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BUREAU OF MINES

JOSEPH A. HOLMES, DIRECTOR

ELECTRIC FURNACES

FOR

MAKING IRON AND STEEL

BY

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By Dorsey A. Lyon and Robert M. Keeney.

THE ELECTRIC FURNACE IN PIG-IRON MANUFACTURE.

By David A. Lyon.

INTRODUCTION.

In the inquiries and investigations that the Bureau of Mines is making with a view to increasing safety, efficiency, and economic development in the metallurgical industries, the application of electricity to various processes, and especially to those in the manufacture of iron and steel, is being given attention. Some results of the work already done are presented in this bulletin, which gives a historical review of the development of electric furnaces for making iron and steel, and discusses the problems that remain to be solved in the use of electric furnaces for the smelting of iron ores and the production of pig iron at a profit on a commercial scale.

DEVELOPMENT OF THE ELECTRIC FURNACE FOR SMELTING IRON.

In 1898 Capt. Stassano, of Italy, patented an electric furnace for smelting iron ores.[a] In 1900 the production of ferro-alloys in the electric furnace was begun, and at the present time practically all ferro-alloys are made in electrically heated furnaces.

INVESTIGATIONS OF THE CANADIAN COMMISSION.

INVESTIGATION OF 1904.

The work of Stassano and the successful production of ferro-alloys in the electric furnace were brought to the attention of the Canadian Government by Eugene Haanel, Government superintendent of mines. As is well known, Canada is not so favored with abundant high-grade ores and good coking coal as is the United States, and so it seemed to Haanel and his associates that the electric furnace might lead to the solution of their problem in Canada, namely, the treatment of low-grade ores, and of those ores high in phosphorus and sulphur.

Ultimately, through the efforts of Haanel, a commission was appointed "to proceed to Europe for the purpose of investigating

[a] Stansfield, A., The electric furnace, 1907, p. 13.

and reporting upon the different electrothermic processes employed in the smelting of iron ores and the making of the different classes of steel, then in operation or in process of development, in Italy, France, and Sweden."

This commission left Ottawa for England on January 21, 1904. When the commission arrived in England, F. W. Harbord, the well-known metallurgist, was engaged to act as metallurgist to it. Although the commission visited several plants in Europe, yet in none of them was direct smelting being attempted, nor were most of them in any way adapted for making experimental tests of direct smelting. While the commission was at La Praz, France, Dr. Héroult was kind enough to demonstrate that it was possible to produce iron from the ore in an electric furnace.

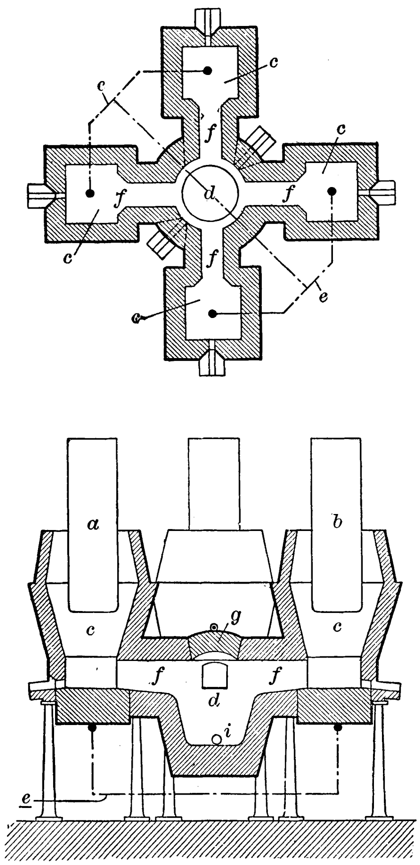

Figure 1.—Sectional plan and elevation of Keller furnace. Used by the Canadian commission in making tests at Livet, France.

EXPERIMENTS WITH KELLER FURNACE, LIVET, FRANCE.

At Livet, France, however, the commission found at the works of Keller, Leleux and Co. an electrical installation well suited for smelting tests of iron ores. Figure 1 shows the type of furnace used for making these tests. It consisted of two or more furnaces with vertical electrodes, connected by a central well, the current flowing from each furnace through the vertical electrodes *a* and *b*. In the tests made by the commission the iron ore, fluxes, and coke were broken to such a size that all would pass through a 1½-inch ring. They were then mixed and "charged into the furnace in the annular space between the electrode and the walls of the furnace." In this connection it should be noted that the report of the commission clearly states that in these experiments the reduction was accomplished by means of solid carbon, as is shown by the following statement: "The heat, generated rapidly, raised the temperature and enabled the carbon mixed with the ore to reduce it to the metallic state, and as the temperature rose the metal fused and collected on the sole of the furnace." Later reference to this point is made. The gases resulting from the operation were allowed to escape and burn at the top of the furnace.

At Livet the commission made two separate experiments, the first lasting 55 hours and the second 48 hours. In conducting these experiments the materials were weighed and the weights checked. Especial attention was also given to such other points as were necessary to obtain accurate data in regard to the following matter:

The output of pig iron for a given consumption of electric energy.

The yield of metal per ton of ore charged.

The quantity of coke required as a reducing agent.

The quality of pig iron obtained, with especial reference to its suitability for (*a*) steel manufacture by (1) Bessemer or Siemen's acid process or (2) Bessemer or Siemen's basic process; and (*b*) foundry purposes.

The tests, performed on March 19, 20, and 21, 1904, marked the real beginning of the present practice of the reduction of iron ores in an electric furnace, for although, as will be seen later, the furnaces in use for this purpose at present differ considerably in construction from the Keller furnace, the principle employed is the same—namely, the ore, flux, and reducing agent are fed around the electrodes, and the heat generated by the current passing through the charge raises the temperature of the ore and fluxes to their melting point, and thus enables the carbon to reduce the ore with which it is mixed.

PROBLEMS NOT SOLVED BY COMMISSION OF 1904.

After the report[a] of the commission had been carefully studied it was evident that further data would have to be obtained in order to establish with some degree of exactitude the quantity of electric energy required per ton of product and the consumption of electrode. Also, the following important questions referring to Canadian conditions were either not taken up or were left in doubt by the Livet experiments:

Could magnetite, which is Canada's chief ore and is to some extent a conductor of electricity, be successfully and economically smelted by the electrothermic process?

Could iron ores with comparatively high sulphur content, but not containing manganese, be made into pig iron of marketable composition?

The experiments made at Livet with charcoal as a reducing agent in substitution for coke having failed, could the process be so modified that charcoal could be substituted for coke?

[a] Haanel, E., Report of the commission appointed to investigate the different electrothermic processes for the smelting of iron ores and the making of steel in operation in Europe: Mines Branch, Department of Interior, Canada, 1904.

The last problem was especially important, as charcoal and possibly peat coke would constitute Canada's home products, whereas coal coke for metallurgical processes has to be imported into several of the Provinces.

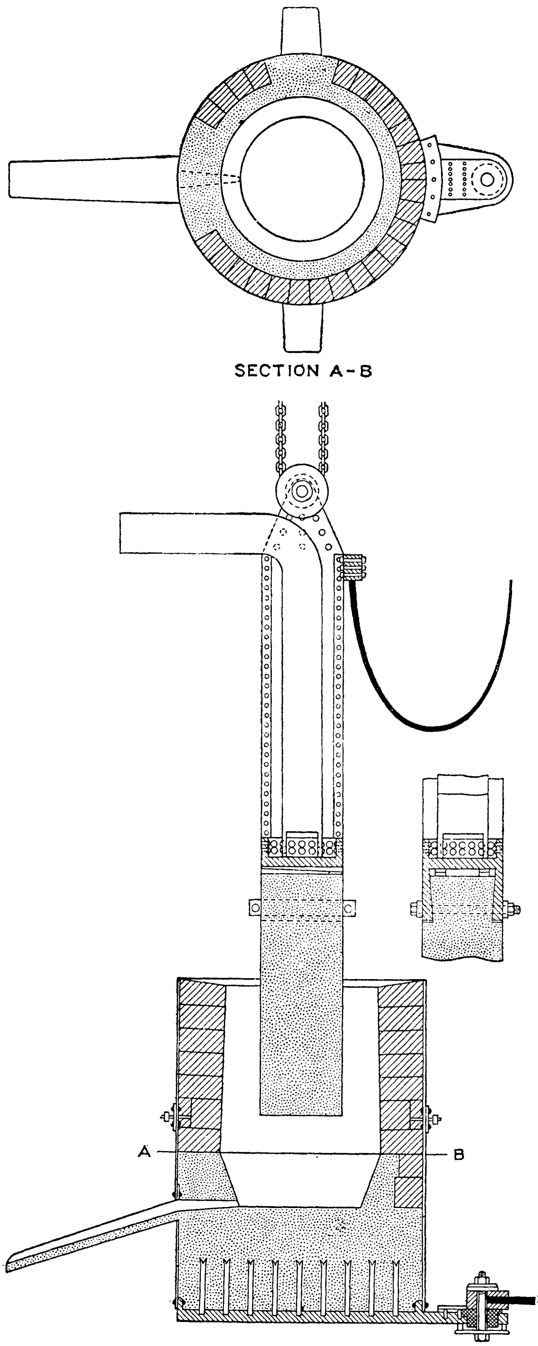

FIGURE 2.—Experimental furnace used at Sault Ste. Marie, Ontario.

EXPERIMENTS AT SAULT STE. MARIE, ONTARIO, 1906.

A sum of $15,000 was placed at the disposal of the Canadian commission for prosecuting experiments at Sault Ste. Marie, Ontario, in 1906. Owing to the advantages offered, the experimental furnace[a] was erected at the plant of the Lake Superior Corporation at Sault Ste. Marie, Ontario, under the direction of Erik Nystrom, a member of the staff of the mines branch of the interior department, who was later prominently connected with the work at Trollhättan, Sweden. The furnace is shown in section in figure 2.

The experiments at Sault Ste. Marie were continued for several weeks. The report made to the Canadian Government by the superin-

[a] Haanel, Eugene, Report on the experiments made at Sault Ste. Marie, Ontario, under Government auspices, on smelting of Canadian iron ores by the electrothermic process: Mines Branch, Department of Interior, Canada, 1907, p. 2.

tendent of mines contained substantially the following conclusions relative to the experiments:

Canadian magnetite ores can be as economically smelted as hematites by the electrothermic process.

Ores of high sulphur content can be made into pig iron containing only a few thousandths of 1 per cent of sulphur.

The silicon content can be varied as required for the class of pig that is to be produced.

Charcoal, which can be cheaply produced from mill refuse or wood that could not otherwise be utilized, and peat coke can be substituted for coke without being briquetted with the ore.

A ferronickel pig practically free from sulphur and of fine quality can be produced from roasted nickeliferous pyrrhotite.

Titaniferous iron ores containing up to 5 per cent of titanium can be successfully treated by the electrothermic process. This conclusion is based upon an experiment made with an ore containing 17.82 per cent of titanic acid, yielding a pig iron of good quality.

The electrical horsepower-year used per ton of pig produced during these experiments was about 0.277. As noted later, an average of 18 months' running at Trollhättan, Sweden, indicated that the electrical horsepower-year used per ton of pig produced was 0.340.

After the Government had discontinued its tests the experimental plant was acquired by the Lake Superior Corporation, and for a time was employed for the semicommercial production of ferronickel pig, but up to the present time no other electric pig-iron reduction furnace plants have been installed in Canada. This lack of plants is not because the reduction of iron ores in the electric furnace has not met the expectations of the commission, but because the peculiar economic and geographic conditions in Canada have not seemed to warrant, to the present time, the introduction of the electric furnace for the production of pig iron.

DEVELOPMENT OF THE ELECTRIC IRON-REDUCTION FURNACE IN SWEDEN.

The development of the electric iron-reduction furnace in Sweden has been due to the following reasons:

In Sweden the conditions are somewhat analogous to those found in Canada, that is, there are iron ores, but no coal for coking. There is, however, this difference between the conditions in Canada and in Sweden—in Sweden, as also in California, the ores are for the most part high in their iron content and rather free from impurities. Moreover, as has been indicated by Sundbarg[a], the iron industry has been well established in Sweden for some hundreds of years. The ores have been smelted in a blast furnace, charcoal for the most part having been used as a reducing agent, and Swedish charcoal iron is known the world over for its purity. However, it has long been

[a] Sundbarg, A. G., Sweden, its people and its industries, 1904.

apparent to those familiar with the situation that there would have to be some innovation in order to enable Swedish iron manufacturers to keep the cost of production down. Each year has seen an increase in the cost of charcoal, because wood for making charcoal is becoming scarce owing to the depletion of the forests and the increased production of wood pulp. These facts caused Swedish engineers to turn their attention to the possibilities of electric smelting.

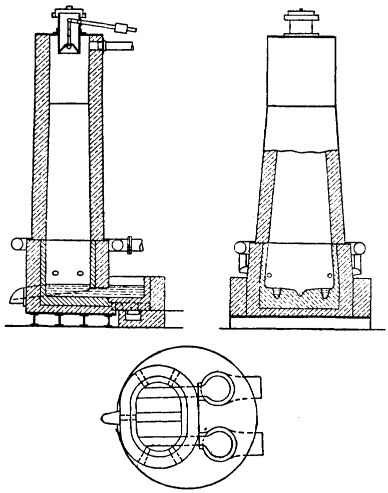

FIGURE 3.—First type of shaft furnace used in experiments of Grönwall, Lindblad, and Stalhane.

EXPERIMENTS OF GRÖNWALL, LINDBLAD, AND STALHANE, DOMNARFVET, SWEDEN.

The first electric-furnace smelting experiments made in Sweden were conducted by Grönwall, Lindblad, and Stalhane. The types of furnaces used by them are shown in figures 3, 4, and 5. The construction of the furnace shown in figure 3, is described by Yngstrom[a] as follows:

It was a shaft furnace with the hearth lined with stamped silica. In the bottom of the hearth there were three channels: One in the middle leading to the tap hole for the pig iron, and one on each side. The latter communicated with two receptacles placed outside the shaft and filled with iron. The bottom of these receptacles was formed by blocks of granite packed on copper plates and connected with the electric-current supply. The furnace was started with an air blast as an ordinary blast furnace, and when sufficient iron had collected on the hearth the air blast was cut off and the electric current turned on. The

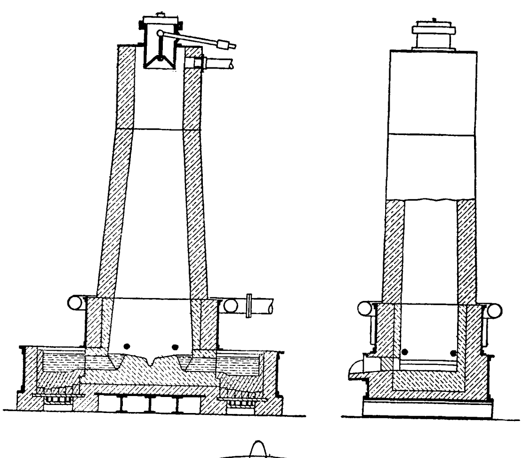

FIGURE 4.—Second type of shaft furnace used by Grönwall, Lindblad, and Stalhane.

[a] Yngstrom, Lars, Electric production of iron from iron ore at Domnarfvet, Sweden: Engineer (London), vol. 109, Feb. 25, 1910, p. 206.

idea was that the current entering the furnace through the iron by one of the channels would melt the charge in its passage to the opposite channel. It was possible to work the furnace in this manner during short periods, but it proved impossible to make the hearth durable. In part this was due to the fact that at the high temperatures used the silica became conductive of electricity. The furnace was therefore reconstructed in the manner shown in figure 4. The general principle of the design was the same as in the first furnace, but the lower portion of the furnace was of more solid construction. The electric current was introduced at opposite sides of the furnace. The most important alteration was, however, that the hearth was lined with magnesite brick. In consequence the hearth lasted somewhat better than before, but, in general, the same difficulties remained, and even the magnesite proved to be a fairly good conductor of electricity at high temperatures.

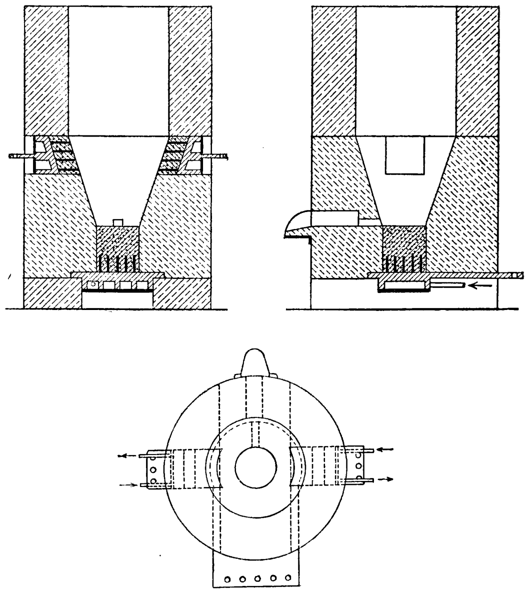

FIGURE 5.—Third type of furnace used by Grönwall, Lindblad, and Stalhane.

Finding that the types of furnaces above described were not suited to the work of reduction, Grönwall, Lindblad, and Stalhane turned their attention to the development of the type that later proved successful and is now being successfully operated in Sweden and Norway. In the work of developing this furnace to a feasible and commercial success these men were ably assisted by the engineers and capitalists of Sweden. An agreement was made with the Trafikaktiebolaget Grangesberg Oxelosund which enabled them to carry out their experiments on a large scale at the Domnarfvet Iron Works. Although the preliminary work on the furnace at Domnarfvet was begun in April, 1906, the furnace was not operated until April, 1907. Experimental work was conducted with it during the summer of 1907. The furnace is shown in figure 6. As the shaft of the furnace is low and open at the top, large quantities of charcoal were consumed at the top of the open shaft, and the gas escaping from the furnace consisted almost entirely of carbon monoxide. Based on the data obtained during the operation of this furnace, a new furnace was constructed. This furnace, which is shown in figure 7, was higher, was closed at the top, and was so constructed as to permit the return to the crucible of a part of the gas passing from the top of the shaft. The furnace has been described in detail by Yngstrom in his report.[a]

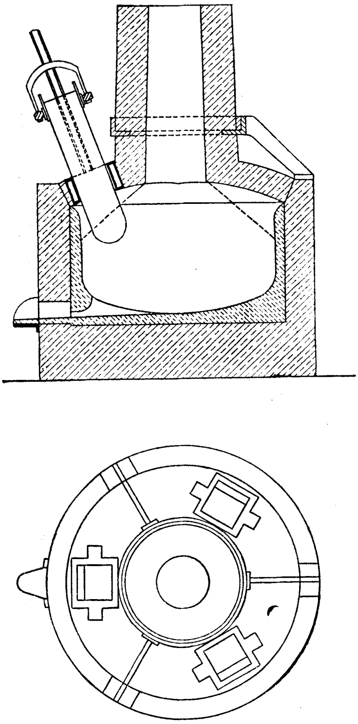

FIGURE 6.—First type of furnace used at Domnarfvet, Sweden.

