, Aarau, Switzerland, a 2,000-volt two-phase current system supplies a 450 H.P. motor, running at 560 revolutions, and is coupled direct to a single-phase alternator, giving 4,600 to 5,000 amperes single-phase current at 65 to 75 volts, the frequency being 37·4 periods per second. Twelve heavy copper cables, each 0·8 in. diameter and composed of twelve copper wires twisted together, carry the current to the furnace. The voltage drop is 2·5 volts from the machine to the furnace. The furnace is 6 feet 8 inches diameter, 20 inches high inside, and is electrically tipped and regulated. The electrode passing through the roof is automatically regulated so as to keep the current at the desired strength by an automatic regulator designed by R. Thury, of Geneva. The electrode is 14 inches square by 60 inches long, and weighs at starting 440 lbs., and lasts, on an average, from five to seven charges.

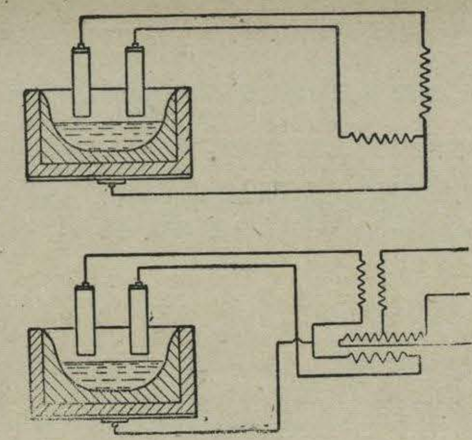
The usual charge consists of steel and cast-iron scrap and turnings, with some pig iron, and each charge takes from five to six hours after charging to finish completely.



Sectional Elevation. *Plan and Sectional Elevation through pouring spout.*

Fig. 199.—The Girod Furnace.

The furnace is basic lined, Magnesite being generally used for the hearth, and the roof is as usual made of Silica brick. The smaller furnaces are used principally for the manufacture of steel castings, but large furnaces up to 12½ tons capacity are being used at Ugine. The advantages claimed for this furnace are that the current can be easily regulated automatically owing to there being only one fall of tension to be regulated; that the low voltage, about 50 to 55 volts, renders it easy to insulate the electric conductors thoroughly; and that the current passing through the metal bath, the entire mass is traversed by the current, and almost the whole of the difference in voltage at the terminals of the furnace is absorbed by the resistance of the charge, which is of special advantage during the melting down period. Either a continuous or an alternating current can be used.



Figs. 200 and 201.—Electric connections to Grönwal Furnace.

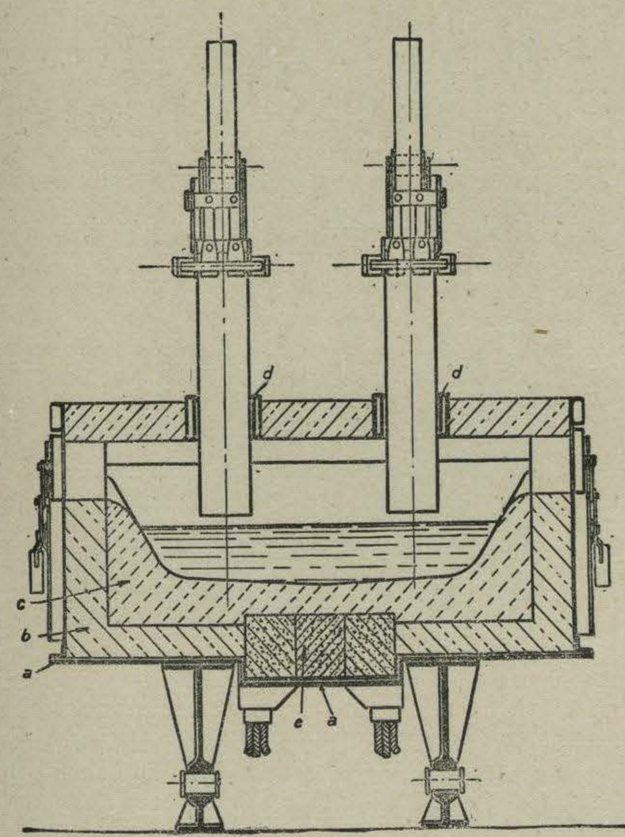


Fig. 202.—Grönwal Furnace—Longitudinal Section.

a. Cast-iron plates.
b. Layer of Graphite or Carbon.
c. Basic material or Magnesite.
d. Water-cooled blocks round electrodes.
e. Solid Carbon block embedded in the lining.

