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.

General Construction of the Furnace.

The hearth of Girod's electric steel-making furnace consists of a circular or oblong cavity, in which the metal when molten reaches a height of from 25—30 cms. One or more electrodes of a like polarity are suspended above the bath, and soft steel pieces embedded in the hearth of the furnace and in direct contact with the molten metal, form the negative electrodes. The electric current, entering by way of the upper electrode, forms an arc between itself and the bath, traverses the bath, and passes out through the lower electrodes. The upper parts of these lower pole pieces become molten at their extreme ends; but their length is not decreased by more than 5 or 10 cms., as has been proved by making sections of these pieces when cold, after several months' work. With a view to reducing the length of the fused part, and also to preserving the lower lining of the furnace intact, the extreme end of the pole pieces are water-cooled. The details of the cooling arrangement are shown in Fig. 37, and consist of a cavity on that part of the piece which projects outside of the furnace frame. This projection carries likewise the device for leading the current to the poles.

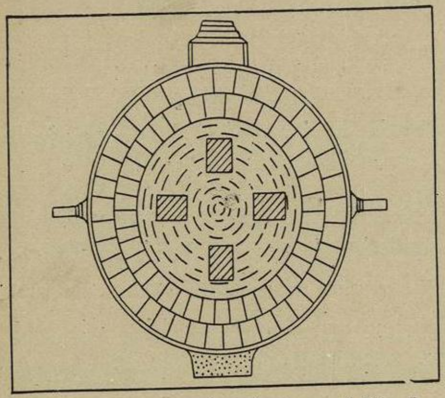

FIG. 29.—Plan of early type of Girod Furnace.

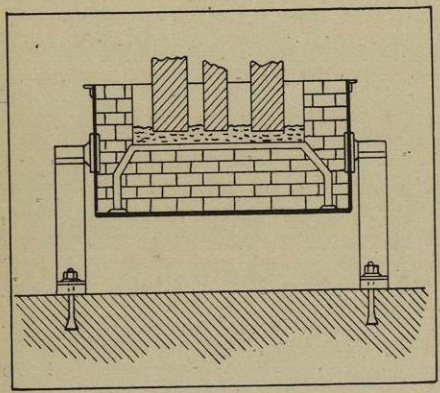

FIG. 30.—Sectional Elevation of early Girod Furnace.

The design of the refining furnace has not been altered in any material point, since the first English patent was taken out by Girod for a tilting crucible furnace, electrically heated, in 1904. Figs. 29 and 30 show a plan and sectional elevation of the early furnace, and Figs. 31, 32 and 33 represent the latest form of furnace. The changes that have been introduced, as the result of experience, relate chiefly to the arrangement and grouping of the negative electrodes in the base of the furnace, and also to the grouping of the conductors and cables in order to minimise the losses arising from induction when operating the furnace with three-phase currents.

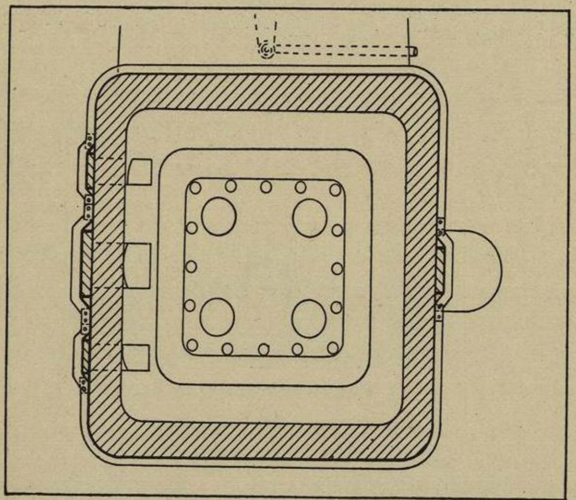

FIG. 31.—Plan of latest 8-ton Girod Furnace.

The Earlier type of Girod Furnace.

The earliest type of Girod furnace consisted of a shallow iron tank, cylindrical in shape, mounted on trunnions and lined with magnesite brick.[1] The removable cover was made of silica

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[1] "The Electric Furnace in Iron and Steel Production," J. B. C. Kershaw, Electrician Publishing Co., 1907, p. 51.

brick, and was perforated by openings for admission of the carbon electrodes. The bottom of the furnace was formed of a number of pieces of cast-iron embedded in the channelled brickwork—these acted as the lower or negative electrodes of the electrical circuit. For a furnace 2 metres in diameter, fourteen of these electrode plates were used. Each plate was in contact with the contents of the crucible of the furnace by means of canals, which were filled with molten iron before the work commenced. Alternating current was employed. The upper electrodes were suspended in the slag, and the decarbonisation of the charge was carried as far as possible. The steel was then recarburised, by adding a calculated weight of high carbon metal. A furnace of this type, utilising 250 kw., was operated at the Electrometallurgical Works at Albertville in 1907, and was producing 1 ton of steel from $1\frac{1}{2}$-ton charges in $4\frac{1}{2}$ hours per heat.