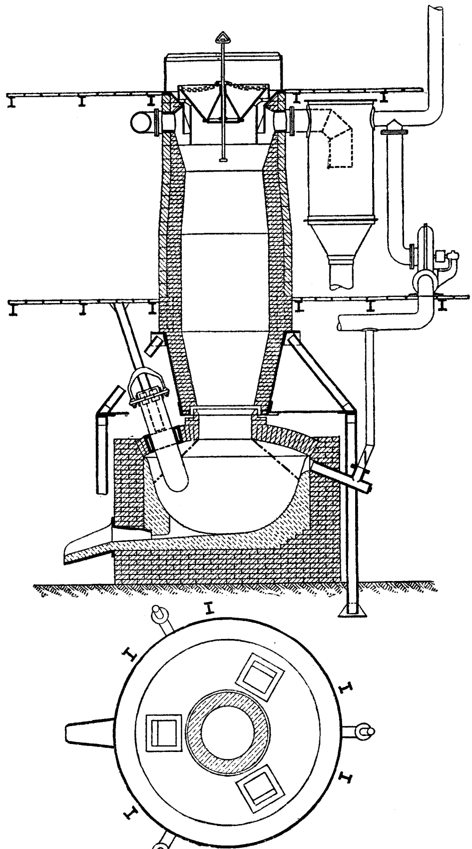

FIGURE 7.—Second type of furnace used at Domnarfvet, Sweden.

EXPERIMENTS OF THE JERN-KONTORET, TROLLHÄTTAN, SWEDEN.

The experimental runs conducted at Domnarfvet satisfied those interested in the undertaking so well that it was decided to go a step farther and to construct and perfect a furnace of a size suitable for commercial purposes.

[a] Yngstrom, Lars, Electric production of iron from iron ore at Domnarfvet, Sweden: Engineer (London), vol. 109, Mar. 4, 1910, p. 237.

DESCRIPTION OF FURNACE.

This work was undertaken by the Jern-Kontoret, an association of the ironmasters of Sweden. Realizing the importance of the work to the iron industry of that country, the association voted $90,000 for the purpose of putting up a plant and developing the process. The Swedish Government also assisted the project to the extent of furnishing power at a nominal figure from the plant at Trollhättan. Plans and sectional elevations of this furnace are shown in figures 8 to 11. The following description is taken from the official report delivered by the engineers to the Jern-Kontoret:[a]

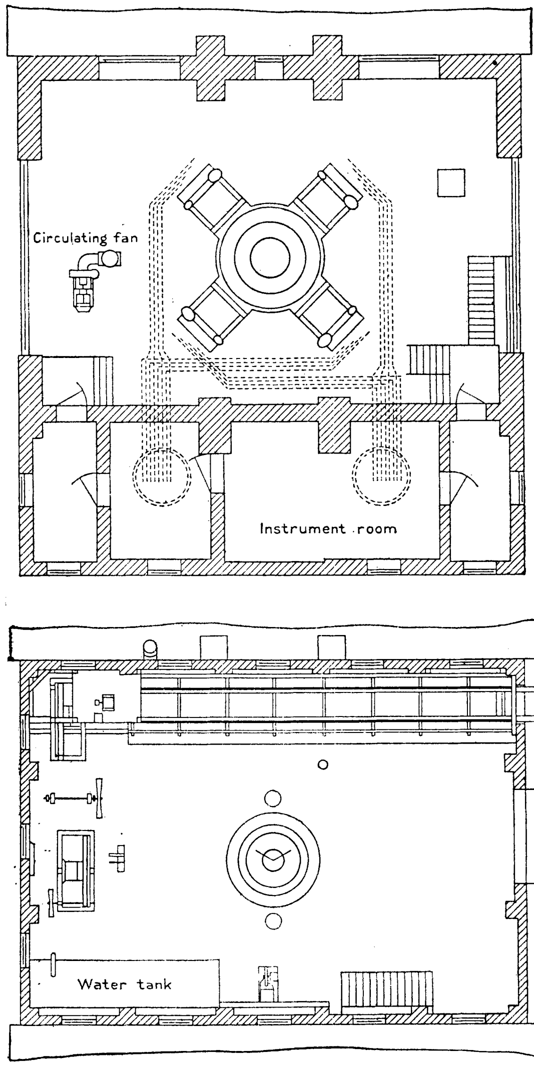

FIGURE 8.—Plan of furnace house at Trollhättan, Sweden.

The hearth is lined with "Hoganas" fire brick to a thickness of 360 mm. in the bosh and 450 mm. in the stack.

At the top of the shaft is a Tholander charging bell and cone, which is raised or lowered by means of a capstan driven by a motor.

The crucible rests on a concrete foundation. Like the shaft, it is surrounded by a sheet-iron shell ⅝ of an inch thick. At the top this shell is reinforced by an iron band to take up the pressure of the arched roof.

The four electrodes project through the roof in a slanting position at an angle of 65° to the horizontal. At the openings in the roof the electrodes are surrounded by cooling jackets of copper provided at the top with asbestos packing

[a] Leffler, J. A., and Odelberg, E., Redogörelse för Jern-Kontoret's Försoksverk I Trollhättan, May 31, 1911. Abstract: Iron and Coal Trades Rev., vol. 82, 1911, pp. 957, 1010.

to prevent the leakage of gas. The contacts for conducting the current to the electrode are arranged at the upper end and wedged between the electrodes and a holder of cast steel. This holder, in its turn, is supported on a frame movable up and down between two guides placed on each side of the electrode.

In this process provision is made for a circulation of the gases in such manner that gas is drawn by means of a fan from the gas outlets and blown into

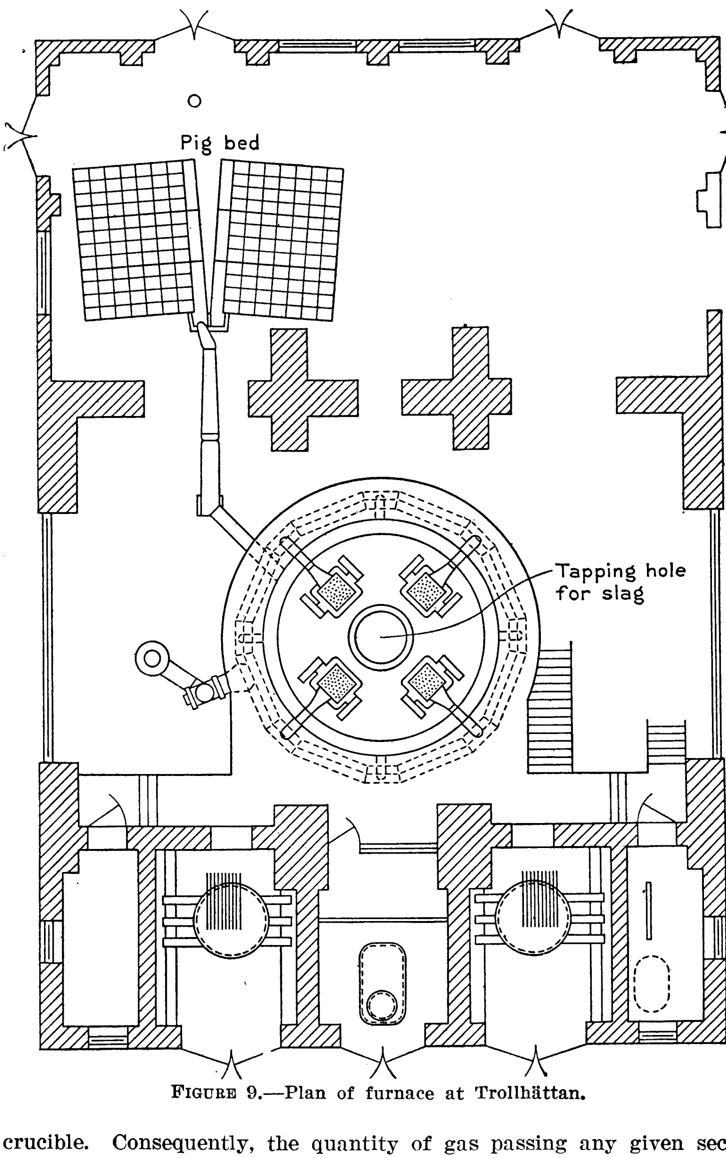

FIGURE 9.—Plan of furnace at Trollhättan.

the crucible. Consequently, the quantity of gas passing any given section of the shaft can be varied within certain limits by varying the speed of the fan.

This circulation of gas has two special objects, namely, (*a*) The gas blown into the crucible is there heated and gives off its heat to the charge in the shaft in passing up through it. Through this heating of the charge in the shaft a reduction of the ore by CO is facilitated, so that this gas is utilized to some extent for the process. (*b*) The second purpose of the circulation of the gas is connected with the construction of the crucible, as the gas cools the roof and thus protects it from overheating. This cooling action of the gas is due in part to the absorption of heat or raising the temperature of the gas and in part to the decomposition of CO_2 and H_2O in the gas in contact with the incandescent carbon in the crucible.

A diagram of the electrical connections is shown in figure 12.

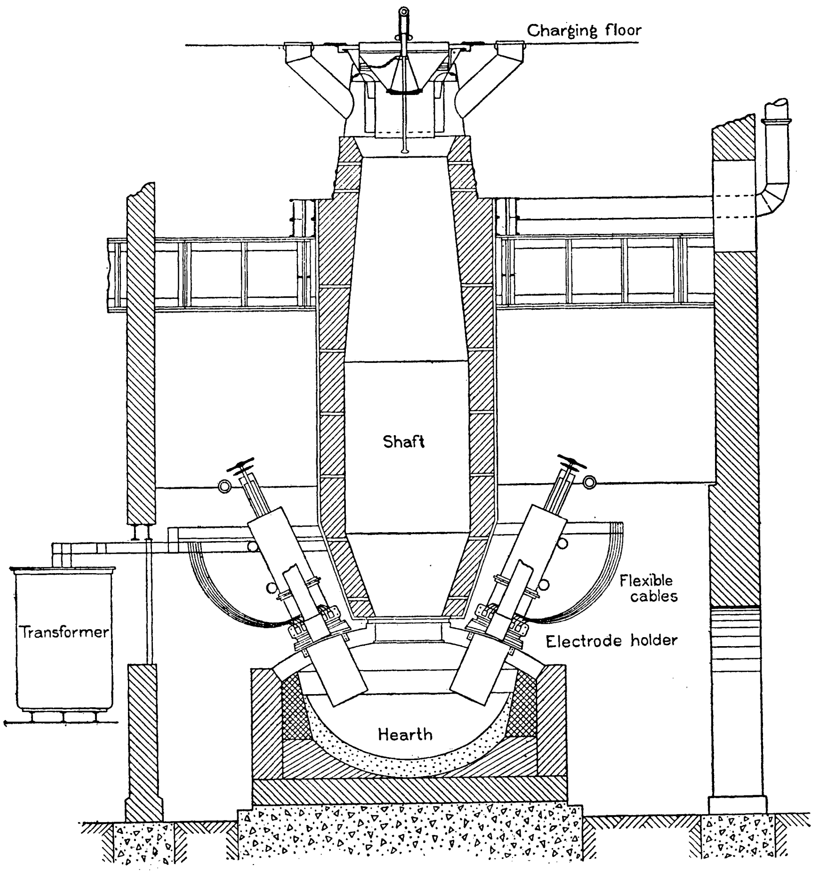

FIGURE 10.—Sectional elevation of furnace at Trollhättan.

CHANGES AFTER THE FIRST EXPERIMENTS.

Operations with this furnace were started November 15, 1910, and were continued without interruption until May 29, 1911. During this period various kinds of ore were smelted, and such grades of acid and basic slags were produced as seemed best suited to the treatment of each particular ore. The furnace worked well from the start, and was closed down that such alterations might be made as experience had demonstrated would be beneficial, and also that the crucible might be relined and a new roof built, as the frequent alternation of acid and basic slags had damaged the brickwork of the crucible. The

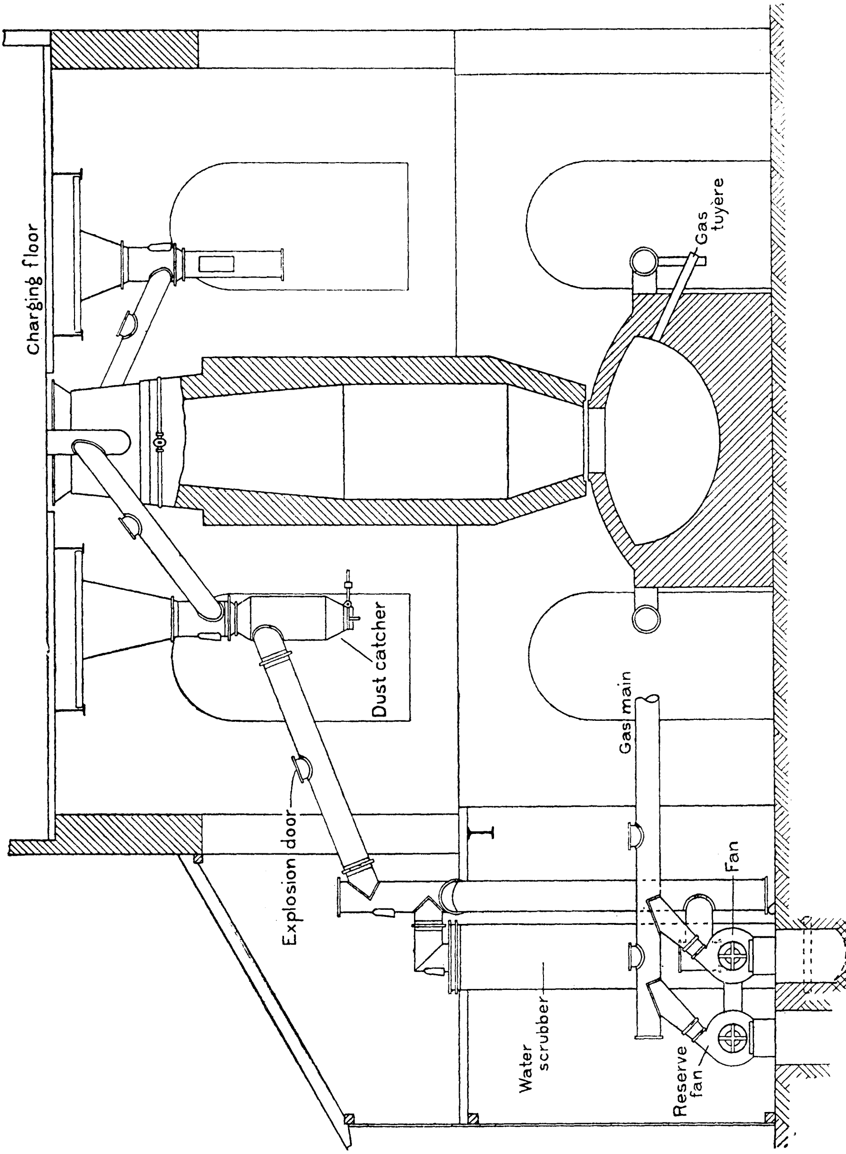

FIGURE 11.—Sectional elevation of furnace at Trollhättan, showing arrangement of gas circulation.

principal changes and additions that were made after the closing down of the furnace were as follows:

A system was installed for washing the gas which is returned to the crucible, so as to free the gas from dust particles before it reached the fan that caused the circulation.

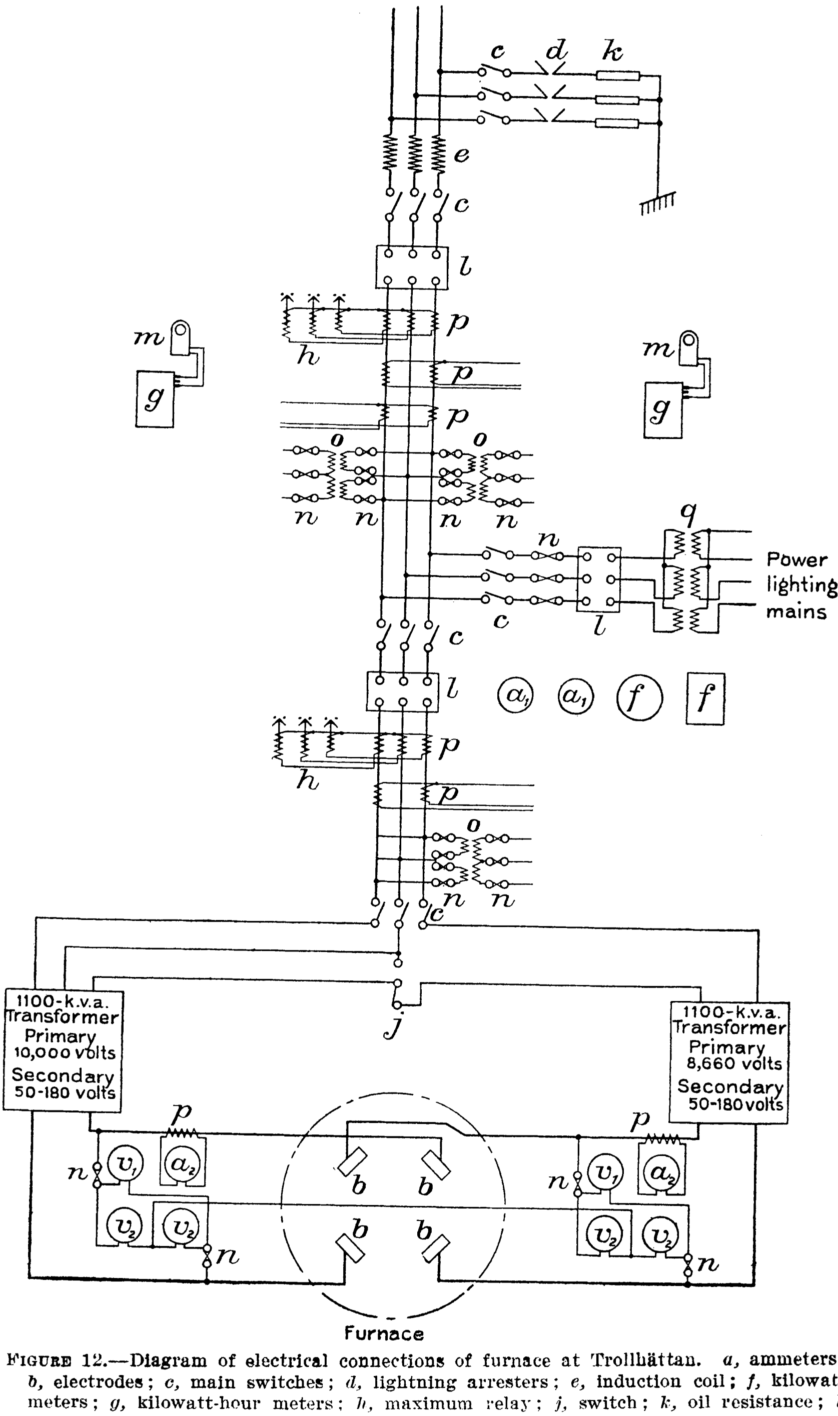

FIGURE 12.—Diagram of electrical connections of furnace at Trollhättan. *a*, ammeters; *b*, electrodes; *c*, main switches; *d*, lightning arresters; *e*, induction coil; *f*, kilowatt meters; *g*, kilowatt-hour meters; *h*, maximum relay; *j*, switch; *k*, oil resistance; *l*, automatic switches; *m*, clock control; *n*, fuses; *o*, *p*, *q*, transformers; *v*, voltmeters.