THE GRÖNWAL FURNACE.

This is another electrode or arc resistance furnace designed to employ a two-phase current instead of a single-phase or three-phase current, which has been introduced in Sweden. The furnace is mounted on a tilting frame the same as a Héroult or Keller furnace. It is built up on cast-iron plates, a layer of Graphite or Carbon of high conductivity being placed upon these, and upon this the basic material to form the hearth; solid Carbon blocks are embedded in the bottom lining as shown in the sketch, Fig. 202. The advantages

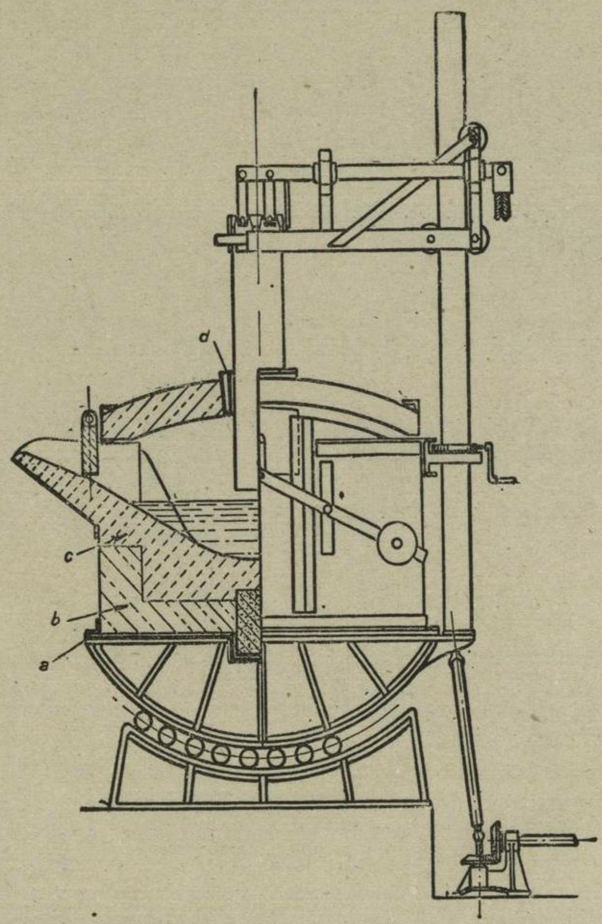


Fig. 203.—Grönwal Furnace—Cross Section.

claimed for this two-phase arrangement are that the generating plant and transmission are cheaper and more satisfactory in operation; that a three-phase current can be generated and transmitted, and transformed into two-phase in the furnace room; that the heat is transmitted through the charge, and stirs the metal up from the bottom of the furnace and the circulation of the bath is more complete; and that the two arcs not being in series but separate phases, are independent of each other, and can be regulated separately, so that the control of the current is more complete.

Fig. 200 shows diagrammatically the electric connections for an ordinary two-phase current, and Fig. 201 the arrangement for transforming the three-phase into a two-phase current. Fig. 202 is a vertical longitudinal section of the furnace, showing details of Carbon sole, &c., and Fig. 203 shows furnace in cross section, method of tilting, &c.

From the metallurgical standpoint this furnace is identical with other arc furnaces, and the operation of melting and refining is exactly the same. Whether the Carbon sole will give satisfactory results in practice can only be determined after the furnace has been in operation for a considerable period.

THE RUTHENBURG FURNACE.