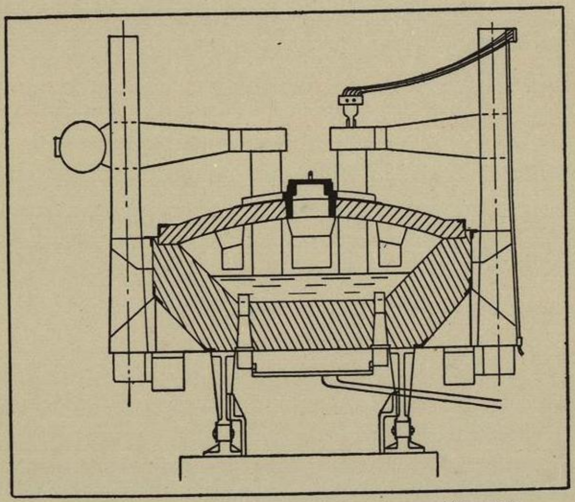

FIG. 32.—Sectional Elevation of latest 8-ton Girod Furnace.

Description of the Latest Girod Furnace.

The details of the latest Girod refining furnace are illustrated in Figs. 31 to 36. The hearth of the furnace is formed by a rectangular iron shell, and is lined with crushed dolomite in place of the earlier used and more expensive magnesite. The furnace is provided with three charging holes closed by sliding doors, and with a tapping hole on the opposite side through which the molten metal can be discharged. A metal framework supports the arched roof, which is made of silica brick, and has openings in it for the four carbon electrodes, which hang vertically with their lower ends near to but not touching the slag layer.

At the bottom of the furnace and removed as far as possible from the upper carbon electrodes, six or more steel electrodes are embedded in the refractory bottom, and are in direct connection with the furnace shell and with the low-tension side of the power plant. Since these bottom electrodes are placed as far as possible from the upper ones, the current passes through all the charge, and by this means the whole mass is uniformly heated. The current in crossing the bath also produces an electro-magnetic field, which gives the bath a rotary movement quickening the chemical reactions. As the steel electrodes are water-cooled, their life is practically unlimited. The steel frame of the furnace is placed on bearings, so that the furnace can be tilted forwards for the tapping, or backwards for the removing of the slag. This is effected by the charging doors. The tilting movement is obtained either by an electric motor or by an hydraulic plunger. The electrodes are of round section and of different sizes, and are made at Ugines in a factory fitted up with all modern improvements. Their electric resistivity on an average is 4,000 microhms per square centimetre of

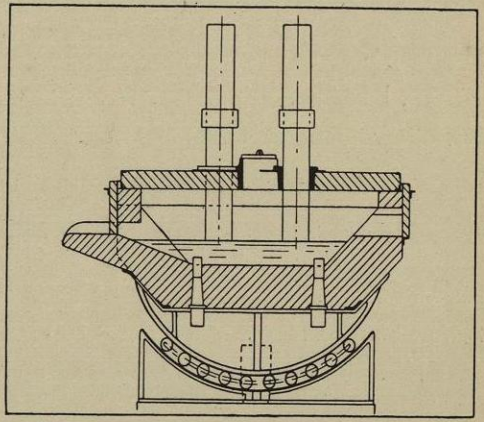

FIG. 33.—Sectional Elevation of latest 8-ton Girod Furnace.

section; their density is 1·65 to 1·80. The sectional area of the electrodes is so calculated that the current intensity does not exceed 5—6 amperes per square centimetre.

Current and Voltage Requirements.

Any kind of current, continuous, single-phase, or three-phase, is stated to be suitable for the Girod electric refining furnace. The E.M.F. required is about 65 volts for small furnaces, and 70 volts for the larger furnaces. The frequency may go up to 50 periods, but on account of the effects of self-induction it is better to have a low frequency, as this produces a higher electrical efficiency. The low voltage also minimises the dangers for the workmen.

Single-phase alternating current is found to be specially suitable for furnaces of small capacity, with only one carbon electrode. Its use, however, entails the necessity for installing rotary transformers, which have about 14 per cent. transformation losses. Three-phase current, on the other hand, is specially adapted for large furnaces, and can be employed wherever it is possible to connect the furnace directly to the alternator. The use of three-phase current also obviates the losses arising from the use of rotary transformers. Step-down transformers, for bringing the E.M.F. down to the voltage required, are, however, still necessary.

A special star connection is used when working the Girod furnace on the three-phase system, the principle of the connection being that one of the phases is reversed in relation to the other two. When the intensity of the current is equal in the three upper electrodes, the equilibrium of the three phases is perfect, and the current in its passage through the molten metal in the furnace heats the whole charge equally. The following claims are made for the Girod furnace when operated with three-phase current:—

(1) Simplicity of construction.
(2) Ease of management and control.
(3) Economy in power consumption.
(4) High thermal efficiency.
(5) Quiet melting of cold charges.