Electrode contact jackets were constructed and installed which permitted the electric current to be introduced to the electrodes at the point where they pass through the roof of the crucible rather than at the end of the electrode as was formerly done (fig. 10).

Round electrodes, 23⅝ inches in diameter, were substituted for square electrodes. The latter were built of four carbons, of about 12 by 12 inch section. The electrodes were threaded so as to permit their being joined by means of screw nipples, thus avoiding the waste of butt ends, as formerly, as soon as the electrodes became too short for further use.

SUMMARY OF WORKING RESULTS AND ANALYSES.

The following tables present in condensed form the results obtained by the operation of the furnace from November 15, 1910, to April 9, 1911:

TABLE 1.—*Results of electric iron smelting at Trollhättan, Sweden.*

Item.	Nov. 15, 1910.[a]	Nov. 16, 1910, to Feb. 11, 1911.	Feb. 11 to Feb. 19, 1911.	Feb. 19 to Mar. 19, 1911.	Mar. 19 to Apr. 9, 1911.	Total.
Iron in ore, per cent	64.92	65.57	65.06	49.50	57.92	61.54
Iron in charge, per cent	59.80	62.10	62.56	42.42	53.06	57.00
Slag per ton of iron, kg	390.00	205.00	224.00	780.00	458.00	327.00
Material charged per hectoliter of charcoal, kg		66.49	71.13	90.31	69.88	70.77
Charcoal per ton of iron, hectoliters		24.22	22.47	26.10	26.97	24.79
Charcoal contents:						
Water, kg		69.1	50.8	59.8	40.2	60.9
Gas, kg		41.7	36.9	49.3	43.1	42.9
Ash, kg		11.8	11.0	13.2	17.2	12.8
Coke, kg		293.1	277.6	323.4	325.7	301.4
Total, kg		415.7	376.3	445.7	426.2	418.0
Time consumed in working, hours, minutes	7 50	2,009 56	184 32	639 18	506 34	3,348 10
Time consumed in interruptions, hours, minutes		105 39	4 58	20 57	22 11	153 45
Total time, hours, minutes	7 50	2,115 35	189 30	660 15	528 45	3,501 55
Average load, kilowatts	1,121	1,319	1,694	1,017	1,733	1,344
Total kilowatt-hours used	8,780	2,651,029	312,601	650,480	877,706	4,500,596
Kilowatt-hours per ton of iron	3,800	2,296	2,149	2,623	2,643	2,391
Iron per kilowatt-year, tons	2.31	3.82	4.08	3.34	3.31	3.66
Gross electrode consumption, kg		13,012	1,578	2,281	2,474	19,345
Net electrode consumption, kg		6,743	763	1,121	1,285	9,912
Gross electrode consumption per ton of iron, kg		11.24	10.84	9.19	7.45	10.28
Net electrode consumption per ton of iron, kg		5.83	5.24	4.52	3.87	5.27

[a] Furnace being filled. [b] Term "net" represents 51.24 per cent of gross.

TABLE 2.—*Analyses*[a] *of ore and limestone used in electric iron smelting plant at Trollhättan, Sweden.*

[From Iron and Coal Trades Review, June 9, 1911.]

Number of sample.[b]	Oxides.											Loss on ignition.	Total.	Elements.				
	Fe_2O_3	Fe_3O_4	FeO	MnO	MgO	CaO	Al_2O_3	TiO_2	SiO_2	P_2O_5	S			Fe	Si	Mn	S	P
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1	0.24			0.35	0.31	54.32	Trace.		1.68	Trace.	0.001	42.94	99.811	0.17	0.79	0.27	0.001	Trace.
2	1.41	91.05		.16	1.12	.28	0.16	0.10	3.42	0.050	.011	.16	97.921	66.94	1.61	.12	.011	0.022
3		64.80	2.95	7.30	3.17	3.95	1.16		8.45	.016	.019	c 7.88	99.695	49.18	3.97	5.66	.019	.007
4	53.36	25.07		.40	.60	.71	.59		20.13	.034	.013	.27	101.177	55.45	9.47	.31	.013	.015
5	89.85		2.49	.18	.85	.99	.42		5.08	.014	.007	.59	100.471	64.80	2.39	.14	.007	.006
6	5.52	37.45		.14	1.84	.53	.06	.48	3.47	.037	.012	.14	99.679	67.10	1.63	.11	.012	.016
7	80.88		4.01	.63	2.57	.65	1.82		7.31	.032	.017	1.54	99.459	59.68	3.44	.49	.017	.014
8		79.35	1.42	.45	4.23	2.31	2.55		7.83	.028	.023	1.31	99.501	58.51	3.68	.35	.023	.012
9		73.31		.22	4.73	4.29	2.67		13.25	.025	.014	1.03	99.539	53.05	6.23	.17	.014	.011
10		73.10		.19	6.90	4.37	1.87		11.19	.025	.011	2.17	99.826	52.90	5.26	.15	.011	.011
11		71.69		.12	7.35	1.34	1.27		16.28	.025	.009	1.22	99.304	51.88	7.65	.09	.009	.011
12	2.92	78.02		.14	.13	.82	1.34		15.05	.027	.009	.90	99.356	58.50	7.08	.11	.009	.012
13		70.13		.12	7.90	7.05	.90		10.63	.029	.011	5.06	101.830	50.71	5.00	.09	.011	.013
14		68.18		.12	6.17	2.88	1.77		21.97	.009	.004	.00	101.103	49.34	10.33	.09	.004	.004
15	62.22		8.81	.17	.70	.44	1.06		27.60	.009	.002		101.011	50.41	12.98	.13	.002	.004
16		71.11		.41	3.60	7.98	2.65		11.14	.025	.011	2.84	99.766	51.42	5.23	.32	.011	.011
17		78.50		.37	4.68	3.34	2.26		8.28	.009	.020	2.18	99.539	56.76	3.19	.29	.020	.004
18	48.24	26.20		.98	.82	1.29	.55		21.96	.027	.002	.80	100.869	52.69	10.31	.76	.002	.012
19		72.57		.34	4.90	4.38	1.96		12.98	.009	.021	2.21	99.370	52.47	6.09	.26	.021	.004
20		83.53	.58	.17	2.53	2.81	1.49		7.96	.009	.004	.25	99.333	60.85	3.74	.13	.004	.004
21		75.60	1.07	.35	5.32	4.68	2.12		13.35	.014	.052	1.56	99.216	51.88	6.27	.27	.052	.006
22		90.42	1.20	.15	2.54	.78	1.02	.20	4.09	.021	.013		100.434	66.31	1.92	.12	.013	.009
23		65.14	1.63	.37	7.02	5.19	1.56		15.15	.018	.011	3.02	99.109	48.37	7.11	.29	.011	.008
24		67.59	1.12	.28	4.75	6.10	1.96		15.98	.011	.023	1.28	99.094	49.75	7.50	.22	.023	.005
25		62.11	.19	.36	7.08	6.25	2.33		21.25	.066	.051	1.39	101.077	45.06	9.97	.28	.051	.029
26		72.44	1.12	.44	6.20	4.03	1.40		12.05	.021	.055	2.16	99.916	53.25	5.66	.34	.055	.009
27	.56	91.98		.13	2.33	.59	.58	.79	3.35	.025	.001	.04	100.376	66.90	1.57	.10	.001	.011

[a] Analyses made at the Degerfors Iron Works laboratory.

[b] Samples taken at the works.

[c] CO_2, 7.02; C, 0.86.

TABLE 3.—*Analyses of iron, slag, and furnace gas.*

INCOMPLETE ANALYSIS OF IRON.

Date.	Number of charge.	C	Si	Mn	S	P
1911.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Jan. 3	138	4.19	1.35	0.90	0.004	0.021
Jan. 14	171	4.04	.75	.82	.005	.020
Mar. 16	324	3.00	.14	.08	.028	.019
Mar. 30	372	3.10	.45	.40	.014	.010

ANALYSIS OF SLAG.

Date.	Number of charge.	SiO_2	Al_2O_3	TiO_2	FeO	MnO	CaO	MgO	CaS	P_2O_5	Total.
1911.		*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Jan. 3	138	44.76	1.20	2.58	1.75	1.35	31.70	15.10	0.077	Trace.	98.517
Jan. 14	171	41.60	6.85	2.72	1.49	1.48	28.91	16.70	.063	0.000	99.313
Mar. 16	324	46.82	5.06	....	6.89	.23	33.27	7.97	.023	.041	100.274
Mar. 30	372	37.98	6.98	.37	1.28	.52	27.98	23.45	.123	.000	98.683

INCOMPLETE ANALYSIS OF SLAG.

Date.	Number of charge.	Fe	Si	Mn	S	P
1911.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Jan. 3	138	1.36	21.05	1.05	0.034	Trace.
Jan. 14	171	1.16	19.56	1.14	.028	0.000
Mar. 16	324	5.36	21.97	.18	.009	.018
Mar. 30	372	1.00	17.82	.40	.054	.000

ANALYSIS OF FURNACE GAS, BY VOLUME.

Date.	Number of charge.	CO_2	O	CO	H	CH_4	N
1911.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Jan. 3	138	28.2	....	....	....	....	....
Jan. 14	171	27.2	0.0	57.5	14.8	0.0	0.5
Mar. 16	324	12.6	....	71.9	13.0	1.7	.8
Mar. 30	372	19.2	....	59.7	17.6	2.5	1.0

REPORT ON OPERATION OF THE FURNACE FROM AUGUST, 1911, TO MAY, 1912.

The furnace was again put into operation in August, 1911, and was in continuous operation up to July, 1912, when it was relined. In May, 1912, a report was submitted to the Jern Kontoret by the engineers in charge of the operation of the furnace from August, 1911, up to that time. The following summary is taken from an abstract of the report that appeared in Metallurgical and Chemical Engineering, July, 1912, p. 413:

Results of operation of furnace from August, 1911, to May, 1912.

Iron, in ore, per cent	60.95
Iron, in burden, per cent	66.84
Weight of slag per ton of iron, kg	323

Weight of fuel per ton of iron, kg	404
Volts on furnace	73.6
Amperes on furnace	11.423
Power on furnace, kw	1,482
Power per ton of iron, kilowatt-hours	2,225
Output of iron per kilowatt-year, tons	3.94
CO_2 in throat gas, per cent	23.49
Volume of circulating gas, cubic meters per second	0.24
Pressure of gas in furnace, mm. water	225
Temperature at bottom of shaft, °C	441
Temperature at middle of shaft, °C	279
Temperature at top of shaft, °C	17
Electrode consumption, per ton of iron:	
Gross, kg	5.72
Net, kg	5.18

The variation in the charcoal and power consumption per ton of iron produced, depending upon the iron content of the ore used, is shown in the following tabulation, taken from the article mentioned above:

Variation in power and charcoal consumption.

Fe in ore, per cent	67.66	66.71	57.15	54.83
Slag per ton of iron, kg	166	209	409	521
Coal per ton of iron, kg	347	380	439	490
Kilowatt-hours per ton of iron	1,819	2,253	2,369	2,525

The composition of the pig iron produced varied between the following limits:

Variation in composition of pig iron.

Element.	Range.		Average.
	Low.	High.	
	Per cent.	*Per cent.*	*Per cent.*
Carbon	2.688	3.859	3.406
Silicon	.183	2.473	.725
Manganese	.190	1.366	.477
Sulphur	.0037	.0341	.0126
Phosphorus	.0134	.0454	.0200

The composition of the gases produced varied as follows:

Variation in composition of gases.

Gas.	Range.		Average.
	Low.	High.	
	Per cent.	*Per cent.*	*Per cent.*
CO_2	14.63	31.80	23.49
CO	31.80	71.10	63.15
H_2	7.87	14.50	10.35
CH_4	.82	2.37	1.52
N_2 (difference)	.50	3.41	1.49

The ratio of CO to CO_2 by volume varied from 4.8 to 1.8. The calorific power of the gas per cubic meter varied from 2,035 to 2,569, an average of 2,297 calories, or from 57.5 to 72.7 calories per cubic foot.

The oxygen ratio of the slags produced varied from 2.09 to 1.23. Analysis of the slags showed the following variations in composition:

Variation in composition of slags.

	Per cent.
SiO_2	36. 54 to 45. 15
Al_2O_3	1. 96 to 9. 20
TiO_2	Trace to 7. 42
FeO	. 58 to 6. 22
MnO	. 19 to 6. 00
CaO	21. 08 to 45. 58
MgO	6. 22 to 26. 65
CaS	. 04 to . 44
P_2O_5	Trace to . 034

The temperatures of the iron and the slag issuing from the furnace varied as follows:

Iron, °C	1, 230 to 1, 420
Slag, °C	1, 290 to 1, 460

In September, 1912, the Jern-Kontoret leased the plant at Trollhättan to the Strömsnäs Iron Works, which has since worked it as a commercial plant. The final report on the research work at Trollhättan, as well as a report on similar commercial installations elsewhere, has now been published.[a] A summary of the report, as furnished by Electro-Metals, of London, is largely presented below.

Use of concentrates.—The proportion of concentrates ought not to exceed 20 per cent of the ore charged. This figure, however, does not appear to be final, as in a somewhat modified furnace of the same type constructed later at the plant of the Uddeholm Co. at Hagfors 25 per cent of concentrates is used without any difficulty.

Power consumption.—The power consumption per ton of pig iron varies in proportion to the iron content in the ore. A poor ore and a pig iron high in silicon and manganese require more power than rich ore and pig iron low in silicon and manganese. For such iron the power consumption averages only 2,067 kilowatt-hours per ton of pig iron—that is, there is obtained 4.22 tons of pig iron per kilowatt-year, or 3.10 tons per horsepower-year.

Charcoal consumption.—The charcoal consumption per ton of pig iron varies from 20 to 24 hectoliters (57 to 68 bushels), depending on the quality of the charcoal and the charge. Coke, unless mixed with charcoal, is unsuitable for this furnace.

[a] Abstract of report, Iron and Coal Trades Rev., vol. 86, 1913, p. 714.

Consumption of electrodes.—The consumption of electrodes at Trollhättan has been reduced to less than 3 kilograms per ton of pig iron. At Hagfors it has amounted to as much as 6 to 9 kilograms. This discrepancy is explained by the fact that the electrode consumption is increased in proportion to the higher power consumption for a poor charge, and is further increased by the more efficient circulation of gases and higher carbon dioxide content in the gas. The lower electric load per unit of surface at the Hagfors furnaces also contributes to the higher electrode consumption at this plant.

Cost of repairs.—The cost of repairs is lower than was at first expected. In the manufacture of pig iron containing silicon and manganese the cost for repairs is higher than in producing pig iron with a low content of those elements.

Quality of the pig iron.—The silicon content does not vary more than in the product of an ordinary blast furnace. The phosphorus content is lower than when the same quality of charge is used in an ordinary blast furnace, owing to the lower consumption of charcoal in the electric furnace. The sulphur content is, however, slightly higher in the product of the electric furnace. However, it should be observed that both at Trollhättan and at Hagfors unroasted ores have been used without any difficulty arising from the sulphur present.

The quality of the pig iron from the electric furnace has been highly commended. It acts particularly well in the open-hearth furnace, and steel made from it is certainly not inferior to steel made from ordinary pig iron. E. Odelberg, managing director of the Strömsnäs Iron Works, states that the electric pig iron is "of the very best quality for the open-hearth process and, as regards the uniformity of the silicon content, fully as uniform as iron from an ordinary blast furnace." A. Herleinus, managing director of the Uddeholm Co., states that "the electric pig iron has been used with satisfactory results, both for the open-hearth, Bessemer, and Lancashire processes. Generally speaking, there has been no difficulty in obtaining pig iron of uniform quality, although slightly better uniformity may possibly be obtained with a very carefully conducted blast furnace."

Value of the gas.—At the plant of the Uddeholm Co., at Hagfors, the gas from the furnaces has been used with very good results for heating the open-hearth furnaces. It is estimated that the value of the gas obtained per ton of pig iron may be taken at 2.50 kroner (about $0.67).

With regard to the furnace that was used, the report expresses the opinion that its construction and general dimensions have been found to be suitable. A summary of the most important figures relating to the economic results is presented in Table 4 following.

TABLE 4.—*Results of electric iron smelting with furnace at Trollhättan.*

Item.	Nov. 15, 1910, to May 29, 1911.	Aug. 4, 1911, to June,21, 1912.	Aug. 12, 1912, to Sept. 30, 1912.	October to December, 1912.
Ore, concentrates and briquets, kg	4,336,338	7,917,214	[a] 1,406,530	2,914,830
Limestone, kg	345,405	647,479	108,150	169,944
Charcoal, hectoliters	65,474.5	107,282.5	21,859.5	44,934.5
Coke, kg	....	70,854	....	....
Electric energy, kw.-hours	6,339,131	10,845,180	1,939,073	3,957,565
Iron content of ore, per cent	60.79	60.75	68.67	65.38
Iron produced, kg	2,636,098	4,809,670	965,915	1,905,865
Slag per ton of iron, kg	350	324	192	....
Electrodes, per ton of iron, gross kg	10.00	6.08	3.02	2.78
Electrodes per ton of iron, net kg	4.95	5.17	3.02	2.78
Charcoal per ton of iron, hectoliters	24.84	22.31	22.63	23.58
Working time, hours, minutes	4,441 20	7,218 23	1,173 8	2,158 30
Repairs, hours, minutes	236 53	506 07	13 47	49 30
Repairs, percentage of total time	5.06	6.55	1.16	2.24
Average load, kw	1,427	1,502	1,653	1,833
Kilowatt-hours, per ton of iron	2,405	2,255	2,007	2,076
Iron per kw.-year, tons	3.64	3.88	4.36	4.22
Iron per hp.-year, tons	2.68	2.86	3.20	3.10

[a] 1,209,825 kg. represented Kiiruna "A" ore containing 69.61 per cent of Fe.

The table shows that step by step the results have been improved, the quantity of iron per horsepower-year increased, whereas the electrode consumption and time for repairs have been reduced, these three items in conjunction with the saving in charcoal being the decisive factors as regards electric iron smelting.

The figures show that during the last few months of the experimental work as much as 3.20 to 3.10 tons of iron were obtained per horsepower-year, whereas before the alterations were made the highest average figure was 2.86 tons. The highest expected yield was 3 tons per horsepower-year, which was therefore exceeded. It may also be mentioned that during single periods of several weeks when especially suitable ores were used, the highest average figures above mentioned were materially exceeded. It will thus be seen that as regards efficiency the results of the furnace surpassed expectations. The electrode consumption shows a remarkable decrease. The consumption of 13.8 kilograms during the first period of working was finally reduced to about 3 kilograms per ton of pig iron. The cost and time required for repairs were items that could not be estimated beforehand. Experience has shown that both the cost and the time required are less than could have been expected. Utilization of the gas, when practicable, should also be taken into account. At Hagfors the use of gas for firing the open-hearth furnaces is estimated to reduce the cost of the pig iron about 65 cents per ton.

DURABILITY OF THE ROOF OF THE CRUCIBLE.