An experimental furnace of this type has been erected at the works of the Brush Company, Loughborough, and although up to the present it is not installed in any works producing steel commercially, it has several novel features of considerable interest. It is a resistance furnace using a three-phase alternating low-tension current, and the ends of the electrodes are

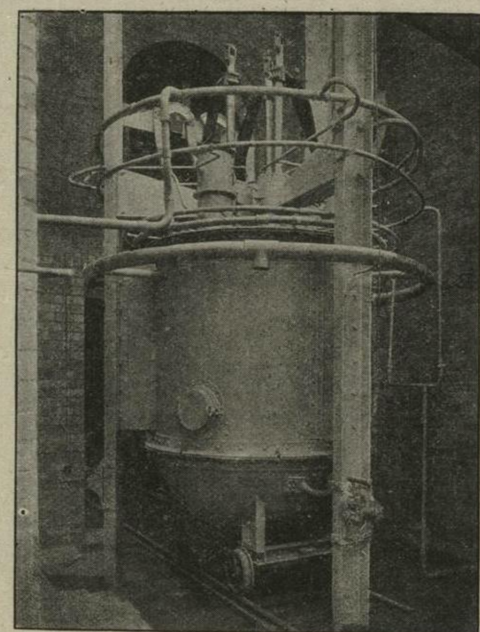


Fig. 204.—Ruthenburg Furnace.

immersed in the slag, which acts as a resistance, and consequently becomes heated to a high temperature. The body of the furnace consists of a circular iron casing lined with refractory material provided with doors for charging, &c., and with a movable bottom mounted on a carriage or bogie, so that it can be readily withdrawn from the furnace body and replaced by another, thus facilitating repairs, and enabling the furnace to be kept in continuous operation during the relining of the hearth; the bottom is withdrawn for casting the metal, but in regular work it is doubtful if this would be practicable, and it is probable that better results would be obtained by mounting the furnace on a tilting frame, and pouring the metal into a ladle and teeming in the usual way. The electrodes are vertical, and pass through the roof, the special feature being that they are water-jacketted to *within a few inches of the bath;* these jackets are lined with a refractory material. The water-jacket largely protects the electrodes from the action of any furnace gases generated and air which leaks into the furnace, and enables the Carbon electrodes to be fed through the jacket, so that the whole of the electrode can be used, thus resulting in considerable economy in electrodes. The consumption of energy is apparently about the same as in other resistance furnaces producing steel from similar materials, but this point, and also the actual saving in electrodes, cannot be accurately determined until detailed results from a furnace running continuously over a period of some months are available. The furnace is also suitable for manufacture of alloys, and numerous experiments have been made in smelting different classes of ore. Fig. 204 illustrates the general design of the furnace.

THE GIN FURNACE.

This is a resistance furnace designed to avoid the disadvantages attending the use of electrodes, and it depends upon the resistance offered by a bath of molten steel of small cross-sectional area.

The furnace hearth consists of a trough or channel of considerable length and small cross-section; this channel is filled with molten pig-iron, and terminal water-cooled blocks are provided for connections for the electric circuit. For convenience, the channel which holds the metal is doubled upon itself several times, so that in plan it has the form of a huge filament of an incandescent lamp. By varying the current passing into the fused metal the required temperature can be obtained. It is stated that by having the terminal blocks of very large section in comparison with the section of the channel carrying the molten metal, and by internal water-cooling, they are prevented from attaining a very high temperature. The furnace is basic lined, and can be used as a crucible or melting furnace for the production of steel, by melting selected pure materials to give the composition of steel required, or it can be used with pig and scrap, additions of ore, lime, &c., being made in the usual way to effect the oxidation and removal of impurities. The difficulty of charging the pig-iron, scrap, ore, &c., into such a furnace during the working of the charge, and the maintaining of the hearth or channel in fair repair, seems to rule out a furnace of this design for the manufacture of steel on anything like a commercial scale, and so far it has not been a success.

A combined form of induction and arc furnace was described by Gin at the meeting of the American Electro-chemical Society at Niagara in May, 1909, in which there were two reservoirs heated by arcs and united by tubular channels inclined in opposite directions, one of which was heated by induced currents from primary and secondary windings, and the other formed with the two reservoirs, the secondary circuit. So far as one could judge from the description there would be considerable difficulty in repairing these canals or channels, and the furnace, from a metallurgical standpoint, does not appear to offer any special advantage over the other types which have proved satisfactory in practice.