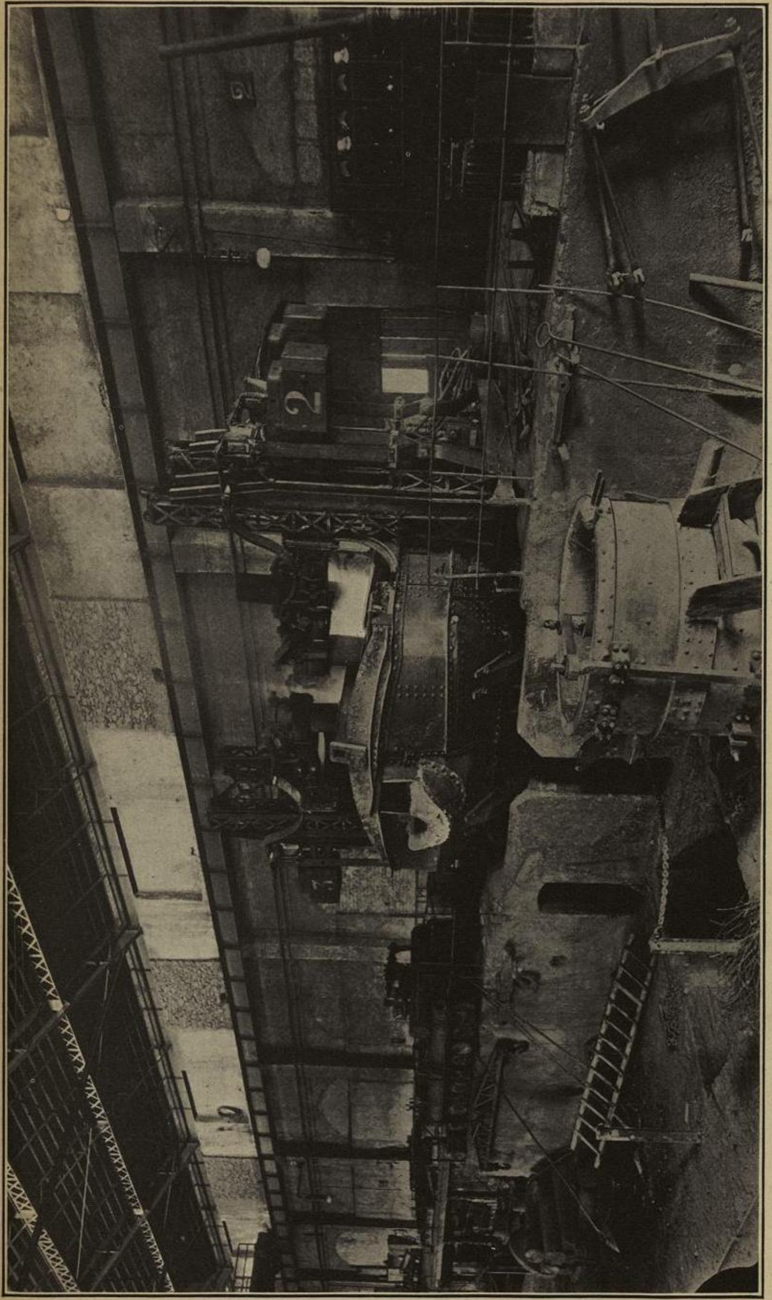

Fig. 34.—General View of 12-ton Girod Furnace at Ugine.

Electrical Connections.

The losses involved by different cable arrangements for conveying the current to the furnace have been most carefully studied at the Gutehoffnungshütte, and the result of this study has been made public in the article referred to below.[1] The plan finally adopted, to reduce the induction losses to a minimum at this works, was to arrange the cables systematically around the furnace, as in Fig. 36; A and B being the earlier arrangements which were found unsatisfactory in practice. The advantages claimed for the new arrangements, shown in C, are :—

(1) The electric arc circling about the periphery of the carbon electrode causes a strong agitation of slag and metal. This accelerates the speed of reaction between the slag and the molten iron in the furnace, and therefore reduces greatly the time of refining.

(2) The arches of the roof, as well as the furnace walls, receive a more uniform radiation from the electric arc, and last longer.

(3) The saving in energy consumption is 10 per cent., compared with the former arrangement.

(4) Copper bus-bars can be used instead of cables.

(5) The metal bath is heated more uniformly throughout, and the resulting product is more uniform.

(6) Current interruptions, due to the rupture of the arc, are avoided, eliminating the resulting rushes of current on the motor-generator set, and allowing an easier melting of cold charges than with method B.

(7) The consumption of the carbon electrode is more uniform, whereas with the former arrangement one side of the electrode was consumed more quickly than the other, resulting in greater expense for electrodes.

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[1] Dr. A. Mueller, *Stahl u. Eisen*, July and August, 1911, translated and slightly abstracted in *Metall. and Chem. Engineering*, November, 1911.