In perfecting the electric furnace one of the most serious difficulties that had to be overcome was maintaining the brickwork of the crucible. In the operation of the furnace at Trollhättan from August 4, 1911, to June 21, 1912, the following repairs were made: October 26, 1911, the arch over the crucible was partly repaired;

February 13, 1912, the arch was entirely rebuilt; April 27, 1912, the arch was partly repaired. At Hagfors the arch was rebuilt after working four and one-half months.

COMMERCIAL FURNACES OF THE SWEDISH TYPE.

As a result of the successful working of the furnace at Trollhättan the following furnaces have been built:

Furnaces built subsequent to the Trollhättan furnace.

Place.	Number. of furnaces.	Horsepower of each.	Total horsepower.
Sweden:			
Domnarfvet	1	3,500	3,500
Hagfors	2	3,000	6,000
Norway:			
Hardanger	2	3,500	7,000
Arendal	3	3,000	9,000
Switzerland	1	2,500	2,500

However, the furnaces at Hardanger, after having been operated for about nine months, were closed down, the reason given being that suitable raw materials were not available in Norway. In Sweden charcoal is used as a reducing agent, whereas in Norway only coke is available for that purpose. During the experimental work at Trollhättan, coke was tried as a reducing agent, but was found unsatisfactory, and the failure at Hardanger, where coke only was used, confirms the conclusions reached by the engineers at Trollhättan regarding the unsatisfactory results with the use of coke as a reducing agent.

The bus-bar connections and the arrangements of electrodes around the crucible in the Swedish type of electric shaft furnace are shown in figure 13.

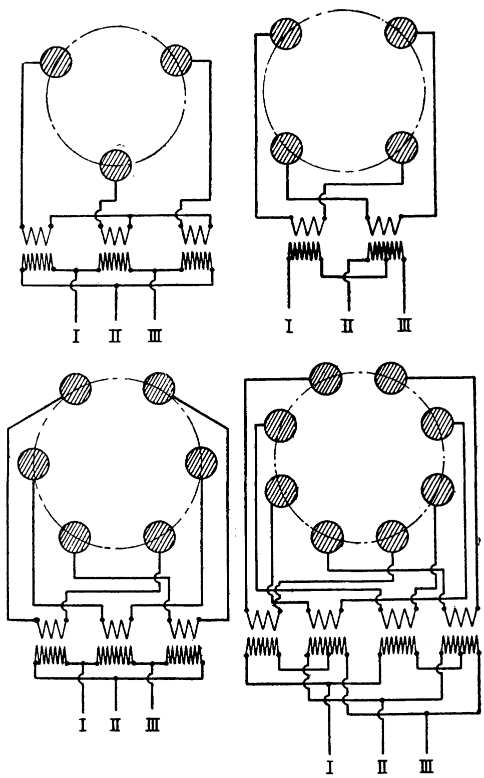

FIGURE 13.—Bus-bar connections and arrangement of electrodes in Swedish type of electric shaft furnace.

The Uddeholm Co., at Hagfors, Sweden, is adding a third furnace to its electric furnace installation at Hagfors, and is constructing three similar furnaces at its Nykroppa works. It will probably substitute electric smelting altogether for its blast furnaces.

The Stora Kopparbergs Bergslags is also preparing to introduce electric smelting on a large scale, and according to reports, other iron works in Norway and Sweden will follow its example.

The cost of construction of the plant at Trollhättan is given below:

Cost of construction of electric iron smelting plant at Trollhättan, Sweden.

Preparation of site:		
Excavations, foundations, and fencing; narrow-gage tram lines, 3 turntables, and 5 trucks; 1 5-ton and 1 40-ton weigh bridge; railroad siding (about 1,830 feet) with 1 turntable; earthenware water main from the canal (400 feet)		$10,727.42
Buildings:		
Furnace house with 2 windlasses and inclined tracks	$14,735.00	
Charcoal storage house with conveyors and elevators	6,032.51	
Crusher house and elevator	1,282.97	
Office, laboratory, and storeroom	1,393.87	
Repair shop with equipment	1,040.63	
General storehouse	243.64	
		24,728.62
Furnaces:		
1 furnace for 2,500 horsepower (ironwork, castings, masonry, etc.)	13,117.12	
Electric equipment	13,781.70	
Bars and cables to the electrodes	3,381.93	
Exhaust fan for furnace gases	826.94	
Pump and motor (for water)	1,452.64	
Water tank and pipes	942.19	
		33,502.52
Crusher		1,010.80
Electric lighting and motors: Transformers and wiring; 4 motors for exhaust fan, crusher, ore and coal elevators, and conveyors; direct-current transformers		5,157.24
Laboratory equipment		889.88
Instruments (self-recording) for measuring temperature, pressure, and volume of gas		1,894.25
Tools and sundry supplies		1,212.30
Furniture and fittings for office, etc		675.00
Supervision and sundry expenses		5,637.86
Drawings, specifications, and license fee		7,500.00
Total		92,935.89

CHEMISTRY OF THE REDUCTION OF IRON ORES IN THE ELECTRIC FURNACE.

As is well known, the reduction of iron ores is effected by heating the ore and the reducing agent to such a temperature that a reaction takes place between the oxygen and the reducing agent, which usually is some form of carbon. For the most part, iron ores at the present time are reduced in the blast furnace. In order to get a clear idea of the difference between a blast furnace and an electric-reduction furnace, let us first briefly note how the work of reduction and subsequent melting of the reduced iron and fluxes is brought about in the blast furnace.

The charge is composed of ore, oxide of iron plus gangue materials, fluxes for combining with the gangue materials of the ore in such proportions determined by analysis and calculation as will make a fusible slag, and the fuel, which is needed to provide heat and also acts as a reducing agent. This fuel is generally coke or charcoal and contains practically no volatile matter. In the tuyère zone the larger part of the fixed carbon passes to CO, but whether it first passes through the CO_2 state and is then reduced to CO by incandescent carbon is still a debated subject.[a] At any rate CO is the final product, and in its production a high enough temperature is produced to melt down the previously reduced iron and to form a fluid slag from the fluxes and gangue materials present. At this point the difference between the blast furnace and an electric-reduction furnace should be noted, for in the electric furnace the heat necessary for melting the charge is furnished by the electric current. In the blast furnace the quantity of fuel necessary to produce the smelting temperature, and not the amount necessary for the reduction of the oxides, determines the amount of fuel that is used. In the electric furnace the amount of electric energy necessary for producing the smelting temperature is used in place of coke or charcoal; and as only one-third or less of the coke that is used in blast-furnace work is needed in the electric furnace for the reduction of the iron oxides, it is possible to produce in the electric furnace three times as much iron with 1 ton of coke or charcoal as in a blast furnace. Such being the case, the amount of electrical energy and carbon that are necessary to produce 1 ton of pig iron in an electric furnace may now be considered.

This problem has been carefully worked out by Yngstrom,[b] Richards,[c] and others, and hence it is necessary in this connection to give only the essential details in such a calculation.

In determining the amount of electrical energy necessary to produce 1 ton of pig iron from a given ore the amount of heat absorbed by the following processes must be calculated: The reduction of the iron oxides to iron; the reduction of the SiO_2 to Si; the melting and superheating of n kilograms of iron; the melting and superheating of n kilograms of slag; the heating of x kilograms of CO_2 plus CO to whatever temperature it is determined that they should escape from the shaft.

[a] Belden, A. W., Foundry-cupola gases and temperatures: Bull. 54, Bureau of Mines, 1913, pp. 14–19.

[b] Yngstrom, Lars, Electric production of iron from iron ore at Domnarfvet, Sweden: Engineer (London), Feb. 25, 1910, p. 206.

[c] Richards, J. W., Metallurgical calculations, pt. 2, 1907, p. 403.

From the number of calories absorbed in this manner may be deducted the heat that would be developed by the combustion of the x kilograms of carbon needed for the reduction. The calculation of the amount of carbon needed for the reduction of the oxide is not an easy matter, for, as has been pointed out by Richards, in calculating the amount of carbon necessary to reduce the oxide of iron there is no way of knowing what proportion of carbon will form CO and what proportion CO_2. The amount of each that will be formed depends upon the temperature, CO being almost the only product that is formed at a high temperature, whereas CO_2 is formed in increasing quantities as the temperature decreases, the reactions being represented as follows:

$$Fe_2O_3+3C = Fe_2+3CO$$
$$Fe_2O_3+2C = Fe_2+CO+CO_2$$

From these equations we note that if the gaseous product of the reduction is all CO, not more than one-third as much carbon is required for the reduction as is required in the case of blast-furnace practice. Yngstrom in his calculations assumes that when carbon combines with oxygen in the electric furnace a mixture is formed that contains 30 per cent (by volume) of CO_2, and on this basis he calculates the carbon necessary for the reduction of the iron oxides present and the subsequent development of heat by the formation of CO and CO_2 by the following equation:

$$14Fe_2O_3+30C = 12CO_2+18CO+28Fe$$

In his computations he uses the following theoretical values:

To reduce 1 kg. of Fe from Fe_3O_4 there is required 1,650 calories.
To reduce 1 kg. of Fe from Fe_2O_3 there is required 1,800 calories.
To reduce 1 kg. of Si from SiO_2 there is required 7,830 calories.
By oxidation of 1 kg. of C to CO_2 there is developed 8,080 calories.
By oxidation of 1 kg. of C to CO there is developed 2,470 calories.
1 kilowatt-hour corresponds to 857 calories.
1 kg. of pig iron requries for melting and superheating 280 calories.
1 kg. of slag (monosilicates) requires 595 calories.

As a result of his calculations it is seen that for the production of 1 ton of pig iron containing 3 per cent of carbon, 1 per cent of silicon, 96 per cent of iron, and traces of manganese, phosphorus, and sulphur, made from a charge containing 60 per cent iron in the form of Fe_3O_4 and with the escaping gases containing 30 per cent of CO_2, 248 kg. of carbon, or 292 kg. of coke, and 1,460 kilowatt-hours would be required, which would correspond to 4.4 tons of pig iron per horsepower year of 365 days.

The production of this amount of iron per kilowatt-year has not been attained in actual practice, for, according to the latest reports from Trollhättan, only 3.94 tons is produced per kilowatt-year. At this point it may be interesting to compare the number of heat calories computed by Yngstrom as being necessary to produce 1 ton of pig iron with the number that can be calculated from Junge-Hermsdorf's "Heat Balance of a Blast Furnace of 250-ton Capacity." A furnace producing 250 tons in 24 hours will produce, in round numbers, 10 tons an hour, and as 10 tons of coke is needed per hour, this would practically correspond to 1 ton of coke for each ton of iron produced.

One ton of coke is equivalent to 1,000 kg., and as 1.18 kg. of coke is equivalent to 1 kg. of pure carbon, 1 ton of coke is equivalent to practically 850 kg. of pure carbon. If 4,153 kilogram-calories, as estimated by Yngstrom, be taken as the number of calories that are given off when 1 kg. of carbon combines with oxygen, forming a mixture that contains 30 per cent (by volume) of CO_2 ($0.3 \times 8{,}080 + 0.7 \times 2{,}470 = 4{,}153$), the heat necessary for producing 1 ton of pig iron in the blast furnace is $850 \times 4{,}153 = 3{,}530{,}050$ calories. As 2,121,284 calories represents the amount of heat that is necessary to produce 1 ton of pig in the electric furnace, there is a difference of 1,408,766 calories between the heat necessary for producing 1 ton of pig iron in the blast furnace and that required for producing 1 ton of pig iron in the electric furnace.

PROBLEMS IN THE ELECTRIC SMELTING OF IRON ORES.

Having thus traced the history and evolution of the electric pig-iron furnace up to the present time, and having stated the fundamental chemical principles upon which the reduction of iron is based, the authors will now briefly consider some of the difficulties that had to be overcome in order to bring the Swedish type of furnace up to its present stage of development and some of the problems that yet remain to be solved.

EARLY DIFFICULTIES.

An inspection of Harmet's drawings, and of the drawings of practically all others who gave their attention to the development of an electric furnace for the reduction of iron ores, shows that the first idea was to construct a shaft similar to a blast-furnace shaft, and then to substitute electrodes for tuyères. This seemed feasible, but in practice the furnace wall in the neighborhood of the electrodes proved to be short lived. Water cooling did not obviate this difficulty, but rather tended to increase it, due to jackets burning out and to other reasons. As was early observed by Héroult, the proper way to maintain the walls of an electric furnace crucible is to remove the electrodes as far as possible from the side walls. In the development of the furnace in California and in Sweden it was found necessary not only to do this, but also to keep the charge as far as possible from the roof of the crucible, as otherwise the roof was short lived owing to the intense local heat generated at the point where the electrodes enter the charge. In overcoming this most serious difficulty the present shape of the roof of the crucible and the manner in which the electrodes are introduced into the crucible have been evolved. As a further protection to the roof of the crucible, a part of the gases that were escaping from the top of the shaft, as previously stated, was returned to the crucible in order to cool the walls, as well as to assist in the reduction of the charge.

ELECTRODE PROBLEM.

Although the Swedish experimenters did not have so much trouble with electrodes, in California the difficulty of procuring suitable electrodes greatly interfered with the progress of the work. When experiments were begun in California the manufacturers of electrodes in this country had not previously been required to furnish electrodes of such large size, namely, about 20 inches square and about 72 inches long. Of those first furnished, that part of the electrode projecting into the crucible would either break off completely after it became heated, or else would spall off in large chunks and give trouble in operating the furnace. That others also encountered this difficulty is evident from the following quotation from a paper [a] presented by W. R. Walker at the April, 1912, meeting of the American Iron and Steel Institute:

> Our problems—mechanical, metallurgical, and otherwise—proved many, and our experience soon demonstrated that the conditions surrounding the successful operation of a large electric furnace were in many respects entirely different from those involved in the use of smaller units. In illustration the demands of a 15-ton electric furnace proved to be far in advance of the art of manufacturing electrodes. Our necessities represented a requirement that the electrode manufacturers of America and Europe had not been called upon to meet, and it took much time and money before there was finally accomplished the 20-inch round amorphous-carbon electrode that is now being used at South Chicago.

At the plant of the Noble Electric Steel Co. it was finally decided to try graphite electrodes. These worked satisfactorily in all respects except that on account of the angle at which it was necessary to insert them in the crucible they were subjected to a severe strain which caused them to break at the threaded joints. The electrode problem is, however, no longer a serious matter. As stated by Walker, the 20-inch round electrodes now in use at South Chicago give satisfaction, and the engineers at Trollhättan also report that the large carbon electrodes of about the same size as those used at South Chicago meet their requirements.

[a] Walker, W. R., Electric furnace as a possible means of producing an improved quality of steel: Metall. Chem. Eng., vol. 10, 1912, p. 371.

UNSOLVED PROBLEMS.

In connection with the unsolved problems in the electric smelting of iron ores it may be well to take up first a discussion of the results obtained at Trollhättan and in California.

A most careful record was kept of the work done at Trollhättan during the period November 15, 1910, to April, 1911, and the data thus obtained were incorporated in a report submitted to Jern-Kontoret by two of its engineers—J. A. Leffler and E. Odelberg. The essential parts of the report have been translated by Dellwik.[a] This report has been ably discussed by Robertson[b] in a paper that he presented before the Toronto meeting of the American Electrochemical Society, September, 1911. The work at Trollhättan is also the subject of a paper by Frick.[c] In this paper Frick also discusses the results obtained in California. Some of the points brought out in his paper are discussed below.

VOLUME OF SHAFT AS COMPARED WITH CAPACITY OF FURNACE.

Theoretically, the volume of the shaft of an electric furnace should be great enough to permit the practically complete reduction of the ore before it enters the crucible. In other words, the ideal condition in electric reduction furnace work would be to have the charge in such a condition as to require only melting by the time it comes into proximity with the electrodes. So far the degree of reduction that has taken place in the shaft of the electric furnace has varied all the way from nothing up to a considerable proportion less than complete reduction. Granted that the size of the shaft at Trollhättan has been properly calculated, and that the ratio of the volume of charge in 24 hours to the volume of the furnace should be 1:55, then in order to insure the best economical working conditions of the furnace, the reduction of the charge in the shaft must take place in the proper manner.

REDUCTION OF ORE IN SHAFT.

In an ordinary blast furnace the weight of the gases produced exceeds the weight of the charge by 30 to 50 per cent, whereas in electric-furnace reduction the gases evolved amount to only about 40 per cent, by weight, of the charge. In other words, in the blast furnace three to four times as much gas is given off in the production of 1 ton of iron as is given off in the production of 1 ton of iron in the electric furnace. Moreover, the temperature of the gas as it leaves the vicinity of the tuyères may be as high as 1,600° C., whereas the

[a] Dellwik, C., Electric iron smelting at Trollhättan, Sweden: Iron and Coal Trades Rev., vol. 82, June 9, 1911, pp. 957–962.

[b] Robertson, T. D., Recent progress in electrical iron smelting in Sweden: Trans. Am. Electrochem. Soc., vol. 20, 1911, p. 375.

[c] Frick, Otto, Electric reduction of iron ores with special reference to results obtained in Electro-Metals furnace at Trollhättan, Sweden, and Noble furnace at Heroult, Cal.: Metall. Chem. Eng., vol. 9, Dec., 1911, p. 631.

highest temperature stated to have been attained at the lower end of the stack in the work at Trollhättan was 965°. Granting that the temperature of the gas as it enters the stack may be even 1,000°, inasmuch as the weight of the gases produced is only about 40 per cent of the weight of the charge, the charge would not be heated to more than about 350° C., as pointed out by Frick, owing to the fact that the specific heat of the gas and that of the charge are about the same. For this reason complete reduction in the shaft can not be accomplished solely by the heat from the gases generated in the regular manner. In other words, the shaft acts merely as a preheater, most of the reduction taking place in the crucible by means of solid carbon.

Thus it is seen that an electric furnace may be operated in one of two ways: The ore may be reduced in the crucible by means of solid carbon, with no attempt at reduction in the stack, as is done in California at the present time by the Noble Electric Steel Co., or there may be part or complete reduction in the stack, this being the principle on which the Swedish furnaces are operated.

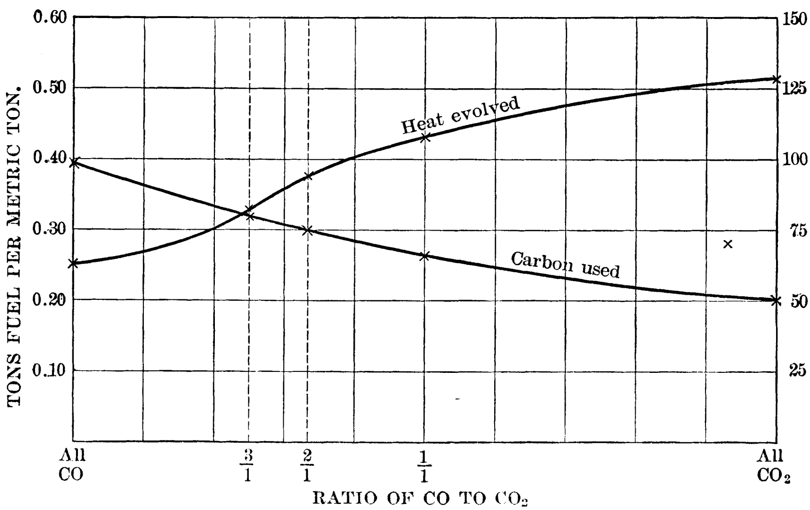

FIGURE 14.—Curves showing variation of fuel required and of heat evolved.