THE GIFFRE FURNACE.

This furnace differs from those resistance furnaces already described, in that only one of the electrodes passes through the main roof of the furnace into the hearth of the furnace, and the other electrode is contained in a separate chamber built on to the main body of the furnace, and the electrical connection is maintained by a narrow channel of molten metal between the two electrodes. One advantage of this form of furnace is that structurally it is stronger than the Héroult type, as the roof is not weakened by two electrodes passing through it, and, further, there is no danger of any short circuiting of the current between the two electrodes. The furnace is a resistance furnace, the channel of molten metal being maintained in the fluid condition by the resistance it offers owing to its small cross-sectional area. So far as the author is aware, this furnace has been used exclusively for the production of Ferro-Alloys, and has not been used for steel making or refining, although there seems no reason why it should not give good results in this direction. Comparatively little, however, is known about the details of construction or methods of working this furnace, as nothing has been published, and the patentees are somewhat reticent about giving any particulars. It has, however, been very successfully employed for the manufacture of alloys, especially Ferro-Alloys, low in Carbon like ery rich Ferro-Manganese, Tungsten, Molybdenum, &c., containing less than 1 per cent. of Carbon.

THE STASSANO ARC FURNACE.

In this type of furnace the necessary heat is obtained by direct radiation from the arc and by reflection from the roof and sides of the furnace. As far back as 1879 the late Sir Wm. Siemens designed a small crucible furnace capable of melting a few pounds of steel on this principle, and the Stassano furnace is the best known furnace of this type used for the smelting of iron and steel. It is shown in Fig. 205, with a description attached. The furnace rotates round an axis inclined about 7° to the vertical. In one modification of the furnace it is mounted on a tilting frame, the rotation being dispensed with. There are three electrodes, which nearly meet in the centre of the furnace, their distance being regulated by hydraulic rams. A three-phase alternating current is used and distributed between the three electrodes.

The furnace is capable of producing 4 or 5 tons of steel per day, a current of 4,900 amperes at 150 volts being distributed to four electrodes supplying two arcs with 2,450 amperes for each arc. The electrodes are cylindrical in shape, about 6 inches in diameter, from 50 to 60 inches long, and weigh about 132 lbs. The furnace is lined with Magnesite blocks made specially to the shape of the furnace, the roof also being built of Magnesia bricks. The weak point about this type of furnace is the cost of repairs, the direct radiation from the arc on to the roof being very destructive; the life of the roof might probably be considerably prolonged by slight modification in design, and possibly Silica bricks may be used, but so far as present experience goes no refractory material except Magnesite bricks have been found capable of withstanding the high temperature, and the cost of these is considerable.

This furnace is doing very good work in the manufacture of steel castings of extremely soft quality from miscellaneous iron and steel scrap. The scrap, mixed with a little oxide of iron and lime, is charged and melted down as usual, and towards the end of the operation a portion of the slag is poured or raked off and a fresh slag formed by suitable additions to reduce the Phosphorus to the required extent and desulphurise the bath. For small charges of about 1 to 2 tons, especially when the metal has to be poured into a number of small moulds, this furnace is particularly suitable, the fluidity and purity of metal enabling very sound castings of highest quality to be produced.

Various experiments have been made in this furnace to produce steel direct from the ore, and with exceptionally pure ores very promising results have been obtained, but owing to the difficulty of controlling the composition of the slags with average ores, the production of steel of any required grade is far from easy, and the wear and tear on the furnace is so considerable that