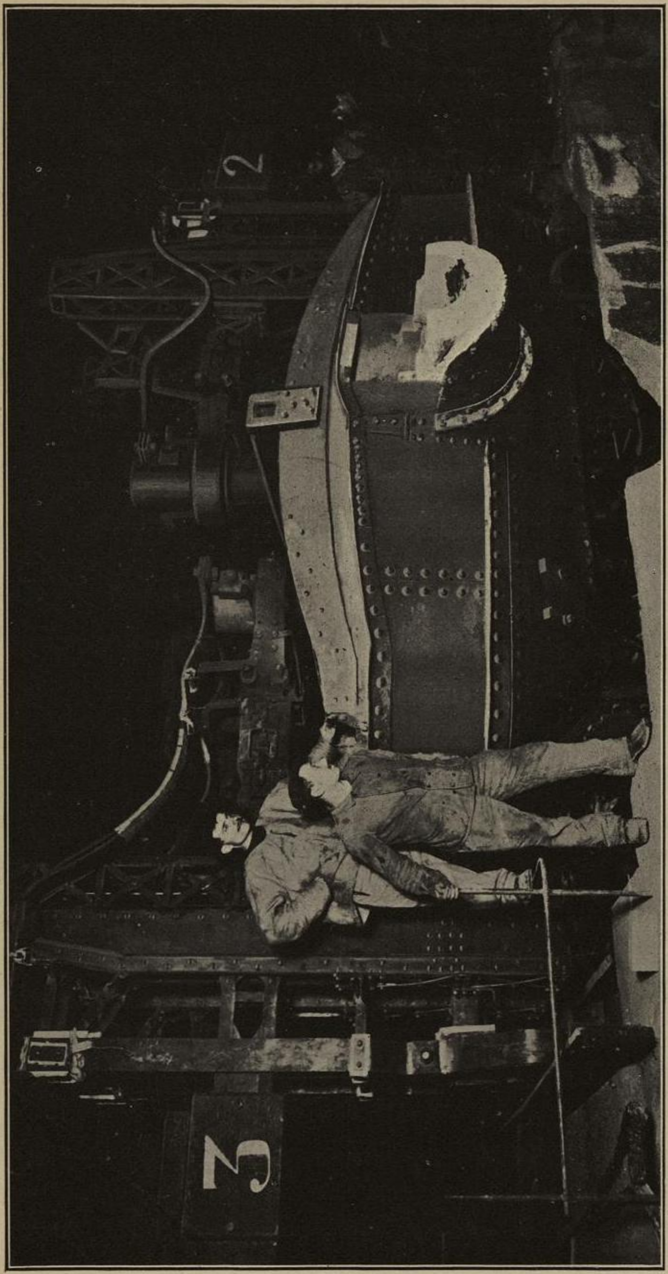

FIG. 35.—External Details of 12-ton Girod Furnace at Ugine.

Water-cooled Electrodes; their Dangers and Losses.

Dr. Mueller's article (see p. 74) also deals with the heat losses due to the water-cooling of the upper and lower electrodes, and with the supposed dangers of hearth-electrode cooling. This is the one special feature of the Girod type of furnace, which is most strongly criticised and condemned by electrometallurgists and practical steel-makers, and it is interesting to find that Dr. Mueller, as the result of considerable practical experience, considers that these criticisms are unfounded. The following quotation from his article, proves this:—

> "Hearth-electrode cooling is still little understood and has even been called a great drawback to the efficient operation of the Girod furnace. Fig. 37 shows, however, that only portions of the soft steel bars which project below the furnace body are cooled by water, the bars being connected by a common pipe-line.
>
> "The difficulties of maintenance of the lining of the Girod hearth are also often exaggerated. The dolomite hearth of the Gutehoffnungshütte furnace rammed by compressed-air rammers, has lasted through more than 1,000 charges, and has never given any trouble, in spite of the different lengths of heats and the very different composition of the charges."

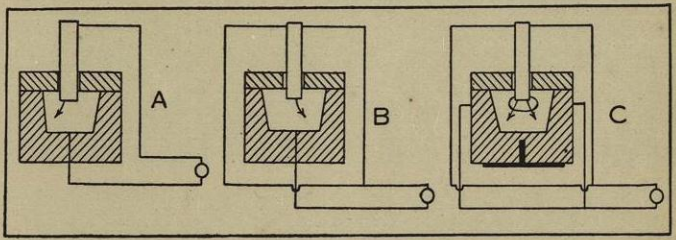

Fig. 36.—Arrangement of Electrical Connection to Furnaces.

Details are also given in Dr. Mueller's article of the calorimetric tests made to determine the heat losses with the water flowing from the cooling pipes around the positive and negative electrodes of the 3-ton experimental furnace. The losses were as follows:—

Bottom steel electrodes 1·01 per cent. of total energy; *top carbon electrodes* 3·65 per cent. of total energy supplied to the furnace.

The running of this small experimental furnace has also thrown much light on the nature of many reactions in the refining of the steel.