As is well known, a method that may seem best theoretically is not always best in practice. In this instance it is not possible to judge by results, as sufficient data are not available, and so the matter can be viewed only theoretically. In the reduction of any given iron ore, a definite amount of oxygen must be removed for every ton of iron obtained. Therefore it would theoretically be best to remove all the oxygen in the form of CO. However, as the oxidizing action of CO_2 gas varies with different temperatures, such removal is not possible, as experiments show that the ratio of CO_2 to CO should not be greater than 1:1, whereas 1:2 is the determined ratio in which they are usually present in blast-furnace gases. The curves in figure 14, the work of Prof. Richards, show that in electric-furnace work the greater the proportion of CO_2 in the gas the less is the amount of carbon required to remove the oxygen from the ore. Figure 15 (also prepared by Richards) shows that the consumption of electrical energy is proportional to the production of CO. Therefore, judging from deductions made from the curves, the efficiency of the electric furnace will be increased as reduction is effected by the gases in the shaft, and the most desirable ratio of CO_2 to CO in the escaping gases is 1:1. If this be granted, it would seem that reduction in the shaft is necessary, and the problem becomes how to effect the most satisfactory reduction in the shaft.

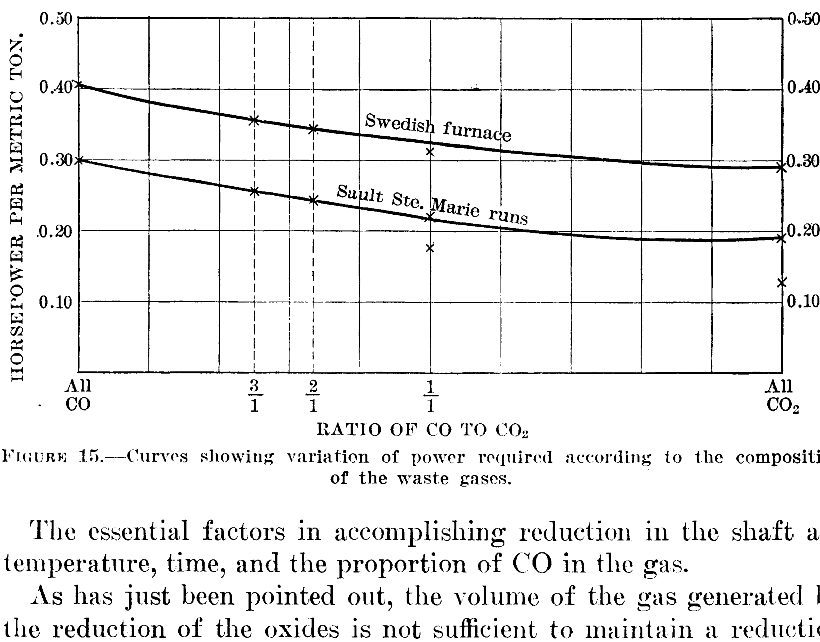

FIGURE 15.—Curves showing variation of power required according to the composition of the waste gases.

The essential factors in accomplishing reduction in the shaft are temperature, time, and the proportion of CO in the gas.

As has just been pointed out, the volume of the gas generated by the reduction of the oxides is not sufficient to maintain a reduction temperature in the stack. As a remedy for this difficulty the present system of gas circulation was adopted. The system is briefly discussed below.

GAS CIRCULATION.

As has been pointed out by Frick,[a] the idea of using circulating gas in the electric furnace was conceived by Harmet and incorporated by him in his papers[b] on the reduction of iron ores in the electric furnace.

[a] Frick, Otto, Electric reduction of iron ores, with special reference to results obtained in Electro-Metals furnace at Trollhättan, Sweden, and Noble furnace at Heroult, Cal.: Metall. Chem. Eng., vol. 9, 1911, p. 631.

[b] Report of the commission appointed to investigate the different electrothermic processes for the smelting of iron ores and the making of steel in Europe: Mines Branch, Department of the Interior, Canada, 1904, pp. 124, 139.

METHOD OF UTILIZATION.

At present gas circulation is used in the Swedish type of furnace in order to cool the superheated brickwork of the crucible and to carry up through the stack a volume of gas that is large enough and hot enough to bring about reduction in the stack.

This method has been the subject of a great deal of discussion.

OBJECTIONS.

The following are the principal objections to the circulation of gas in the electric furnace:

(1) The moisture of the charge, the CO_2 of the flux, and the CO_2 gas naturally produced in the furnace are returned in a large part to the crucible and react on the unconsumed carbon by the reactions—

$$CO_2+C=2CO$$
$$H_2O+C=H_2+CO.$$

(2) The reactions noted materially cool the smelting zone of the furnace, which is its most vital working part.

(3) The system is cumbersome and expensive, and soon reaches the maximum of useful effect.

In order to overcome the objections mentioned it has been proposed to keep the ore in the shaft at a low red heat, and then to allow the CO gas produced by reduction in the crucible to rise slowly up through the charge, thus giving it the best opportunity of producing the maximum amount of CO_2. In the circulation of gas, as has been pointed out by Richards,[a] it is not the increased volume of the circulating gas that performs the reduction, as it is evident that when the amount of gas passing through the furnace is increased two or three times its velocity is also increased to that extent, and therefore its contact with the ore is only one-half to one-third as long. Such being the case, the only value of circulating a part of the gas escaping from the top of the shaft, so far as the problem of reduction is concerned, is that the charge in the shaft is kept at the temperature necessary for reduction, but, on the other hand, the CO_2 returned to the crucible is reduced by C to CO, and thus one aim of electric-furnace reduction is defeated, namely, the removal of the oxygen from the ore with a minimum amount of carbon.

Nevertheless there are objections to the methods that have been proposed for obviating the difficulties connected with the present method of gas circulation which may be briefly stated as follows:

(1) It would probably be difficult to heat successfully the charge in the stack by means of surface electrodes embedded in the walls of the shaft.

(2) As at a low red heat (say 480° C.) reduction takes place slowly, the volume in the shaft would have to be large in order to

[a] Richards, J. W., Gas circulation in electrical reduction furnaces: Trans. Am. Electrochem, Soc., vol. 21, 1912, p. 403.

give the charge time enough to be reduced in passing through the shaft.

(3) The use of burnt limestone, where shaft reduction is attempted, would introduce an unnecessarily large quantity of fine material into the charge.

(4) The water-cooled plates in the arch of the crucible, although useful, would not of themselves form a satisfactory substitute for the introduction of cold gas beneath the roof of the crucible.

As has been stated by Leffler,[a] one of the engineers of the Jern-Kontoret, gas circulation would be abandoned for a more simple and practicable method if such should be discovered.

However, the use of gas circulation at Trollhättan seems to be necessary, at least with the Swedish type of furnace. If this be true, efforts to improve the system ought to be directed somewhat along the following lines:

As is now done at Trollhättan, that part of the gas from the top of the shaft that is to be circulated could be drawn through a "Cottrell system" for the removal of the solid particles of ore and flux, by means of the circulating fan, and forced through a regenerator filled with coke heated electrically to such a temperature as to bring about the reduction of the CO_2 to CO. The gas at the same time would be heated, but not to a temperature too high to absorb heat as it entered the crucible, and would thus pass up into the shaft at such a temperature as to readily effect reduction. Part of the excess waste gases could then be burned in a jacket around the shaft of the furnace so as to prevent radiation losses; the waste gases from the jacket could be passed to a preheater and completely burned, whereby the charge, minus the reducing agent, would be dried and raised to a temperature high enough to admit of the ore being reduced as soon as or soon after it was introduced into the stack.

The obvious advantages of such a system would be the doing away with the introduction of water vapor into the gas, as is done by the present system of scrubbing the gas; the removal of CO_2 from the gas; and the raising of the temperature of the circulating gas.

Although the system as above outlined is just as cumbersome and expensive as the present method, it would probably be more effective.

OTHER METHODS SUGGESTED.

Some of the methods suggested as improvements are:

(1) *Calcining the limestone outside of the furnace.*—This subject is discussed in a later section dealing with the comparison of the Swedish and Californian types of furnaces.

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[a] Leffler, J. A., In discussion of Richards's paper on "Gas Circulation in Electrical Reduction Furnaces": Trans. Am. Electrochem. Soc., vol. 21, 1912, p. 412.

(2) *Preheating the ore.*—Judging by experience gained in California, the writer believes that the preheating of the charge is beneficial, for the following reasons: (*a*) It dries the charge and thus permits a more accurate weighing of the same, which is especially important in the electric reduction furnaces; (*b*) the initial temperature of the charge on entering the stack is thus sufficiently high to permit its being reduced immediately.

(3) *Smelting of fine ores.*—The authors are privileged to quote from a communication from Electro-Metals, Ltd., in regard to this matter, as follows:

> As was explained in our first publication on this subject, the object of this plant [at Trollhättan] was to determine the relative merits of electric smelting as compared with ordinary blast-furnace smelting. For this reason the work has been carried out under widely varying conditions and with different kinds of ore and fuel. In consequence the results are by no means uniform and scarcely suitable for conclusions based on the average figures.
>
> One object of some importance in Sweden was to determine the proportion of ore concentrates which could be used. The results prove that a large proportion of concentrates is detrimental to smooth running and good results.
>
> This is readily understood from the fact that only about one-third as much charcoal is used as in the blast furnace, and concentrates therefore have an increased tendency to choke the passage of the gas.

As will be seen from the above, it is not feasible to use a large proportion of fine material in making up the charge for the electric furnace. This limitation, however, does not prevent the smelting of fine ores, for they may be sintered.

(4) *Sintering.*—The advantages derived from sintering in electric-furnace work would be as follows: (*a*) The fine material would be caked in lumps, permitting free passage of the gases up through the charge in the shaft, and as the lumps would be porous they would be readily reduced, and (*b*) the fine ore would be preheated; that is, the hot sintered ore could be charged directly into the shaft at reduction temperature.

(5) *Increasing the size of the unit.*—The electric reduction furnaces now in operation vary in size as regards their horsepower from 1,500 up to 3,500. The largest yet designed requires 7,500 kilowatts and is at a plant in Sweden. As can be readily understood, it is important that the size of the unit be made as large as possible, and it is quite probable that larger furnaces will be built.

(6) *Increasing the general efficiency of the furnace.*—Improvements will probably be along the following lines: (*a*) The utilization of the waste gases; (*b*) the securing of a high-power factor; (*c*) the correction of induction losses; and (*d*) the perfecting of the single-phase furnace as recommended by Catani.[a]

[a] Catani, R., Large electric furnaces in the electrometallurgy or iron and steel: Trans. Am. Electrochem. Soc., vol. 15, 1909, p. 168.

STATUS OF THE IRON INDUSTRY IN THE WESTERN STATES.

At the presenti time the only important iron-reduction plant west of the Mississippi River is at Pueblo, Colo. The plant has six stacks, twelve 50-ton open-hearth furnaces, two 15-ton Bessemer converters, four 400-ton furnaces, and two 250-ton furnaces. That there are no other large iron-reduction plants in the West is due largely to the fact that there is lacking in that part of the country, especially in California, the grade of coal necessary for making a suitable metallurgical coke. Then, too, although there are several known large iron-ore deposits scattered throughout the Western States, not much attention has in the past been paid to this class of deposits.

For nearly half a century after the discovery of gold in California the prospector along the Pacific coast looked for gold-bearing rock only. In recent years the discovery of valuable deposits of copper in California gave the prospector the copper craze, so to speak. In prospecting he looked for iron only as an indication of the presence of copper; that is, if he came across an iron deposit he looked upon it as a gossan or capping, and at once examined it for gold and copper, as his experience had taught him that gold is frequently found near the surface in rock of similar appearance and copper at a greater depth. It is well known that there are many deposits that yield oxidized ores above water level and sulphides below, so it is easy to understand why the prospector should have mistaken a true iron deposit for a deposit of the nature just mentioned. Even such iron ores as those in Shasta County were never seriously considered as such by prospectors. The miners in that part of the country commonly believe that iron indicates the presence of copper, and they insist that copper will be found below the iron.

IRON-ORE DEPOSITS ON THE PACIFIC COAST.

As above stated, it has long been known that there are large deposits of iron ore in Nevada, Arizona, and California, especially in southern California. As has been pointed out by Jones,[a] most of the present known deposits of the Southwest have been discovered in places where there has been more or less erosion. Owing to the erosion, faces of ore several hundred feet in height, and of as great or greater width, are shown in certain intersecting gulches. Intrusions in limestone beds are common in the desert regions of Arizona, western Nevada, and California, and, as Jones states, there is in these regions scarcely a range of this nature that does not show some ledges of iron or float ore, and he ventures the assertion that syste-

[a] Jones, C. C., Iron ores of the southwest: Paper read before the American Mining Congress, September, 1910; published in Min. and Min., vol. 31, April, 1911, p. 574.

matic prospecting and mining would uncover as great bodies of ore as have been already accidentally exposed by erosion.

For some time past the railway and oil interests of California have been systematically acquiring iron-ore holdings. For example, Jones [a] states that in 1911 the Union Oil Co., through its subsidiary company, the California Industrial Co., was reported to hold an aggregate proven tonnage of 300,000,000 tons, one-third being in California and two-thirds in Lower California, Mexico. This company has acquired these properties for the reason that they believe the problem of using oil as a reducing agent will ultimately be solved, and thus permit the establishment of an iron and steel industry in that section of the country. The Southern Pacific Railroad Co., operating under the name of the Iron Chief Mining Co., controls several deposits throughout the State, one of which is in Riverside County, some 140 miles from Los Angeles. Jones [b] states that it has some 30,000,000 tons of proven ore of such a nature that it can be mined cheaply. The average analysis of the ore is claimed to show 64 per cent iron and phosphorus within the Bessemer limit.

In addition to these deposits Jones also mentioned the following: At Scotts Siding, 190 miles east of Los Angeles, where 10,000,000 tons of ore have been blocked out, there being three times that quantity of ore on the property; in the Providence Mountains, 236 miles from Los Angeles, is a deposit of 5,000,000 tons of soft hematite, of Bessemer quality, that can be mined with a steam shovel; 12 miles west of Silver Lake Station and 230 miles east of Los Angeles is a deposit owned by the Colorado Fuel & Iron Co. that it states shows over 13,000,000 tons of ore that can be mined with steam shovels. In addition to the deposits named there are the Minarets deposits in Madera County, which are at present inaccessible, being about 80 miles from the railroad, but it is thought that a railroad line will soon be built into this district, thus making them accessible both to San Francisco and Los Angeles. It is stated that this is one of the largest deposits of iron ore to be found anywhere in the United States. As a result of his investigation Jones is of the opinion that there is 200,000,000 tons of available high-grade ore in southern California alone within 300 miles of Los Angeles, and that the ore can be laid down at Los Angeles at a cost of $3.50 to $4 per ton. If these figures are correct, there is a basis for the hope that an iron industry will be established on the Pacific coast, provided there can be found a commercially feasible process that will permit the utilization for metallurgical purposes of those fuels that are available in that part of the country.

[a] Jones, C. C., Op. cit., p. 53.

[b] Jones, C. C., Idem.

DEVELOPMENT OF THE ELECTRIC REDUCTION FURNACE IN CALIFORNIA.

ORE DEPOSIT OF SHASTA IRON CO.

For 30 years or more a company known as the Shasta Iron Co. has owned a deposit of iron ore situated about 7 miles from the mouth of the Pitt River, in Shasta County, Cal. This ore is a high-grade magnetite. An average of a large number of analyses gives the following percentages:

Average of analyses of magnetite from Shasta County, Cal.

	Per cent.
Fe_3O_4	89.4
Fe_2O_3	7.3
Fe	69.90
MgO	.10
MnO	.18
SiO_2	2.40
P	.011
S	.009

The ore is found near a contact between limestone and diorite. The ore body is markedly uniform, a series of 20 samples taken by the writer over a cut 60 by 40 feet giving the following iron content:

	Per cent.
Maximum	70.5
Minimum	68.8
Mean	69.7

The limestone is also of an excellent quality; an average analysis is as follows:

Average of analyses of limestone from Shasta County, Cal.

	Per cent.
SiO_2	1.2
Al_2O_3	.5
MgO	1.1
CaO	53.8
FeO	.2

The percentage of CaO is equivalent to about 98 per cent calcium carbonate.

Although the Shasta Iron Co. had previously planned to make pig iron from this ore, nothing definite was done until the summer of 1906. At this time the possibility of smelting the ore by electricity was brought to the attention of H. H. Noble, president of the Northern California Power Co. Owing to Héroult's connection with the experimental work that had been done at Sault Ste. Marie, he was commissioned to construct a plant for the purpose of treating the ores above mentioned. The place selected was at a point on Pitt River, near the mines. The place was named Heroult, and is still known by that name.

FIRST EXPERIMENTAL ELECTRIC REDUCTION FURNACE.

In July, 1907, the first furnace having been completed, experimental work was begun. This furnace was a 1,500-kilowatt, three-phase furnace of the resistance type. It soon presented mechanical difficulties that made its commercial use impracticable, and so it was closed. This furnace is shown in figure 16. In construction the crucible resembled a long, elliptical-shaped iron box. The bottom was made of heavy cast-iron plates, into which had been cast cast-iron lugs or pins, and upon the iron plates was tamped a bottom made of carbon paste. The bottom plates were connected with the bus bars in such a manner as to form a neutral in the three-phase system.

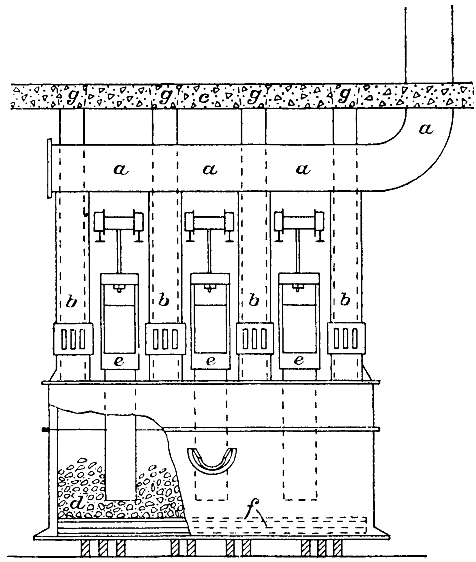

FIGURE 16.—Héroult 1,500-kilowatt, three-phase reduction furnace.

The electrodes passed through the roof, as shown in the figure. They were suspended from copper holders which were water jacketed. The charge was fed into the crucible through the pipes, *b*, and the gases from the crucible passed up around *b* into *a* to preheat the charge in *b* by burning the gases around *b*, air being admitted for that purpose through slots in the outer pipe just above the roof of the crucible. The pipes, however, proved too small, and the charge in them became so hot as to hang, and so they had to be discarded. It was also impossible to maintain a roof over the crucible, and so the furnace was finally operated as an open-top furnace. Several tons of excellent foundry iron was made in this furnace, and later it was used for making ferrosilicon, but was finally closed and removed in order to make room for the type of furnace subsequently adopted.