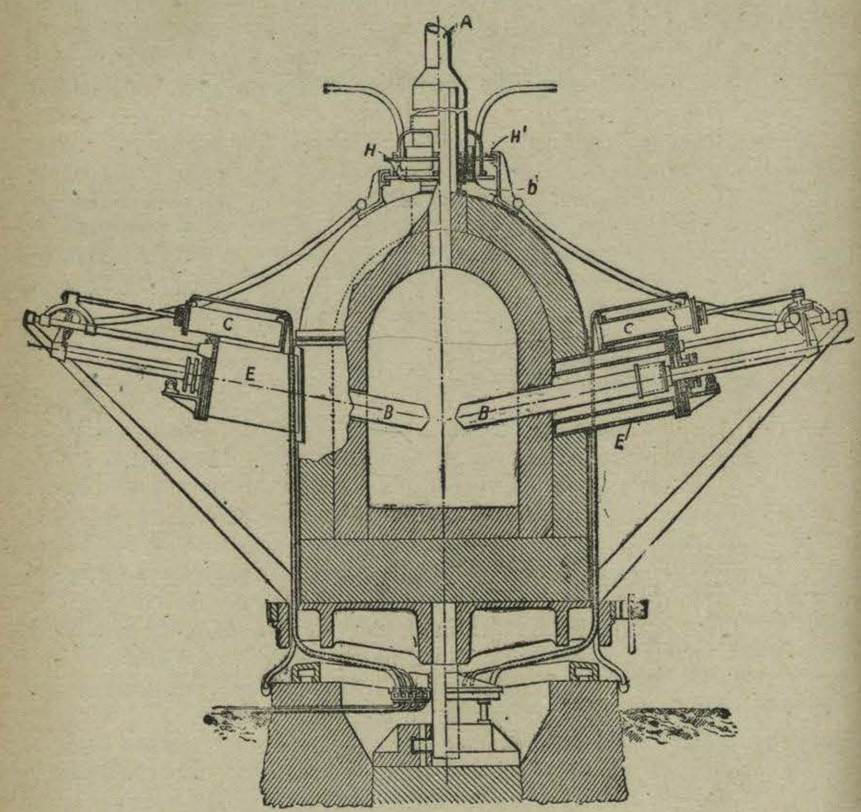


Fig. 205.—Sectional Elevation of Stassano Electric Furnace.—Furnace lined with Magnesite bricks. The furnace is slightly inclined to the vertical, and rotated by mechanism, shown below. Volatile products led off through tube, A. B B, Electrodes; C C, hydraulic cylinders for regulating electrodes; E E, water-jacket for electrodes; H H', two strong metal insulated rings (fastened to fixed tube, *b*, which does not rotate with furnace) to receive current from cables. The current is conducted to the electrodes from these rings by means of brushes, which run along the rings with the movement of the furnace; the electrodes rotate with the furnace. There is a tap hole for metal at bottom of furnace, and a slag hole at somewhat higher level. The charge is fed through a hopper and inclined shoot to deliver below the electrodes.

there does not seem any probability of this being commercially successful; in any case a large amount of experimental work will have to be done before the commercial stage is reached.

The Removal of Phosphorus and Sulphur.—Under proper conditions the elimination of Phosphorus and Sulphur from the metallic charge in the electric furnace is far more complete than in the open hearth or any other process of steel manufacture. If we except the Kjellin induction furnace, all types of electric furnaces may be regarded as basic open hearth furnaces, in which refining can be carried on at a much higher temperature, and in which a nearly neutral or non-oxidising atmosphere can be maintained during the whole operation. So far as the removal of Phosphorus is concerned, the slightly oxidising slag, combined with its high basicity and the fluidity which can be maintained by the high temperature, is sufficient to explain its complete removal, and to some extent the same applies to the removal of Sulphur, but it does not entirely account for the latter. It is well known in basic open hearth practice that Sulphur, especially when it is desired to remove it to below ·05 or ·04 per cent., cannot be eliminated until the end of the operation, and the necessary conditions are a non-oxidising basic fluid slag; the lower the percentage of oxide of iron and the higher the percentage of lime the more completely is the Sulphur removed. The elimination, however, is limited by the difficulty of maintaining a highly basic slag of sufficient fluidity, free from oxide of iron, and, further, by the fact that Sulphur is liable to be taken up from the gases in an oxidising atmosphere and oxidised into Calcium Sulphate, when it may pass again into the bath of metal according to the equation—

$$CaSO_4 + 4Fe = FeS + 3FeO + CaO.$$

The Sulphur in the metal is present as Sulphide of Iron dissolved in the steel, and its removal in combination with Calcium as Calcium Sulphide is not an oxidising reaction like the removal of Phosphorus, but a reaction taking place under reducing conditions; hence the presence of a reducing agent facilitates, while the presence of oxides of iron retards its removal.