During the oxidation period, carbon is but slowly removed; manganese more rapidly; phosphorus very rapidly; and about 20 to 35 per cent. of the sulphur. The sulphur appears to be removed in three ways:—(1) During the oxidation period by the action of the iron oxide in the slags; (2) during the deoxidation period by solution in the high lime slags; and (3) by volatilisation as silicon sulphide. It has also been noted that oxides, slag emulsions and gases have a much more important bearing on the physical properties of the finished metal than the sulphur and phosphorus present.[1]

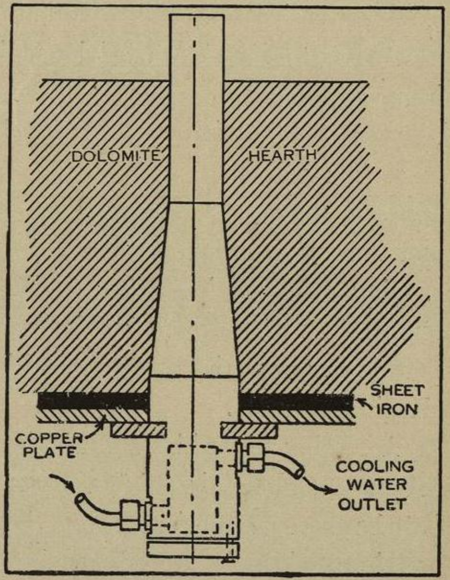

Fig. 37.—Arrangement of Water-cooling Pipes in Hearth of Girod Furnace.

Methods of Operating the Girod Furnace.

The methods of working the Girod Electric Refining Furnaces are very similar to those used in working the basic open-hearth furnace; the method of obtaining deoxidation of the charge alone being different from that used in the open-hearth process of steel making.

When the 3-ton furnace was charged with molten metal, it was found possible at the Gutehoffnungshütte to obtain five tappings in twelve hours under favourable conditions, or eight

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[1] From abstract of Mueller's article in *Metall. and Chem. Engineering*, November, 1911.

tappings (equal to twenty-five tons steel) in twenty-four hours, when working continuously.

The best method of charging the electric furnace with molten metal from the open-hearth furnace is to run the metal directly into the former by means of a 23 ft. long spout, the weight of the metal being adjusted by the eye or by time. If a ladle be used and the metal is weighed, much loss of heat occurs. The refining operation may be divided into two periods:—(1) oxidation period, and (2) deoxidation period.

The first period is started by adding to the charge lime and iron ore. The proportion of these additions varies according to the chemical purity of the charge, and is determined in such a way that after complete melting, the bath shows approximately the following composition:—Carbon, manganese and silicon less than 0·10 per cent. During this period of refining, oxidation is carried on vigorously, and the original low temperature of the bath favours a marked elimination of the phosphorus, practically all of which is removed before the slagging proceeds.

A forging test will show whether the metal is in the extra soft state, and at this point, as soon as the temperature of the bath has become sufficiently high, the slag containing phosphorus and iron oxides is tapped off through the charging door by tilting the furnace slightly backwards. The first slag is immediately replaced by some lime, which clears the bath from the last traces of phosphoric slag. One slag is generally sufficient to remove all but traces of phosphorus.

The Second or Deoxidation Period.

The oxidising and cleaning slag being removed, a first deoxidation of the bath is effected by adding deoxidising agents such as ferro-silicon, or ferro-manganese, etc., these alloys being added in such proportion that they will not remain in the bath.

As regards the use of aluminium in the final stages of the refining operations, this metal is never employed alone as a deoxidising agent, but in the form of an alloy, with silicon, iron or manganese, or combined with all three in the form of ferro-mangano-silico aluminium.

The bath is then rapidly covered with a slag consisting of about five-sevenths of lime, one-seventh of silica sand, and one-seventh of fluorspar, together with a slight addition of carbon, in the form of petroleum coke. During the second period (of deoxidation), care must be taken that the furnace is properly closed, the temperature being held sufficiently high to reduce the iron oxide in the slag. The reduction of the ferrous oxide in the slag is indispensable for the deoxidation and desulphurisation of the bath. Ferro-silicon and petroleum coke are employed to ensure complete deoxidation, and a slag should be obtained which disintegrates in the air into white powder.

In order to facilitate the complete deoxidation of the bath, it is useful to add small quantities of silico-manganese, silico-manganese-aluminium, or even silicon-aluminium, these alloys acting very energetically upon the oxides in the bath, and forming a very fluid slag which easily mounts to the surface.

During this same period, when the slag is completely deoxidised and is very basic, the desulphurisation, which was incomplete during the first stage of the operation, increases and is rapidly completed at the time of the tapping. Desulphurisation starts vigorously when the highly basic lime slag becomes white and readily fluid, *i.e.*, after the removal of the metallic oxides. Carburising materials are eventually added for finishing the metal; and a final addition of ferro-silicon, ferro-manganese or other alloy, is made in order to arrive at the required composition of the steel.

The following figures for the *power consumption and working* costs of the Girod Electric Refining Furnace are taken from detailed information supplied recently to the author, by the Soc. a. Electrometallurgique Procedes Paul Girod. The figures are based upon the practical experience obtained at Ugine with the Girod furnace.

Power Consumption and Working Costs.

The power consumption was recorded at the terminals of the furnace and covered smelting, refining and finishing a charge of cold scrap. It amounted to 850 kw. hours for a 3-ton furnace, or 750 kw. hours for a 10-ton furnace. These figures, of course, varied with the composition of the charge and according to the quality and purity of the steel produced.