SECOND AND THIRD EXPERIMENTAL FURNACES.

After the closing of this furnace experimental work was conducted in a 160-kilowatt single-phase furnace, and, using the results obtained in this furnace and its method of operation as a basis, a second 1,500-kilowatt three-phase furnace was designed and built. This furnace is shown in figure 17. Above the crucible was a superposed shaft resembling that of an ordinary blast furnace.

In the operation of the furnace the ore, mixed with the proper proportion of flux, was fed into a preheater, *b*, that was heated by waste gases from the combustion chamber *k* at the top of the shaft. The gases entered the base of the preheater through a flue, *e*, from an annular chamber surrounding the top of the shaft and communicating with the chamber *k* through openings.

A mechanically operated scale car, *g*, moved on a circular track around the top of the stack and received first a weighed charge of ore and flux from the preheater *b* and then a weighed charge of charcoal from the charcoal hopper *c*, delivering the charges alternately into the furnace.

The charge was kept at about the height of the irregular line shown in the shaft. Above the charge were small openings in the shaft with suitable valves for admitting the requisite amount of air to burn the gases resulting from the reduction of the ore in the lower part of the stack, thus still further heating the charge; as above stated, the waste gases were then passed up through the preheater *b*, thus preheating and drying the ore before it was charged into the furnace.

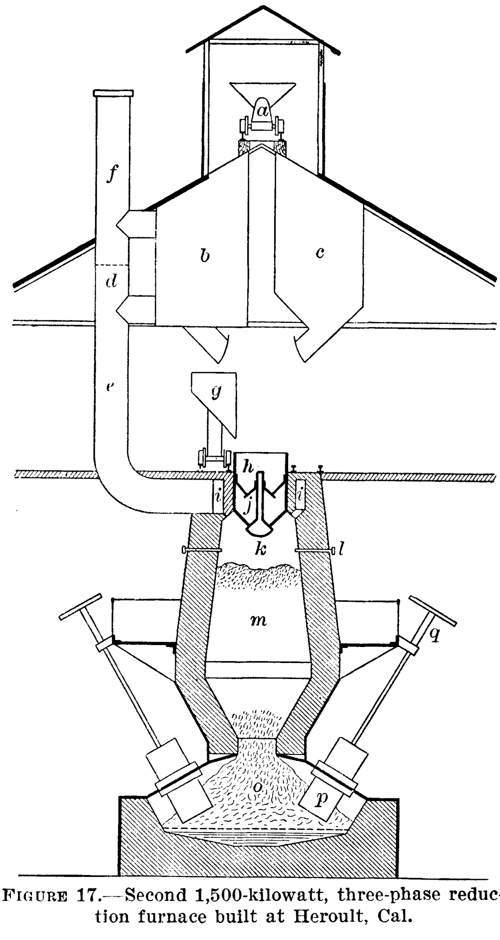

FIGURE 17.—Second 1,500-kilowatt, three-phase reduction furnace built at Heroult, Cal.

The electrodes, six in number, were spaced equidistant around the furnace, so that the current passing between them melted the charge, and the molten metal and slag were collected in the crucible, from which they were drawn as in ordinary blast-furnace work. The tap holes were arranged at different levels, so that the crucible might be partly or completely emptied, as desired.

The electrical equipment consisted of three oil-insulated, water-cooled transformers, having a rated capacity of 750 kilowatts each, 60 cycles, 2,200 volts primary, and a secondary range of 35 to 75 volts, constant output. The secondary current varied from 10,000 to 21,400 amperes.

The range in voltage was controlled by a dial switch in the primary circuit, giving steps of about 3 volts in the secondary. The efficiency was 98.6 per cent at 75 volts on the secondary, guaranteed for 25 per cent overload for two hours. The rise in temperature at full load, by test, was 35° C.

The generation of energy in the furnace was, therefore, controlled externally without movement of the electrodes, whose position was changed only to accommodate their wear in the crucible.

Many experimental runs were conducted in this furnace, and many changes and alterations were made in the construction and shape of the roof of the crucible, the manner of connecting the electrodes, the height and volume of the stack, the method of preheating the charge, the circulation of gases through the crucible and up through the shaft, and the like.

Although several hundred tons of splendid foundry iron was made in this furnace, much of the product was white iron, for the production of which this type of furnace seems best suited, as has also been ascertained at Trollhättan.

PRESENT TYPE OF FURNACE.

In the spring of 1911, owing to electrode troubles and to the irregular composition of the iron produced, the company decided to abandon the type of furnace that had been developed and to attempt to evolve a furnace in which iron could be produced that would better meet the requirements of the Pacific coast foundries. In this connection it may be stated that scrap iron is largely employed in that part of the country for making all grades of castings and that the sulphur, phosphorus, and combined-carbon content of many of the castings is so high as to impart very undesirable qualities to the finished product. For this reason the Pacific coast foundrymen have been in need of an iron high in graphitic carbon and silicon and low in other impurities. The Noble Electric Steel Co. states that it is able to produce such a grade of iron in the type of furnace now being used, and that the following is a fair average analysis of the pig iron that it is producing:

	Per cent.
Si	3. 64
S	. 00
P	. 02
Combined carbon	. 00
Total carbon	3. 58

The details of the construction of this furnace have been furnished by the company, and are presented below, being taken chiefly from a recent article by Van Norden:[a]

THE PLANT.

The furnace is housed in a heavy steel-frame building, sheeted with corrugated galvanized iron. It is 120 feet long and 75 feet wide, and about 60 feet high. The interior is divided into two sections or bays by a line of columns. In the south section is the pouring floor, on which the pigs are cast. Throughout this bay is operated a 50-foot traveling crane. This is electrically operated and has one 20-ton and one 5-ton hoist. A lifting magnet, having a capacity of 2,000 pounds, is used in picking up the pigs. It will lift about 1,000 pounds of hot pigs.

The north bay contains the electric furnaces, their transformers, and the necessary controlling equipment.

THE FURNACE.

The crucible is contained in a steel shell 27 feet long, 13 feet wide, and 12 feet high. The crucible is rectangular, with a sloping bottom to facilitate the flow of the molten bath, when the furnace is tapped. The tap hole is in the center of the front of the crucible. The roof of the furnace is arched, and is penetrated by five stacks 24 inches in diameter and extending 15 feet above the roof of the crucible. In the four spaces between the stacks at the center of the dividing arches are inserted graphite electrodes. The electrode jackets and the arched roof are water cooled. The stacks are used only for charging, no reduction being attempted in them. A charging platform is built along the top of the stacks and supports a track which leads to the mixing platform. The loaded car is run along this track and the charge dumped directly into the stack. Except when receiving a charge, the stacks are closed with tight-fitting caps.

THE ELECTRODES.

Graphite electrodes are used. They are cylindrical in form, 12 inches in diameter, and 4 feet long. The upper end has a tapered male-threaded nipple, and the lower end has a corresponding socket with a female thread. As the electrode is fed into the charge a new one may be fastened to it, making a continuous feed.

An electrode in continuous operation lasts 30 days. Occasionally an electrode breaks in the furnace. Such breakage was formerly a serious matter and caused considerable delay and annoyance in the operation of the furnace, but this difficulty has now been practically obviated.

[a] Van Norden, R. W., Electric iron smelting at Heroult, Cal.: Jour. Elec. Power and Gas, Nov. 23, 1912.

THE TRANSFORMERS.

In the rear of the furnace, and as close thereto as is possible, are the three service transformers which supply three-phase current at 40 to 80 volts to the electrodes. These transformers are oil immersed and water cooled and have a capacity of 750 kilowatts each. The low-tension connections to the electrodes consists of eight pieces of flat copper bar, three-eighths of an inch thick and 5 inches wide, bolted together. On the 2,400-volt primary side there are brought out eight current taps for voltage regulation. These lead to an oil-immersed switch group, each unit of which is operated by a solenoid. This arrangement, with autotransformer compensator, gives 15 steps for voltage variation.

ELECTRIC CONTROL.

Electric control is through a switchboard, there being a panel for each furnace. As the current and power factor in each phase must be under observation at all times during operation, separate meters are installed in each phase. The requirements for one panel are 3 ammeters, 3 voltmeters, 3 wattmeters, 3 power-factor meters, and 3 recording wattmeters. The meters are mounted across the panel in rows of three each. Under the first four sets named are three hand-wheels to control the voltage variation, and under these three switches that control the entire load, and under the latter are the recording wattmeters.

For operating the voltage control and the main circuit breakers there is a $7\frac{1}{2}$-kilowatt motor-generator set, comprising a 125-volt direct-current generator, directly connected to a 10-horsepower induction motor. This set has a small panel board mounting a circuit breaker, ammeter, voltmeter, and two single-pole knife switches. In the event that line voltage should fall, or if for any other cause the direct-current supply should become deranged, there is a storage-battery set, having a capacity of $7\frac{1}{2}$ kilowatts, which may be instantly switched in, and thus prevent the furnaces from cutting out in the case of low voltage.

OPERATION.

The operation of the furnace is continuous. After a period of eight hours the hearth contains a full bath of molten metal, and therefore the metal is tapped three times each day. Charging is done at regular intervals, and the current is never shut off during operation. During the period of smelting the change in electrical conditions is interesting. At the beginning of the charge the power factor is almost unity. This gradually lowers as melting continues, until with a full bath of metal a power factor of 65 per cent is reached. If coke is used in place of charcoal, or if a mixture is employed, a different set of power-factor conditions exists. By studying these conditions it is possible to know the exact condition of the charge by looking at the meters. The load is, of course, a function of the voltage, and with half voltage the load will drop one-quarter.

In charging, the ore cars are run on the mixing floor, which is level with the charging floor. Charcoal and lime and quartz for flux are brought in on the lower floor in cars, hoisted on an electrically operated elevator to the mixing floor, and are dumped into their respective bins. The mixing is done in a car that is run on platform scales. The charge is placed in layers, the proportions depending on the tests made in the laboratory by the chemist. Following is a representative charge: Five hundred pounds of iron ore (magnetite); 135 to 150 pounds of charcoal; 3½ pounds of lime (well burned); 12½ pounds of quartz.

USE OF CHARCOAL AS A REDUCING AGENT.

Although, as explained later, the use of the electric furnace in the production of pig iron permits the manufacture of 3 tons of pig iron from 1 ton of coke or charcoal, the cost of a suitable reducing agent is still an important factor, especially in California. Charcoal is used at the plant of the Noble Electric Steel Co., and its economical manufacture in retorts so constructed as to save the distillation products has been almost as much of a problem as the production of the iron itself. Pit charcoal was used at first. A battery of beehive charcoal ovens, each holding 60 cords of wood, was then constructed. Later it was decided to use by-product retorts, and a vertical retort system was accordingly built. The retorts were arranged in two batteries of four each, each retort being a vertical cylinder 6 feet in diameter and 16 feet high. The volatile products were led from the bottom of the retorts to condensers. Altogether, wood distillation and the attendant recovery and working up of the by-products has not seemed to be a profitable enterprise on the Pacific coast. Soft woods are used for the most part, and these are generally lean in acetic acid and wood alcohol, although fairly rich in tarry products.

A splendid grade of charcoal was made at the plant of the Noble Electric Steel Co. in the retorts above mentioned, but the system proved to be rather cumbersome, and the time necessary for retorting was excessive. Moreover, owing to the manner in which the retorts were constructed, all the products resulting from distillation of the wood had to pass down through the hottest part of the retort. As a result the volatile products were broken up by heat, undesirable products were thus formed, and an inferior grade of by-products was produced. Consequently the company has decided to replace this system with what is known as the Yost system. The retort of the Yost system consists of a horizontal steel cylinder, about 5½ feet in diameter and about 20 feet long, mounted in brickwork. One end of the retort is closed and the other is provided with doors. The wood is loaded on a car, and the car is run into the retort, which is then closed and sealed. The volatile products resulting from the heating of the wood are conducted to the condensers by means of a copper pipe; the liquid tar formed in like manner is drained from the bottom of the retort into a tank. Owing to its simplicity this type of retort is claimed to be much less expensive than the type formerly used, and because of the fact that the wood will not have to be handled as much as formerly the cost of producing charcoal is claimed to be much less.

USE OF CRUDE PETROLEUM AS A REDUCING AGENT.

As is well known, California is favored with a seemingly abundant supply of petroleum. Due to the scarcity of suitable reducing agents such as are at present used in metallurgical work attempts to use crude oil for this purpose have from time to time been made. It is quite possible that a successful process of this kind will be devised. The Bureau of Mines has been conducting investigations along this line and expects to publish the results in the near future. As soon as a commercially successful process of this nature has been devised, it is quite likely that the electric smelting of iron ores on the Pacific coast will receive an impetus, for the use of crude petroleum will not only permit the introduction of electric smelting in those districts where its use, except at prohibitive prices, is not now possible owing to the lack of suitable reducing agents, but should also cheapen the cost per ton of metal produced as compared with the cost when charcoal is used.

COMPARISON OF THE CALIFORNIA AND SWEDISH FURNACES AND PROCESSES.

As to the construction of the two types of furnaces, the difference is so apparent that no comment is necessary. As to the process, the California practice differs from the Swedish practice very decidedly in the following respects, namely: No attempt is made to reduce the ore in the stacks of the furnace; no artificial circulation of gases is employed; limestone calcined outside of the furnace is used. In other words, the California practice is just the reverse of the Swedish practice.

REDUCTION IN SHAFT.

As has previously been noted, the ideal condition in electric reduction furnace work would seem to be to have the charge in such a condition as to require only melting by the time it comes in proximity to the electrodes. The electric current would then be used to furnish only the additional heat necessary to bring about the melting of the hot previously reduced oxide. Of course the heat for the reduction must come from some source, and its origin would be in the crucible and as a result of the heat developed during the melting of the charge, but the excess heat so developed can be transferred by the circulation of the gas to the charge in the shaft instead of being carried away by radiation and by circulating water.

CIRCULATION OF GASES.

As has also been mentioned on page 16, in the Swedish practice a part of the gases rising from the top of the shaft is returned to the crucible and made to pass through it and up through the charge in the shaft. This is done to cool the superheated brickwork of the roof of the crucible and to carry through the stack a volume of gas large enough and hot enough to bring about reduction in the stack.

As stated elsewhere, one of the most serious difficulties that had to be overcome in the development of the Swedish type of furnace was the destruction of the crucible resultant on local heating in the vicinity of the electrodes. Therefore, by returning to the crucible a part of the gases resulting from reduction, it is possible to prevent excessive local heating and at the same time to make use of the heat instead of wasting it. Although gas circulation has its objections, its advantages in the way of economy of operation would seem to outweigh its disadvantages. On the other hand, if reduction previous to smelting be considered the proper practice, this reduction will have to be made in the stack, and the present California practice will not find application except when warranted by the local conditions. As has been previously stated, the present demand in California is for a soft gray foundry iron. Although the furnace now used gives that product, such a construction and such a process are, of course, not absolutely necessary for the production of such an iron.

That the California type of furnace is better suited to the production of a soft gray foundry iron than is the Swedish type is probably due to the fact that reduction is performed solely by solid carbon, and the reduction of silica to silicon takes place at the same time as the reduction of iron oxide to metallic iron. The silicon is dissolved in the iron and by its presence causes the carbon to be precipitated as graphitic carbon, and there is thus obtained the soft gray iron desired. It is also quite probable that in a furnace having a rectangular crucible, such as has the California furnace, the temperature of the charge in the crucible as a whole is much higher than in a furnace of the Swedish type, and this higher temperature is more favorable to the reduction of silica to silicon. As before stated, the latter reaction is largely the controlling element in the production of soft gray foundry iron.

USE OF CALCINED LIMESTONE.

The use of calcined limestone has been repeatedly suggested, and theoretically seems desirable, but in operating a furnace of the Swedish type there are two objections to its use, namely, it increases the proportion of fine material in the charge and it makes the charge hang.

As to the former of these objections, the idea seems to be prevalent that there is no limit to the percentage of fine material that may be used in the electric reduction furnace. However, judging from observations of the smelting of black sands when the furnace consisted simply of a crucible and no shaft, some difficulty was experienced on account of the charge being made up entirely of fine material. In the Swedish practice the proportion of fine material that can be used in a charge was definitely determined in the work at Trollhättan, and it was found that a large proportion of fine material was detrimental to smooth running and good results; but Leffler, one of the engineers in charge of the work at Trollhättan, is of the opinion that calcined limestone may be advantageously added to the charge if no reduction is attempted in the shaft.

In view of the above facts, it would seem that the California practice as compared to the Swedish practice presents the following advantages: It permits the use of limestone calcined outside the furnace and it does not require the circulation of gases.

As to the circulation of gases and also as to reduction in the shaft, the California practice might perhaps prove more efficient if both were done. Although a very complete record of the working of the furnace at Trollhättan has been published, no such record of the operation of the furnace at Heroult is available, and so it is not at present possible to make a definite comparison of the two practices.

ELECTRIC FURNACE AS COMPARED TO THE BLAST FURNACE.

As has been mentioned in the section pertaining to the history and evolution of the electric pig-iron furnace, the electric furnace was not developed as a competitor of the blast furnace, but for the purpose of finding a furnace and a process that would be able to produce iron in those localities where blast-furnace practice was not feasible, or, as in Sweden, where the increasing cost of suitable fuel was becoming prohibitive to the existing practice of smelting in blast furnaces.

Broadly speaking, it may be said that the feasibility of smelting iron ores in an electric furnace depends upon the relative cost of either charcoal or coke and of electric power. As regards the latter, it must be cheap. As is well known, electric power at the present time can be developed more cheaply than it could when Capt. Stassano made his experiments in 1898, and it will probably be produced still more cheaply in the future. However, the present purpose is not to speculate on this point but to state the facts as they are now understood. As has been previously mentioned, the average consumption of charcoal or coke in the electric furnace in the production of 1 ton of pig iron is about one-third of what it is in the blast furnace. Knesche [a] has pointed out that when one takes into consideration the consumption of electrodes, the saving is practically 0.7 ton of coke or charcoal per ton of iron produced.

HYPOTHETICAL CASE.

To make the matter more definite a hypothetical case is assumed, as follows: Coke is assumed to cost $6 a ton and a kilowatt-year to cost $16. From the report of the work done at Trollhättan it is learned that, on an average, 2,391 kilowatt-hours is required to produce 1 ton of pig iron. Hence, the cost for power per ton of pig iron produced would be $4.37, to which must be added the cost of 0.3 ton of coke and likewise the cost of 11.6 pounds of electrode, or an itemized cost as follows:

2,400 kilowatt-hours, at $16 per kilowatt-year	$4. 37
0.3 ton of coke, at $6	1. 80
11.6 pounds of electrode, at $0.06	. 70
	6. 87

As 1 ton of iron can be produced in a blast furnace from 1 ton of coke, the respective costs in the blast furnace and in the electric furnace would be $6 and $6.87. Hence, if considered on this basis alone, the electric furnace, with coke at $6 per ton and power at $16 per kilowatt-year, could not compete with the blast furnace. There are, however, other items to be taken into consideration, such as initial cost of plant, quality of iron produced, and especially the efficiency of the furnace, for, as has been pointed out by Ashcroft,[b] "the efficiency of many nonelectrical furnaces is barely 10 per cent of the theoretical, and very few will exceed 25 per cent, whereas the efficiency of electrical appliances sometimes reaches 75 per cent and is often 50 per cent."