The removal of Sulphur in the Héroult furnace has recently been investigated by Dr. Th. Geilenkirchen,* and he explains it as due to the action of the Carbide of Calcium formed in the slag, which by its reducing action first deoxidises the metal and reduces the oxides in the slag, and then removes the Sulphur according to the following equation:—

$$2Ca + 2FeS = 2CaS + 2Fe.$$

To facilitate the reduction of oxides and obtain a neutral slag, the usual practice is to throw small quantities of powdered Carbon on the top of the slag on which it floats, and while rapidly reducing the oxides in the slag, does not pass into the metal.

In the Héroult or similar type of furnace, the high temperature enables slags of almost any degree of basicity to be maintained in a state of fluidity, and slags containing 63 per cent. to 65 per cent. of lime and 1 per cent. of iron are not uncommon; the atmosphere is practically neutral and there can be no doubt that Carbide of Calcium is produced in the slag, so that we have all the conditions essential to the removal of Sulphur, and the above explanation seems to accord with the facts.

Although the above may explain the Sulphur removal in electrode resistance furnaces it cannot be suggested that Carbide of Calcium is formed in the induction furnace, and as the removal of Sulphur is equally complete, the conditions of its removal require a little consideration.

* *Stahl und Eisen*, July 15, 1908.

Prof. Osann * has very carefully investigated this question, and he at first tried to remove the Sulphur by an extremely basic slag thinned with fluorspar; but this was not successful to the extent required, and he soon found to reduce the Sulphur to ·01 per cent. or less it was necessary to add some powerful reducing agent to remove the oxides in the slag. In the first case Carbon was added to carburise the metal and reduce the oxide of iron in the slag, but this was not found to be efficient, and finally small quantities of 50 per cent. Ferro-silicon were added to the slag. The method of procedure is as follows:—After the removal of Phosphorus, the slag is poured off as completely as possible and a new slag made with lime and fluorspar. Ferro-silicon, in pieces the size of an egg, is added in sufficient quantity to give about ·35 of Silicon in the bath, and then small quantities of Ferro-silicon broken to the size of peas are thrown into the slag until it is white and shows by its colour on sampling that it is free from iron, by which means the Sulphur can be reduced from ·06 or ·07 per cent. to ·008 per cent. The use of Ferro-silicon has the advantage that its oxidation at the expense of the oxide of iron produces heat, and raises the temperature of the hearth. The reducing conditions may be assisted by additions of Carbon powder as well as Silicon.

Prof. Osann considers the presence of oxide of iron in the slag prevents desulphurisation, because of the reaction $FeO+CaS=FeS+CaO$, which is a strongly exothermic reaction, or reaction attended with considerable evolution of heat. It is of considerable interest to note that two quite independent investigators working under different conditions have both arrived at the same conclusions as to the essential conditions for desulphurisation; although the particular means employed to produce these conditions were different in each case, the results obtained are very largely confirmed by ordinary basic open hearth experience, and, in the author's opinion, there is little doubt as to the general soundness of the deductions drawn.

It must be remembered that the addition of reducing agents to the slag is only possible after the removal of the phosphoric slag, as otherwise the Phosphorus would be reduced and pass into the metal, and hence it would be difficult to apply these methods of desulphurisation in the basic open hearth process as worked under ordinary conditions with a highly Phosphoric slag.