The consumption of electrodes per ton of steel made was about 8—9 kgs. for the 3-ton furnace, and 8—10 kgs. for the 10-ton furnace.

Wages.—One smelter, one second-hand and one boy were required to operate the 3-ton furnace ; whereas one smelter, two second-hands and one boy, sufficed to operate the 10-ton furnace.

Linings.—The furnace can be lined either with magnesite bricks or be tamped with a tarred magnesite, or dolomite. Dolomite tamped bottoms are now giving the best results. The work is done with heated hand-tampers, or with pneumatic-rammers. The durability of the lining is about 90—100 heats for the 10-ton furnace, and about 120 heats for the 3-ton furnace. At the end of that time the side walls and the hearth will need repairing. All the burnt or oxidised parts of the walls are scraped. The bottom is broken down about 10—15 cms. and is retamped with a new layer of dolomite, taking care to leave a passage open for the tops of the negative electrodes. This repair of the upper part of the bottom is the only one that requires a stoppage of the furnace, the damage to the walls at the slag line being repaired between the charging operations.

The *furnace roof* is made of silica bricks and lasts on an average for 50 heats for the 10-ton furnace, and 70 heats for the 3-ton furnace.

The costs of *Materials for Slags, etc.*, varies considerably with the purity of the scrap used and with the quality of the steel required. Lime, ore, silica sand, fluorspar and petroleum-coke are all employed in the slagging process. The output of finished

TABLE X.—COLD CHARGES.

—	3-ton furnace.	10-ton furnace.
Raw Materials :		
Scrap, 1,100 kgs. at 75 frs. per 1,000 kgs.	82·50	82·50
Slag	2·30	2·30
Deoxidising additions and recarburisation	3·50—88·30	3·50—88·30
Production Costs :		
Electric power, 850 and 750 kw. hours at 2 centimes . . .	17·00	15·00
Electrodes at 320·00 frs. per ton .	3·00	3·50
Wages	3·00	1·50
Maintaining and repairs . . .	12·00—35·00	8·00—28·00
Total cost per ton, francs.	123·30	116·30

TABLE XI.—MOLTEN CHARGES.

—	3-ton furnace.	10-ton furnace.
Raw Materials :		
Liquid steel 4 per cent. loss in heating, 1,040 kgs. at 80 frs. per ton .	83·20	83·20
Slags	2·00	2·00
Deoxidising additions . . .	3·50—88·70	3·50—88·71
Production Costs :		
Electric power, 275 and 200 kw. hours at 2 centimes . . .	5·50	4·00
Electrodes 3 to 4 kgs. at 320 frs. per ton	1·25	1·25
Wages, 8 heats in 24 hours . .	1·00	1·00
Maintenance and repairs of the furnace	4·00—11·75	2·50—8·75
Total cost per ton of steel, francs.	100·45	97·45

steel runs from about 90 to 96 per cent. of the charged material, and depends chiefly upon the degree of oxidation of the latter before charging. When working with molten metal as charging material, the reduction of the working period per charge to two to two and a half hours leads to a great reduction in the total costs of the refining process.

The estimates of costs on p. 81 are based on the Ugine results, and upon the conditions and costs of raw material, rate of pay, etc., obtaining in the S.E. District of France.

These estimates do not include the expenses for ingot moulds, superintendence, testing, depreciation, and general charges, which vary too considerably to allow a good average to be established.

It is interesting to compare with these latest official figures for the costs of refining cold steel scrap by the Girod furnace and process, the earlier estimates for the same process given by the present writer in the handbook already quoted (see p. 1). The working costs of the Girod furnace and process were given as follows:—

	£	s.	d.
Electric power, 1,060 kw. hours. at ¼d. per kw. hour.	1	2	1
Electrodes, 10 kgs. at £4 3*s.* 4*d.* per metric ton .	0	0	10
Maintenance charges	0	6	8
Total per ton of steel .	£1	9	7

Converting this total into francs and adding 3 frs. for labour we obtain a total of 40 frs., as compared with 35 frs. and 28 frs. for the latest estimates. The chief reduction is in the electrical energy required to operate the 3-ton furnace. This has been brought down from 1,060 kw. hours to 850 kw. hours, a reduction of 20 per cent.

The cost of the 2—3-ton size of Girod furnaces is approximately £600 ($3,000). This furnace will require a 300 kw. generator to provide the energy. This energy may be supplied in the form of single-phase current, 4,600—5,000 amperes at 65—75 volts.

As regards the quality and chemical composition of the steel made in the Girod furnace, the following figures, taken from various sources, show that remarkably pure steel can be produced by this furnace and process:—

TABLE XII.

Average composition of the scrap material used, and of the refined metal produced at the Ugine Electric Steel works.

Scrap Material.		Finished Steel.	
Carbon . . .	·35 per cent.	Carbon from	·04 to ·50 per cent.
Silicon . . .	·20 ,,	Silicon . .	·20 per cent.
Manganese . .	·70 ,,	Manganese .	·30 ,,
Sulphur . .	·095 ,,	Sulphur .	·015 ,,
Phosphorus . .	·095 ,,	Phosphorus .	·015 ,,

TABLE XIII.