Hence, with no greater difference between the respective costs than is shown above, a careful investigation of all items that enter into the total cost of production of a ton of pig iron, as well as the nature of the ore to be treated and the grade of product desired, might disclose that it would be more profitable to produce pig iron in the

[a] Knesche, J. A., Electric smelting of ore in the United States: Iron Trade Rev., Jan. 5, 1911, p. 65.

[b] Ashcroft, A. E., The influence of cheap electricity on electrolytic and electrothermal industry: Trans. Faraday Soc., vol. 4, 1908, pp. 134–142.

electric furnace than in the blast furnace. There are, however, few localities where coke costs only $6 a ton and where the cost of an electrical kilowatt-year is $16. In more localities the cost of coke is $12 to $14, and with coke at these figures the advantage is decidedly with the electric furnace, with power at $16 a kilowatt-year.

COST OF POWER.

In those electric-furnace iron plants that are operated at the present time only hydroelectric power is used. The cost of producing power for electric furnace work must, of course, vary with local conditions and hence depends on the initial cost per kilowatt of installation. In general there are few localities where the electric smelting of iron ores would be feasible with the electrical energy costing more than $20 to $30 per kilowatt-year.

USE OF ELECTRIC-FURNACE PIG IRON IN THE OPEN-HEARTH FURNACE.

The first metal produced at Trollhättan did not look much like pig iron and, moreover, as its analysis was different from that of the metal that had been used, doubt was expressed as to the possibility of using it in the production of steel. The first attempt to use the iron in the production of steel was made at Degerfors, where a basic furnace was used. The iron of the electric furnace was mixed with ordinary gray iron and a smaller quantity of scrap than usual. This mixture was made so as to insure a hot metal upon melting down. The results exceeded expectations, and on the third trial the charge was composed of only the electric-furnace metal and scrap. Much to the surprise of those operating the furnace, it was observed that the boiling which generally takes place immediately after the metal is melted was not so violent as usual. Tests were then made on the electric-furnace metal in an acid furnace. Although small quantities of the metal were at first used, it was soon ascertained that the charge could be composed of the ordinary proportions of 64 per cent pig iron and 36 per cent scrap.

Pig iron of normal composition was finally obtained as a product of the Trollhättan furnace, and when this iron was used for steel melting in the open hearth, together with the same proportion of scrap as had been used in the previous tests, a longer time was required to complete the refining of the metal, and it was necessary to add more ore than in the previous tests.

As a result of the tests at Degerfors the conclusion was reached that a metal could be produced in the electric reduction furnace that would be more suitable for steel making than ordinary pig iron.

In order to understand the reason for this conclusion, it may be well to note briefly some of the reactions that take place in the open hearth when treating pig iron of normal composition as compared to those which take place when treating pig steel.

In converting normal blast-furnace pig iron into steel in the open-hearth process, the pig iron must contain enough silicon to protect the iron from oxidation during the melting, and likewise enough silicon and manganese to free the iron after melting from the oxides and gases that were formed and taken up as a result of the action of the blast during the production of the pig iron in the blast furnace. The silicon and manganese that may be present in excess of this amount only prolong the time required to finish the heat.

During and immediately after the melting the metal boils violently, especially in an acid furnace if a low-silicon iron be used, even though it is not spongy. There is a second and less violent boiling when the metal is charged into the ladle and molds, especially in the case of hard steel. On the other hand, when electric-furnace "pig steel" is heated in the open-hearth furnace process, the second boil does not take place, and the regular boil commences immediately after the charge is melted and before the ore is added. Several theories have been advanced to account for such behavior of "pig steel" upon melting. One theory is that the metal is practically free from minute particles of oxides that are generally present in ordinary pig iron and that, as previously stated, are produced by the reoxidizing effect of the blast. Owing to the absence of the oxides, practically no reaction with the silicon and manganese present occurs at this time, and on this account the second boil in the open-hearth furnaces during and after the melting, when treating electric-furnace metal, does not occur, and it is possible to decarburize the charge at once by ore additions. The presence of silicon in such "pig steel" is therefore unnecessary during the first part of the open-hearth process.

As above stated, in the tests at Degerfors it was found that more time and more ore were required in the treatment of normal electric-furnace pig-iron than in the treatment of normal blast-furnace pig-iron. This is no doubt due to the fact that inasmuch as electric-furnace pig-iron of normal composition contains no oxides it is not necessary that silicon and manganese be present in the iron in order to take up oxides, and hence the removal of the silicon must be accomplished principally by means of ore, and, as pointed out by Odelberg,[a] only after this is accomplished can decarburation proper begin.

In conclusion it may be said that "pig steel" made in the electric furnace is better suited to the production of open-hearth steel than is the normal blast-furnace pig iron and that normal pig iron made in

[a] Odelberg, E., The behavior and qualities of the electric pig iron in the open-hearth process: Metall. Chem. Eng., vol. 9, 1911, p. 509.

the electric furnace is less suited to the production of open-hearth steel than is normal blast-furnace pig iron.

It must not be inferred from the above statements that it is not possible to produce normal pig iron in the electric furnace. As a matter of fact some hundreds of tons have been so produced in this country and in Sweden. Although the furnace at Trollhättan is so operated as to produce " pig steel," because this metal is better suited to steel making than is normal pig iron, the Noble Electric Steel Co., of California, on the other hand, so operates its furnaces as to produce a soft foundry iron which is particularly suited to the foundries of that section of the country. However, it has been found that a greater output may be obtained when making " pig steel " per unit of electrical energy expended than when foundry iron is produced.

AN ESTIMATE FOR THE ERECTION OF AN ELECTRIC IRON-SMELTING AND STEEL-REFINING PLANT.

An estimate of the equipment and cost of erection of an electric iron-smelting and steel-refining plant, with estimates of the cost of production of pig iron and steel in such a plant is here presented from data furnished by Electro-Metals, of London.

ASSUMPTIONS AND CONDITIONS.

The estimate is based on the following assumptions:

OUTPUT.

Annual production of pig iron, 50,000 tons; annual production of steel ingots, 50,000 tons.

SIZE AND NUMBER OF FURNACES.

Five electric shaft furnaces of 3,500 electric horsepower.

One tilting, open-hearth furnace of 50 tons capacity heated by gas from the shaft furnaces.

Three electric steel furnaces of 1,500 electric horsepower and of 10 tons capacity, one being kept as reserve.

ELECTRIC POWER.

For electric shaft furnaces: 18,000 electric horsepower (includes 500 electric horsepower for gas blowers, motors, etc.).

For electric steel furnaces: 3,000 electric horsepower.

The price of electric power is assumed to be $12 per electric horsepower-year. The electric power, 3-phase, of preferably 25 periods, is to be delivered at a high voltage from the water-power plant and to be transformed to a voltage of 50 to 100 volts close to the furnaces. For distribution to the electric motors a higher voltage of 500 to 1,000 volts should be used.

ORE.

To be supplied from local mines.
Iron content, about 60 per cent.
Cost, $0.50 per ton at the works.
Total quantity smelted per year, 80,000 tons.

FUEL.

For electric shaft furnaces, either coke or charcoal from local distilleries of wood alcohol.

Cost of fuel, $5 per ton at the works.
Total quantity consumed per year, 17,000 tons.

LIMESTONE.

From local quarries, lime rock, $CaCO_3$ content, 96 per cent.
Total quantity used per year, 8,000 tons.
Cost, $1.50 per ton, including calcining.

PROPOSED SYSTEM OF WORKING.

The pig iron produced in the electric shaft furnace is transferred either by ladle or, better, direct through launders, into a tilting open-hearth furnace, in which by addition of ore and lime the greater part of the carbon is removed and the temperature raised to about 1,500° C. The open-hearth furnace has a capacity of 50 tons, and also serves as a mixer, from which at regular intervals about 10 tons of partly refined steel is transferred to the electric steel furnaces. In these the metal is further heated to 1,600° to 1,700° C. and refined from any excess of sulphur not removed in the open-hearth furnace. The chief advantage of the electric steel furnace for the final treatment lies in the possibility of maintaining a reducing atmosphere in which reduction of the steel is more complete than in any other kind of steel furnace.

After being treated in the electric steel furnace for 1 to 2 hours the metal is recarburized to the desired carbon content, the ferro-alloys are added, and the metal is cast in the molds. The estimate provides also for fully equipped repair shops.

ITEMS ENTERING INTO ESTIMATED COST OF CONSTRUCTION.

In estimating the cost of construction of the plant the following items have to be taken into consideration:

Excavations for buildings and furnaces, grading and fencing, railway connection to works with crane for handling materials.

Light railway inside works with turntables, carriages, weighbridge, etc.

Water-supply plant with overhead storage tank and water pipes to gas scrubber, furnace water jackets and transformers, and pump with electric motor.

Buildings for furnaces and transformers.

Hoists for ore and lime, storage building for coke, crusher house and hoist.

General stores, offices, and laboratory.

Houses for officials and workmen.

Five electric shaft furnaces for 3,500 estimated horsepower, with foundations, iron constructions, brickwork, and lining.

Electrode holders with water jackets, lifting and regulating arrangements for the electrodes.

Gas blowers with electric motors, gas scrubbers, gas piping.

One tilting open-hearth furnace of 50 tons capacity with rockers and stands, hydraulic tilting cylinder, port ends, chills, gas and air connections and valves.

Working staging.

Iron chimney.

All silica, magnesite, fire, and red brick, silica and fire clay for brick setting, and magnesite.

Three electric steel furnaces, each of 10 tons capacity and 1,500 estimated horsepower, with foundations, iron construction, brickwork and lining, electrode holders with water jackets, automatic regulators, hydraulic tilting cylinders, working stagings, etc.

Two electric cranes of 20 tons carrying capacity.

Transformers for electric shaft and steel furnaces, with oil coolers, regulators, instruments and energy meters, lighting arresters, cables between transformers and furnaces.

Crushing plant with ore and coke crushers and electric motors.

Rails, wagons, weighing machines, tools, and sundries.

Transformers for small motors and for light, including wiring accessories.

Laboratory outfit and office fittings.

Superintendence during construction, drawings, and license.

Contingencies.

The total cost of erection of a plant of this description is estimated at $850,000.

COST OF PRODUCTION.

The estimated cost of producing pig iron and steel in a plant of this description is presented below:

Estimated cost of producing 50,000 tons of electric pig iron a year.

Item.	Weight.		Cost.		
	Per ton. of ore.	Total.	Per unit.	Total.	Per ton of pig iron.
Ore, tons	1.6	80,000	$1.50	$120,000	$2.39
Coke, tons	.33	17,000	5.00	85,000	1.68
Lime, tons	.16	8,000	1.50	12,000	.20
Electrodes, pounds	15	335	75.00	25,125	.52
Power (18,000 horsepower year)			7.50	135,000	2.72
Staff and labor:					
3 foremen, 2 electricians, and 105 workmen				75,000	1.50
Maintenance and repairs				15,625	.31
Laboratory				3,125	.06
Office expenses				3,125	.06
Depreciation				28,125	.56
Royalty				37,500	.75
Contingencies				25,000	.50
Total				564,625	11.25

Estimated cost of producing 50,000 tons of electric steel ingots a year.

Item.	Weight.		Cost.		
	Per ton of steel.	Total.	Per unit.	Total.	Per ton of steel.
Pig iron, tons	1,000	50,000	$11.29	$564,625	$11.29
Iron ore, tons	0.112	5,600	1.50	8,400	.16
Burnt lime, tons	.1	5,000	3.00	15,000	.29
Ferro-alloys, tons				25,000	.50
Electrodes, pounds	20	450	75.00	33,750	.68
Power (3,000 horsepower year)			7.50	22,500	.45
Staff and labor:					
3 foremen, 2 electricians, 50 workmen				37,500	.75
Maintenance and repairs				37,500	.75
Ladles, stoppers, molds, and other tools				50,000	1.00
Laboratory and office expenses				6,250	.12
Depreciation				28,125	.56
Royalty				18,750	.37
Contingencies				31,250	.62
Total				878,650	17.54

THE ELECTRIC FURNACE IN STEEL MANUFACTURE.

By Robert M. Keeney.

INTRODUCTION.

The purpose of the second part of this report is to present a brief historical review of the development of the electric-furnace manufacture of steel up to the present time; to describe in detail the types of electric furnaces in commercial operation for the manufacture of steel and, in general, types which have not yet attained wide use; to give a description of the practice of European and American electric-furnace steel plants that were recently visited by the writer; to compare in a general way the different types of furnaces and the more established methods of steel manufacture with the electric-furnace process; and to discuss various problems of the electric-furnace manufacture of steel and the possible future developments of the process.

HISTORY OF THE DEVELOPMENT OF THE ELECTRIC STEEL FURNACE.

EARLY DEVELOPMENT OF THE ELECTRIC FURNACE.

The process of evolution through which the electric furnace passed before reaching its most highly developed use, which is the manufacture of steel, really began with the furnace of Siemens, the prototype of the modern arc furnace. In 1878 Siemens patented the furnace and operated it in a very small laboratory way. This electric furnace consisted of a crucible of refractory material with a movable vertical electrode, the other electrode being an iron bar passing through the bottom of the crucible. One electrode was connected to the positive pole and the other to the negative pole of a direct-current circuit. The crucible was surrounded by a heat insulator, and the bottom metallic electrode was water cooled.

In 1885 Ferranti devised a furnace the principles of operation of which were the fundamental basis of the modern induction furnace. He used the induced current of a magnetic circuit to heat and melt metals which were arranged like the secondary of a short-circuited transformer.

Although the electric arc and induced currents were applied to furnace heating by these two pioneers, no attempt was made to operate a commercial electric furnace for the manufacture of steel until 1898. In the meantime, in 1886, the Cowles brothers had devised their arc furnace for the production of aluminum alloys. In 1887 Colby patented an induction furnace for melting metals that was quite similar to the modern Kjellin furnace. In 1892 Willson designed a furnace for the manufacture of calcium carbide that was simply a Siemens crucible reproduced on a commercial scale. In 1893 the radiated heat of the electric arc from two horizontal electrodes was used by Moissan during the course of his extensive experiments on carbides and oxides of metals. From 1893 to 1898 the electric arc furnace was developed rapidly in the manufacture of calcium carbide, although it was still essentially the old Siemens crucible with an upper electrode of carbon and a carbon block in place of the lower metallic electrode.

In 1898, owing to overproduction of calcium carbide and the substantiation of the Bullier patents, many works were compelled to stop the manufacture of carbide, and either turn to the manufacture of other products or shut down, which meant the idleness of many hydroelectric plants capable of developing thousands of horsepower. The experiments of Moissan had shown the possibility of making ferro-alloys in the electric furnace. Ferro-alloys were made in the old carbide furnaces, and with the introduction of these electric-furnace alloys, which were of higher percentage and of greater purity than the blast-furnace product, a steady demand for them arose. As a result, by 1900 a new industry was in operation. In many plants both calcium carbide and ferro-alloys were made, as is the case as present.

EARLY DEVELOPMENT OF THE ELECTRIC STEEL FURNACE.

DEVELOPMENT OF THE HÉROULT STEEL FURNACE.

As the manufacture of ferro-alloys developed and the necessity of producing alloys of low carbon content became apparent the design of the electric furnace was gradually altered so as to make the operation possible without a conducting carbon lining. It was only a step from the Héroult ferrochrome furnace lined with chromite, with a bottom carbon electrode, over which metal was permitted to freeze to prevent carburization, to the nonconducting hearth of the modern Héroult steel furnace, shown in figure 18, as it had been found that this freezing of metal hindered the regular operation of the furnace. The fundamental principles of the modern Héroult steel furnace were patented in 1900.

EXPERIMENTS OF STASSANO.

In the meantime Stassano,[a] of Italy, through an interest in the carbide industry, had attempted to produce steel directly from iron ore in the electric furnace, with charcoal as a reducing agent. The experiments were begun in 1898 and were first conducted in a modified blast furnace, in which electrodes were substituted for tuyères. This furnace being unsuccessful, a new furnace similar to the modern Stassano steel furnace, shown in figures 19 and 20, was built, having horizontal electrodes and arcs heating the charge by radiation, as in

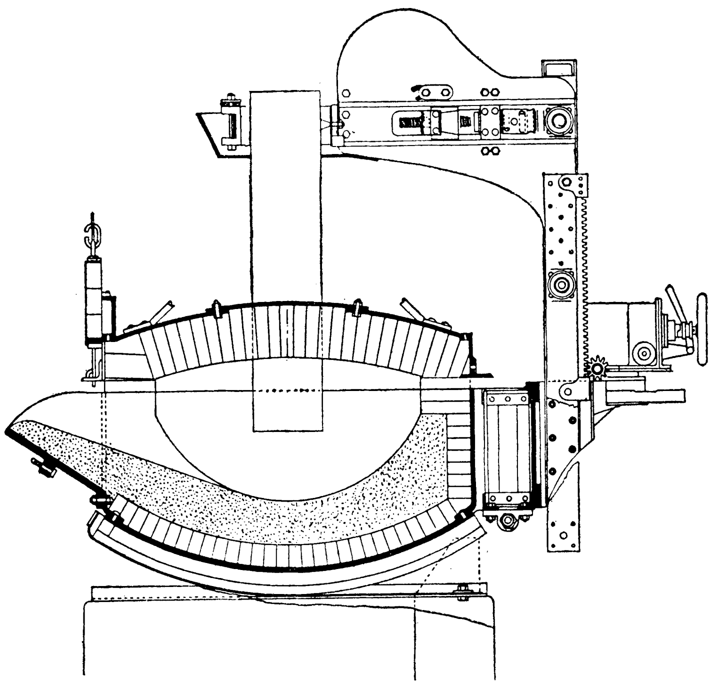

FIGURE 18.—Sectional elevation of 2.5-ton, single-phase Héroult steel furnace, La Praz, France.

the Moissan furnace. However, it was not well suited to reduction of the ores that were first used.