Manufacture of Steel in Different Furnaces.—It is extremely difficult to compare the cost of production in the different furnaces described, as to obtain reliable results it would be necessary to carry out an exhaustive series of experiments with each furnace, working under identical conditions as to supply of raw material, &c., but so far as the consumption of energy is concerned for the production of the same grade of steel, there is probably no very great difference, and the advantage claimed by one furnace over another in this respect is probably due more to some variation in materials used, size of furnace, &c., than to the difference in electrical efficiency. That there is some difference in this respect must be admitted, but this taken alone is hardly likely to be a determining factor in the selection of a furnace, and other considerations, such as the facility with which a furnace can be charged and tapped or repaired, and similar practical considerations, are likely to carry far more weight with the steel maker.

In starting with cold materials, such as steel scrap and pig, the consumption of energy per ton of steel produced may be taken as from 850 to 1,000 kilo-watt hours, according to the grade of steel produced and the size of the furnace, as in larger furnaces the energy consumed per ton of steel

* *Stahl und Eisen*, July 17, 1908.

is less. The cost of refractories will vary considerably with the size of the furnace and the price of the materials delivered at the works, but probably a fair figure is 5s. to 6s. per ton for small furnaces under ordinary conditions, although in steel-making districts in England this might be somewhat less. The consumption of electrodes will also vary somewhat with the type and size of the furnaces; in the Héroult furnace, about 35 lbs. being used per ton of steel produced, and in the Girod about the same, whereas in the Stassano arc furnace only about 20 to 22 lbs. per ton of steel is stated to be consumed.

Where pure materials can be procured, as in Sweden, and pure scrap and pig iron can be mixed together in such proportions as to give a steel of the required composition, the original Kjellin induction furnace has much to recommend it, as we are able to obtain practically all the conditions of crucible melting with the additional advantage that tons can be melted down instead of pounds.

If, on the other hand, the raw material is ordinary miscellaneous scrap, then it is absolutely necessary to have a furnace in which extremely basic slags can be retained in a state of fluidity to refine the metal, and that these slags can be removed when desired, and additions of basic materials added to form new slags to purify the steel completely; in such cases we have to select either an arc resistance furnace, like the Héroult, Keller, or Girod, an arc furnace like Stassano, or the new Roechling-Rodenhauser induction furnace. All these furnaces are capable of making steel of the highest quality from common scrap, and the high temperature obtainable and freedom of steel from oxidation give exceptional fluidity to the metal which is particularly suitable for the manufacture of sound castings; all these furnaces have been very successful in the production of castings from practically dead soft steel.

At best the electric furnace is a dear melter, especially in England, where the cost of producing electric energy must always be comparatively high; but it is an economic refiner at those high temperatures, when the reaction between the slag and the metal is most effective. It is, therefore, as a refiner for ordinary steel that the electric furnace is deserving of most careful consideration.

The consumption of energy in refining molten metal is practically the same in all types of furnace, but will vary according to the quality of the finished product required, from 120 to 300 kilo-watt hours per ton of steel produced. In Germany and the United States, where furnaces are being used for refining basic and acid Bessemer metal for the production of higher-class rail steel, from 100 to 150 kilo-watt hours per ton are required, but for better-class steel 250 to 300, and in case of special tool steels as much as 350 kilo-watt hours per ton of steel have been found necessary.

In England it seems doubtful if the electric furnace will be largely used for rail steel manufacture, as the quality of steel produced from our acid and basic open hearth furnaces and converters gives generally satisfactory results, and it is a question whether the improvement in quality would necessarily give such results in service as would justify the increased cost.

In America the position is somewhat different, as a large proportion of their Bessemer ores cannot produce rails with less than ·10 per cent. of Phosphorus, and to meet the more severe requirements of modern specifications steel makers will either have to scrap their existing Bessemer plants and erect some form of basic open hearth furnaces or adopt some refining method for removing the Phosphorus in their blown metal. The United States Steel Trust have recently erected several 15-ton Héroult steel furnaces to work in conjunction with their Bessemer plants, for refining the blown metal for rail steel, and the results are stated to be very satisfactory, and it is probable other furnaces will be erected.