Composition of the various brands of steel produced.[1]

No.	Properties.	Carbon.	Silicon.	Manganese.	Sulphur.	Phosphorus.	Other constituents.
1	Very soft . . .	0·079	0·106	0·205	0·015	0·012	—
2	Soft . . .	0·236	0·180	0·431	0·012	0·010	—
3	Middle soft . .	0·283	0·208	0·430	0·014	0·010	—
4	Middle hard . .	0·388	0·155	0·342	0·011	0·009	—
5	Middle hard . .	0·463	0·204	0·463	0·010	0·016	—
6	Hard . . .	0·596	0·198	0·302	0·017	0·005	—
7	2 % Nickel . .	0·076	0·099	0·101	0·014	0·010	2·12 % Ni
8	3 % Nickel soft .	0·06	0·123	0·209	0·013	0·007	3·47 % Ni
9	3 % Nickel hard .	0·364	0·144	0·435	0·012	0·015	3·41 % Ni
10	5 % Nickel soft .	0·134	0·148	0·375	0·016	0·013	5·25 % Ni
11	5 % Nickel middle soft . . .	0·250	0·157	0·414	0·010	0·015	5·08 % Ni
12	Nickel-Chrome .	0·420	0·199	0·500	0·010	0·009	25·53 % Ni 0·77 % Cr
13	Tool steel . .	1·223	0·168	0·224	0·011	0·010	—
14	Ditto . . .	1·474	0·199	0·264	0·015	0·007	—
15	Ditto . . .	1·010	0·219	0·306	0·008	0·009	0·32 % Cr
16	Ditto . . .	1·277	0·230	0·130	0·009	0·006	0·24 % Cr
17	Ditto . . .	1·251	0·176	0·258	0·010	0·008	1·21 % Cr 0·49 % Ni
18	Ditto . . .	0·689	0·029	0·096	0·012	0·009	0·07 % Cr 0·46 % Mo 25·82 % W

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[1] *Mining Journal*, November, 1909. Dr. W. Borchers.

Physical tests of the steel produced in the Girod furnace show that it possesses special qualities of a high order, namely, the approximation of the limit of elasticity to the breaking stress and high resilience. Tests of three classes of steel made in the Girod furnace were given by J. A. Seager in the Journal named below,[1] and are reproduced here in Tables XIV., XV., and XVI.

TABLE XIV.

Treatment.	Elastic limit, lbs. per sq. in.	Maximum stress, lbs. per sq. in.	Elongation, per cent.	Contraction, per cent.	Resilience lbs.
Annealed at 900° C. .	39,241	50,485	33	73	1,034
Hardened at 800° C. and tempered at 600° C. .	41,887	63,051	28	75	1,100

TABLE XV.

Treatment.	Elastic limit, lbs. per sq. in.	Maximum stress, lbs. per sq. in.	Elongation, per cent.	Contraction, per cent.	Resilience, lbs.
Soft Steel.					
Annealed at 900° C. .	41,887	58,862	31	60	94·6
Hardened at 800° C. and tempered at 600° C. .	64,374	76,940	22	74	105·6
Medium Soft Steel.					
Annealed at 900° C. .	44,753	71,429	29	60	72·6
Hardened at 800° C. and tempered at 600° C. .	41,005	86,861	21	66	77·0
Medium Hard Steel.					
Annealed at 900° C. .	57,319	92,372	21	34	26·4
Hardened at 800° C. and tempered at 600° C. .	91,049	113,316	14	37	35·2
Hard Steel.					
Annealed at 900° C. .	60,185	97,884	17·5	30	19·8
Hardened at 750° C. and tempered at 600° C. .	114,859	137,126	9	30	26·4
Very Hard Steel.					
Annealed at 800° C. .	65,917	113,316	16	30·5	19·8
Hardened at 750° C. and tempered at 600° C. .	111,993	142,858	9·5	49	26·4

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[1] *Iron Trade Review*, June 3rd, 1909.

TABLE XVI.

Treatment.	Elastic limit, lbs. per sq. in.	Maximum stress, lbs. per sq. in.	Elongation, per cent.	Contraction, per cent.	Resilience, lbs.
1. Air hardened at 850° C., tempered at 600° C., and cooled very slowly in furnace . .	114,859	121,693	15	55	46·2
2. Air hardened at 860° C., and tempered at 400° C. . . .	160,935	167,990	11	48	33·0
3. Air hardened at 850° C.	216,932	231,042	8	38	22·0

Table XIV. represents the tests for an average quality of steel, Table XV. tests of carbon steels, and Table XVI. gives the tests of the special K.N.A. steels, of which the chemical composition is not revealed.

Description of Notable Installations of the Girod Furnace.

In closing this description of the Girod electric steel refining furnace and process, some details of the more notable installations of the same may be given.

The Works at Ugine, Hte. Savoie, are the property of the *Soc. des Forges et Aciéries Électriques Paul Girod*, a company floated in 1909, with a capital of 4,000,000 frs., which has since been increased to 12,000,000 frs., to take over the electric steel furnace patents of Paul Girod.

The electric power utilised at this steel works is derived from three generating stations situated in the valley of the River Arly (a tributary of the River Isère) providing 6,000 h.p.; in the valley of the Dorion (a tributary of the Arly), providing 4,000 h.p.; and in the valley of the Bonnant (a tributary of the Arve), providing 11,000 h.p. The power is transmitted to Ugine, a distance of 45 kms., as three-phase current at a pressure of 45,000 volts. The total energy available fluctuates between 13.000 h.p. and 36,000 h.p. A general view of the steel works at Ugine is shown in Fig. 38.

The furnace and casting house contains at present seven furnaces, ranging from $\frac{1}{2}$ ton to 12 tons capacity per charge. The furnace house is provided with four travelling cranes, and is designed to contain sixteen furnaces and to produce 200 tons of steel per day. The smaller furnaces produce the special alloy and high-priced steel, the large furnaces the high carbon and nickel steels. The works is complete with annealing shop, machine shop, forging department, tempering shop and rolling mills, and was the first successful steel works to be operated throughout by electricity.

FIG. 38.—General View of Ugine Steel Works.

Oehler & Co., at Aarau, Switzerland, are manufacturers of steel and iron castings for engineers. They have replaced their crucible steel plant by a 2-ton Girod furnace, and since August, 1908, have been obtaining most satisfactory results from the latter. Power is obtained from the Aarau City Electricity Station, which has developed between 3,000 and 4,000 h.p. from a fall on the River Aar, and sells current for smelting purposes at 3 to 4 centimes per kw. hour.

Charges of about 1,500 kgs. are prepared in this furnace at Aarau, using a current of 8,500 amperes at 55 volts. Ninety-eight per cent. of all the castings obtained are good, the average tensile strength of the cast metal being 55—65 kgs. per sq. mm., with an elongation of 5—10 per cent.

The Gütehoffnungshütte at Oberhausen, in Germany, have had a 3-ton furnace installed in their No. 1 Martin Steel Works since 1910. The furnace operates with single-phase current of 6,700 amperes at 75 volts, furnished by a motor generator of 500 kw. capacity. The products of this furnace are carbon steels of various degrees of hardness, alloy steels, and special steels for tools, engine-cranks, axles, etc.

The Simmonds Manufacturing Co., of Fitchburg, U.S.A., manufacturers of saws and machine-knives, have installed a 3-ton Girod furnace in the crucible steel department of their Chicago works. The results of the trials of this furnace for melting the best brands of Swedish bar and for producing steel for their ordinary requirements will determine whether an installation of larger electric furnace of the Girod type will be adopted for the new works this Company are about to erect at Lockport, New Jersey.

The Bethlehem Steel Co., of U.S.A., has decided to adopt the Girod furnace and process for producing the higher grade steels required in its foundry, and an order has been placed for a Girod furnace of 10 tons capacity.

Future Developments of the Girod Furnace.

The Girod type of furnace in the 2—4 tons size is especially adapted for refining the high-class steels intended for fine castings and for the manufacture of special alloys. Its high temperature, smooth working, and uniformity of product are all points in its favour for this class of work.

The experience gained with the larger sizes of furnace seems to indicate that the maintenance of the lining of the furnace bottom is likely to prove a troublesome matter, owing to the necessity for preserving openings in it for the negative electrodes. On this account the writer does not expect to see the Girod type of furnace employed for the production of structural steel or of rail steel, which demand large units and low producing costs.

In its own special field, however, the Girod steel-refining furnace would appear to have a promising future before it, and the number in use will no doubt be rapidly increased as the good points of the furnace become better known and appreciated.

CHAPTER VI

THE STASSANO ELECTRIC STEEL FURNACE AND PROCESS

Major Ernesto Stassano, of the Italian Army (Artillery), appears to have been the first electro-metallurgist to apply electric heating *on a practical scale* to the smelting and refining of iron and steel.

Stassano's first English Patent, No. 11604, describing an electrically-heated furnace for producing steel direct in one operation from iron ore was taken out in 1898, and experimental trials were commenced with this furnace at Rome in 1899. Fig. 39 shows a sectional elevation of this earliest form of steel-smelting furnace. Although this design was soon discarded by the inventor, it is interesting to note that it closely followed the blast-furnace form, and that this type of furnace has been copied in the successful electric iron-smelting furnaces of Grönwall and Heroult, now operating in Norway and in California (see Chapter III., p. 27). Stassano's early attempts to produce steel direct from the ore in one operation were doomed to failure for the reasons given in Chapter III., and the trials of the process and furnace at Darfo in Northern Italy in the years 1900—1902, led to no practical or financial success.

The Italian Government became interested however in the furnace, and instituted trials of the same for refining the special brand of steel used for manufacturing shells and ammunition at the Royal Arsenal, Turin, the first 250-kw. Stassano furnace being erected here in 1903.

Since that year the Stassano electrical method of refining mild steel used for shells has been in continuous operation by the Italian Military Authorities at Turin. A new company, the Forni-Termo-ellettrici Stassano, was also formed in 1905 to take