Apart from the manufacture of high-class crucible steel and steel castings, for which there is a comparatively small demand, and steel rails, for which there is a very great demand, there are many intermediate products between these, for which a high-class steel is required, such as axles, tyres, special forgings, &c. All these could be produced by refining molten metal from an open hearth furnace or Bessemer converter at a cost which in many cases would compare very favourably with present costs in the open hearth furnace. Practically for all these steels specially selected pig-iron and scrap has to be used, for which high prices have to be paid, whereas if the electric furnace were used as a refiner the ordinary quality of Bessemer pig-iron and common scrap could be employed, and the decrease in cost of materials would probably quite meet the costs of refining, with the additional advantage that there would be an improvment in the general quality and regularity of the finished steel. Except for the highest class of steel products, the electric furnace cannot hold its own when using cold materials, and it is as a refiner for Bessemer and open-hearth steel that its future development is likely to take place.

It must be remembered that refining is not simply a question of producing a steel of better chemical composition lower in Phosphorus and Sulphur, but the steel is maintained fluid in a neutral atmosphere out of contact with all gaseous products of combustion, and the conditions are such that there is every opportunity for the escape of occluded gases, and for the almost complete deoxidation of the steel. Both deoxidation and the removal of occluded gases are recognised by practical steel makers to have a most important influence on the physical properties of steel, and it is probable that the special qualities of steel made in the electric furnace are largely due to its freedom from oxidation and occluded gases.

General Conclusions.—The present position which the manufacture of steel in the electric furnace holds in relation to other processes may be briefly summed up as follows:—(1) That steel of the highest quality equal to the best crucible steel can be made in this country either from cold scrap or by refining molten open hearth or Bessemer steel in any of the well-known types of furnaces at a price less than it costs to make crucible steel. (2) That steel castings of highest quality, especially when required very small and of light section, can be made at lower cost and equal in every way to best crucible steel castings. (3) When steel of high class quality, such as axle, tyre, and steel for special forgings, is required, such as only can be made from very carefully selected high-priced materials, under favourable conditions, the electric furnace can compete with the open hearth furnace, especially if molten metal from a Bessemer converter or open hearth furnace is available for refining; the cost of refining in such cases is compensated for by the lower cost of the raw materials; no generalisations, however, can be made, each case must be considered independently when all the facts are known. (4) In the present state of development of the electric furnace it cannot compete as regards cost of production with a modern large open hearth furnace or Bessemer plant for the manufacture of rails and structural steel for ordinary purposes, and it is only when superior quality is required, for which a better price can be obtained, that it can be employed.

In the great majority of cases Bessemer metal or, at all events, open hearth steel is good enough for rails, and it is only in cases where the raw materials are such that there are difficulties in obtaining the low Phosphorus and Sulphur demanded by modern requirements, as is the case with much of the American Bessemer steel, that the electric furnace will be used for rail manufacture, unless experience should demonstrate that the life of such rails is so increased as to justify the cost of this refining.

The future development of electric steel manufacture, apart from the manufacture of tool steels and steel castings, will probably be in the direction of the manufacture of the intermediate high-class steels for axles, tyres, guns, and similar purposes, replacing the material at present made from selected high-priced pig-iron in the open hearth furnace; the furnace will not be used for melting cold materials, but in refining molten metal from open hearth furnaces or Bessemer converters. When an open hearth plant is desired, the Talbot process or some form of open hearth tilting furnace will be necessary for the best form of combination plant, and the facilities for a continuous supply will then be similar to those from a Bessemer plant, although probably results equally good as regards quality can be obtained from the latter.

Much depends upon engineers being able to design electric furnaces of from 30 to 40 tons capacity, and so reduce the costs incidental to the working of small furnaces. Provided the difficulties can be overcome with large electrical furnaces, as they have been with gas-fired furnaces, the future of the electric furnace worked as a refiner of molten metal is assured for the manufacture of high-class steel in large quantities, and it will prove a powerful competitor to the open hearth process producing steel direct, and the greatest possibilities of development are probably in this direction.

Some of the sketches in this chapter are reproduced by permission from "The Report of the Canadian Commission appointed to Investigate the different Electro-Thermic Processes for the Smelting of Iron Ores and the Manufacture of Steel in operation in Europe." The horse-power year is taken, in all cases, as 365 days of 24 hours.