In these experiments a high-grade hematite ore of low phosphorus and sulphur content was used. The ore was first crushed and then briquetted with charcoal, lime, and tar. The steels produced contained about 0.10 per cent carbon, less than 0.024 per cent phosphorus, and not over 0.073 per cent sulphur. The power consumption aver-

[a] Stassano, E., Treatment of iron and steel in the electric furnace: Electrochem. and Metall. Ind., vol. 6, 1908, p. 315; Catani, R., The application of electricity in the metallurgical industry of Italy : Jour. Iron and Steel Inst., vol. 84, No. 2, 1911, p. 215; Metall. Chem. Eng., vol. 9, 1911, p. 642.

aged 4,205 kilowatt-hours per metric ton.[a] It will be seen later that this item of power consumption is over five times that of making steel from cold scrap in the electric furnace, a difficult handicap for

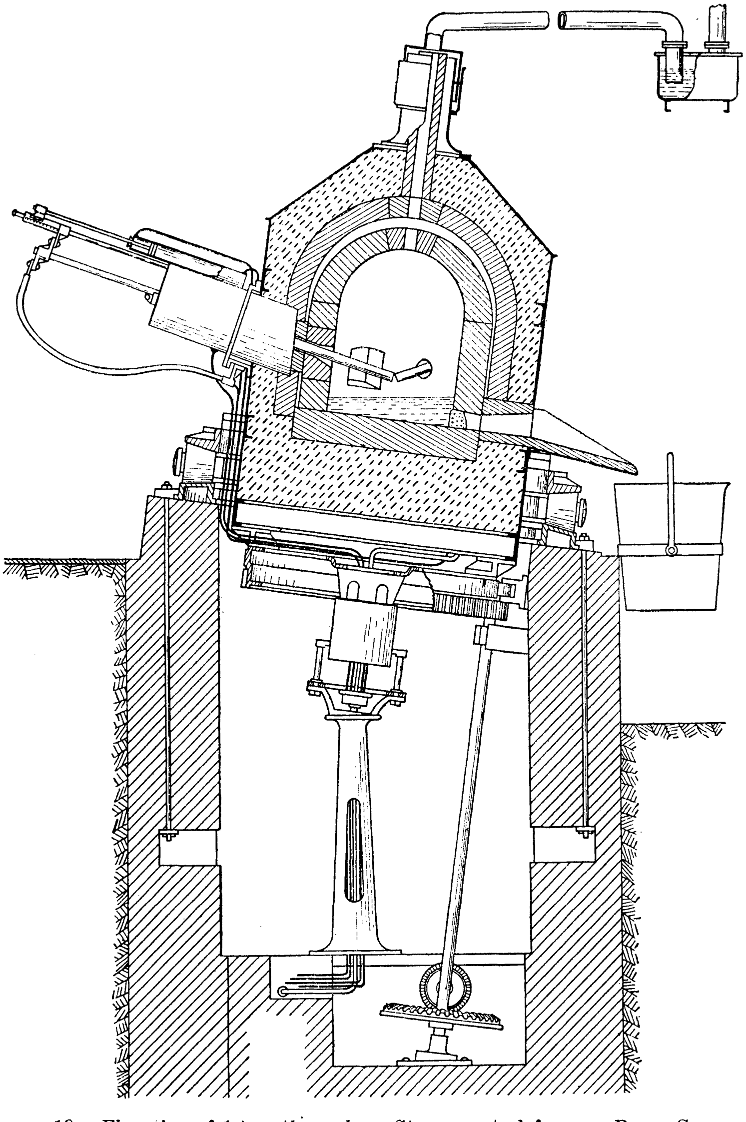

FIGURE 19.—Elevation of 1-ton, three-phase Stassano steel furnace, Bonn, Germany.

any direct electric-furnace steel process to overcome, except under the most favorable circumstances. Later experiments of others have reduced this item considerably.

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[a] Throughout this report the metric ton, 2,204 pounds, is used in reference to European practice, and the long ton, 2,240 pounds, for American practice.

Stassano was the first to demonstrate that malleable iron or a fluid steel can be produced directly from a pure ore in the electric furnace. The power consumption was so high and the cost of briquetting so great as to prevent the commercial application of this process. Later, in 1908, Stassano showed by experiments the possibility of obtaining good steel from ore containing impurities, but the cost was still prohibitive.

From these experiments on iron ore, Stassano turned to the development of his furnace for the manufacture of steel from scrap iron and steel, and he had a furnace operating for this purpose at the Italian Government gun foundry in Turin by the time of the visit of the Canadian Commission in 1904.

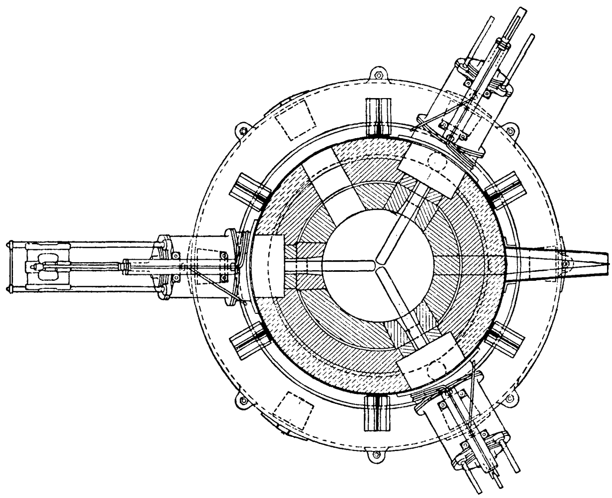

FIGURE 20.—Plan of 1-ton, three-phase Stassano steel furnace, Bonn, Germany.

THE KJELLIN FURNACE.

The application of the induction principle to the manufacture of steel was begun not because of an overdevelopment of any electric-furnace industry, but because of actual need of such a furnace in steel manufacture. In 1899 Kjellin, a Swedish electrical engineer, was requested by the works manager at Gysinge, Sweden, to construct an electric furnace. The furnace was to be lined for the production of the highest grade of tool steel from Dannemora iron manufactured at Gysinge. Kjellin did not approve of the arc electric furnace used in carbide manufacture, because he thought the contact of the electrodes with the charge would contaminate the product. A furnace was designed in which the molten steel lay in an annular ring that was used as the secondary coil of a step-down transformer. Kjellin conceived the construction independently and did not know until later, when he applied for patents, that the same principle had previously been used for this purpose by Ferranti and Colby. To Kjellin, however, belongs the credit of constructing the first induction steel furnace that was a commercial success. Construction was started in May, 1899, and completed in February, 1900. On March 18, 1900, the first steel ingot was cast. The small 58-kilowatt furnace of 100 kilograms (220 pounds) capacity produced about 600 kilograms (1,320 pounds) of ingots per 24 hours, and was successful from the start. A larger furnace taking 165 kilowatts and producing 4 tons per 24 hours was started in May, 1902. In fundamental design these furnaces were practically the same as the modern Kjellin electric steel furnace (fig. 21).

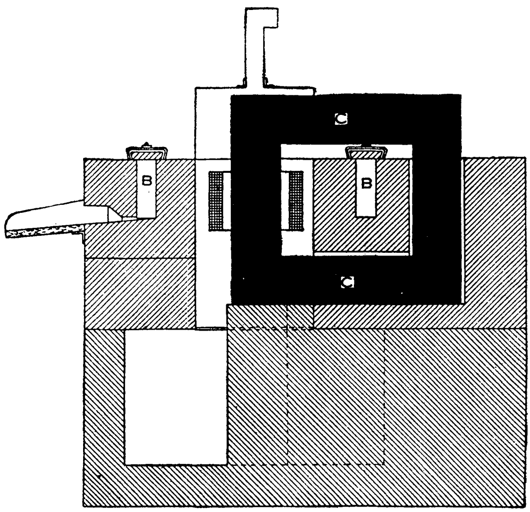

FIG. 21.—Elevation of 1.5-ton, single-phase Kjellin steel furnace, Gysinge, Sweden. C, laminated iron core of primary circuit; B, annular crucible.

INVESTIGATIONS OF THE CANADIAN COMMISSION OF 1904.

In 1904 the commission[a] appointed by the Canadian Government to investigate electric-furnace pig iron and steel processes in Europe found four electric furnaces being used for the production of steel at the following places: A Kjellin furnace at Gysinge, Sweden; a Héroult furnace at Kortfors, Sweden; a Héroult furnace at La Praz, France; and a Stassano furnace at Turin, Italy.[a] Such was the nucleus from which the modern manufacture of steel in the electric furnace has developed.

EXPERIMENTS WITH KJELLIN FURNACE, GYSINGE, SWEDEN.

At Gysinge three experiments were conducted in a 165-kilowatt Kjellin furnace of the type shown in figure 21. The first charge was arranged to give a high-carbon steel containing about 1 per cent of carbon. The charge consisted of high-grade Dannemora pig iron, bar scrap Walloon iron, and some scrap steel left in the furnace from previous runs. All of the materials had a low phosphorus

[a] Haanel, E., Report of the commission appointed to investigate the different electrothermic processes for the smelting of iron ores and the making of steel in operation in Europe: Mines Branch, Department of the Interior, Canada, 1904, p. 1.

and sulphur content. After 6 hours' running about 1 ton of very high-grade steel containing 1.082 per cent carbon was poured. There was very little slag removed in the process. The power consumption was 857 kilowatt-hours per ton.

The object of the second experiment was to make a medium carbon steel containing about 0.5 per cent carbon. The same grade of material was charged as in the first run but in different proportions. After 6½ hours' running about 1 ton of very pure steel, containing 0.417 per cent carbon, was poured. A little more slag was removed than in the first run. The power consumption was 1,100 kilowatt-hours per ton.

In the third experiment the object was to make a low-carbon steel containing less than 0.2 per cent carbon. The charge consisted of bar iron with a low carbon content. Three attempts were made to get a clean pour, but owing to the power on the furnace being insufficient to give a temperature high enough for this grade of steel no precise results were obtained. The steel poured contained 0.098 per cent carbon and had a low phosphorus and sulphur content. A little less than 1 ton of metal was obtained with a power consumption of 1,430 kilowatt-hours per ton.

Kjellin estimated the power cost at this plant as $15.50 per kilowatt-year, or 0.18 cent per kilowatt-hour. On this basis the cost of production of a high-carbon steel of the first class was estimated at $37.48 per ton, or $5.82 per ton exclusive of the cost of material.

The process as conducted in 1904 was, as regards its metallurgical features, similar to the old crucible process, the desired variation in the finished steel being produced by altering the relative proportions of pig iron and scrap iron and little or no purification being attempted. The commission found the Kjellin furnace well adapted for the production of the highest class of steel from pure materials. It seemed to be limited in use to pure materials, and gave better results with high-carbon steel than with mild steel. There was a marked increase in power consumption when the percentage of carbon in the steel was decreased.

EXPERIMENTS WITH THE HÉROULT FURNACE, LA PRAZ, FRANCE.

At La Praz, France, two experiments were made on the production of both high and low carbon steel in a 320-kilowatt Héroult single-phase furnace with a capacity of 2½ to 3 tons (fig. 18), described on page 74. In the first run the materials consisted of scrap iron and steel containing 0.11 per cent carbon, 0.055 per cent sulphur, and 0.22 per cent phosphorus, and a slag of iron ore and lime for dephosphorizing. When completely melted the slag was poured off and two successive slags of lime, sand, and fluorspar were added to remove the sulphur. The charge was poured after a run of 4½ hours. About 1¼ tons of excellent steel was obtained, containing 0.079 per cent carbon, 0.009 per cent phosphorus, and 0.022 per cent sulphur. This steel was for transformers. The yield was 84 per cent of the total charge of metal. The power consumption was 1,555 kilowatt-hours per ton.

The object of the second experiment was to produce a high-carbon steel. The charge was about the same as in the first, but after complete purification at the end of 5 hours and 20 minutes the bath was recarburized by the addition of carburite, a mixture of pure carbon and iron. Eight hours after starting about 2¼ tons of steel was poured. This yield was about 90 per cent of the charge of metal. The steel contained 1.016 per cent carbon, 0.02 per cent sulphur, and 0.009 per cent phosphorus. The power consumption was 2,840 kilowatt-hours per ton.

The electrode consumption was about 18 kg. (39.6 pounds) per ton. There was a 50 per cent loss in electrodes due to unconsumed ends. These, however, were mixed with an equal quantity of fresh coke to make new electrodes. Harbord[a] estimated the cost of converting scrap into steel at La Praz at $15.40 per ton of product exclusive of materials.

The operation at La Praz was decidedly different from that at Gysinge; at Gysinge high-grade steel was produced from pure materials, while at La Praz a high-class steel was made from low-grade scrap. The high power consumption at La Praz was due to the necessarily prolonged use of dephosphorizing slags. When scrap iron nearly free from carbon was used, the first product obtained was soft steel; to obtain high-carbon steel suitable additions of carbon had to be made. For this reason the consumption of energy was greater with high-carbon than with low-carbon products. The process at La Praz was the reverse of the one at Gysinge, where a high-carbon material was available at the start. The methods depend on the materials available. Although fine raw material had to be used at Gysinge, any sort of scrap could be used in the Héroult furnace because of the high temperature and the easy manipulation of slags. The commission found the Héroult furnace admirably suited to the manufacture of high-grade tool steel from impure materials.

CONCLUSIONS OF THE COMMISSION.

The conclusions reached in 1904 by Harbord,[b] metallurgist of the commission, in respect to the electric production of steel, were as follows:

1. Steel equal in all respects to the best Sheffield crucible steel can be produced either by the Kjellin or Héroult processes at a cost considerably less than the cost of producing high-class crucible steel.

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[a] Harbord, F. W., Report of the commission appointed to investigate the different electrothermic processes for the smelting of iron ores and the making of steel in operation in Europe; Mines Branch, Department of the Interior, Canada, 1904, p. 50.

[b] Harbord, F. W., loc. cit., p. 115.

2. Structural steel to compete with Siemens or Bessemer steel can not be economically produced in electric furnaces, and such furnaces can be used commercially only for the production of exceptionally high-class steel for special purposes.

LATER DEVELOPMENT OF THE ELECTRIC STEEL FURNACE.

THE GIROD ARC FURNACE.

In connection with the development of the Girod ferro-alloys works at Ugine, France, Girod had devised an arc furnace with a noncarbon-conducting hearth that was used for the manufacture of low-carbon alloys. As the ferro-alloy industry became well established, Girod turned his attention to a steel furnace, and in 1905 constructed a furnace based upon the principles of the earlier ferro-alloy furnace. The furnace (fig. 22) has a conducting hearth consisting of magnesite, in which iron poles are embedded to serve as conductors. The poles are water-cooled at the lower ends. There may be one or more upper carbon electrodes. Thus the chief feature of the Girod furnace may be traced back to the lower water-cooled iron electrode of Siemens. Girod was the first to apply the noncarbon conducting hearth to the steel furnace.

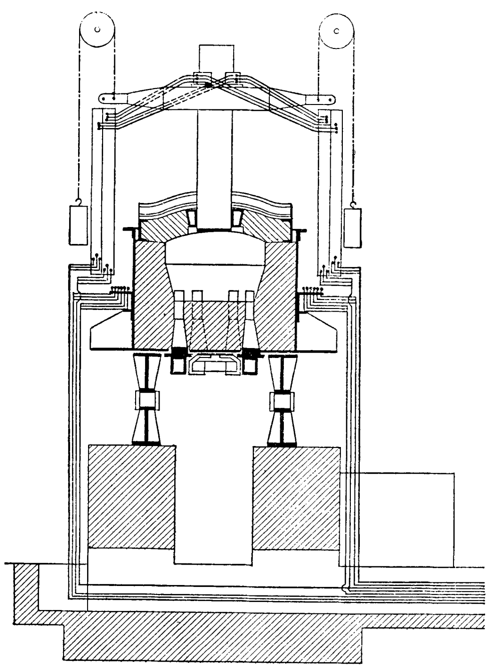

FIGURE 22.—Elevation of 2.5-ton, single-phase Girod steel furnace showing arrangement of conductors.

OTHER ARC FURNACES.

After the introduction of the noncarbon conducting hearth in 1905 other furnaces similar to the Girod were developed. The Keller furnace (fig. 23) is similar to the Girod furnace, except that there are numerous iron rods embedded in the hearth of magnesite about 1¼ inches apart, instead of about six poles, as in the Girod furnace. The whole mass of magnesite and iron acts as a conductor when hot.

Grönwall constructed a furnace (figs. 24, 25) having a conducting hearth composed of a mixture of dolomite and tar, and two upper car-

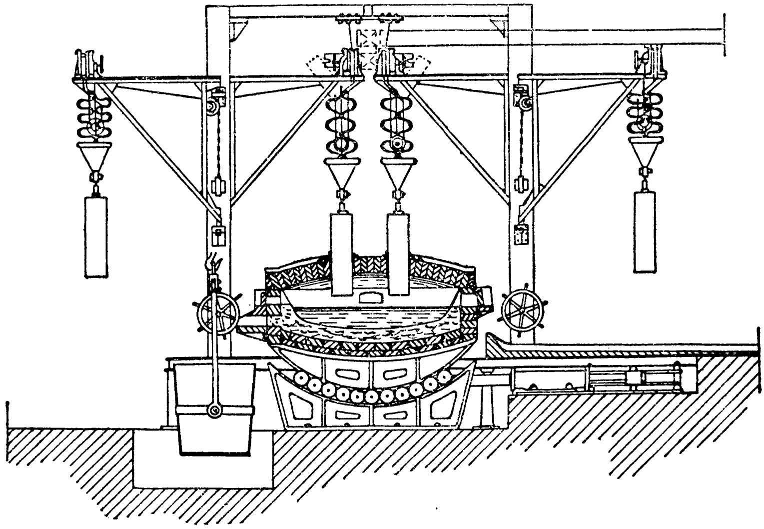

FIGURE 23.—Elevation of 8-ton, three-phase Keller steel furnace, Unieux, France.

bon electrodes which were each connected to a phase of a two-phase system, the hearth forming the neutral point of the system.

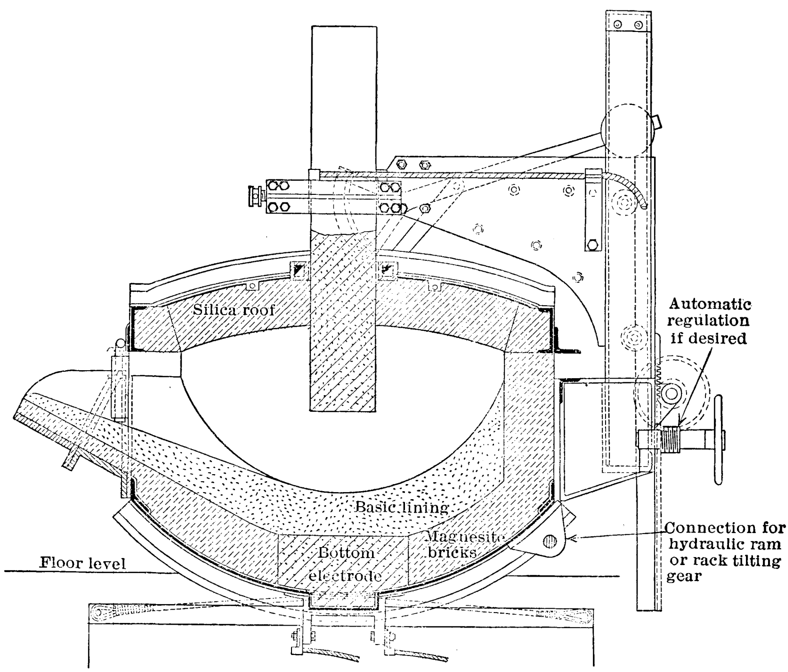

FIGURE 24.—Elevation of 2.5-ton, two-phase Grönwall steel furnace, Sheffield, England.

Nathusius has built a furnace (fig. 26) combining the principles of the arc and resistance furnaces, as the hearth contains three poles of iron, each connected to a phase of a three-phase system, while there are also three upper carbon electrodes, each connected to a phase. This is the latest development of the arc-resistance furnace.

Other furnaces of the arc type which have been designed and built since 1904 are the Anderson, Chaplet, and Soderburg furnaces.

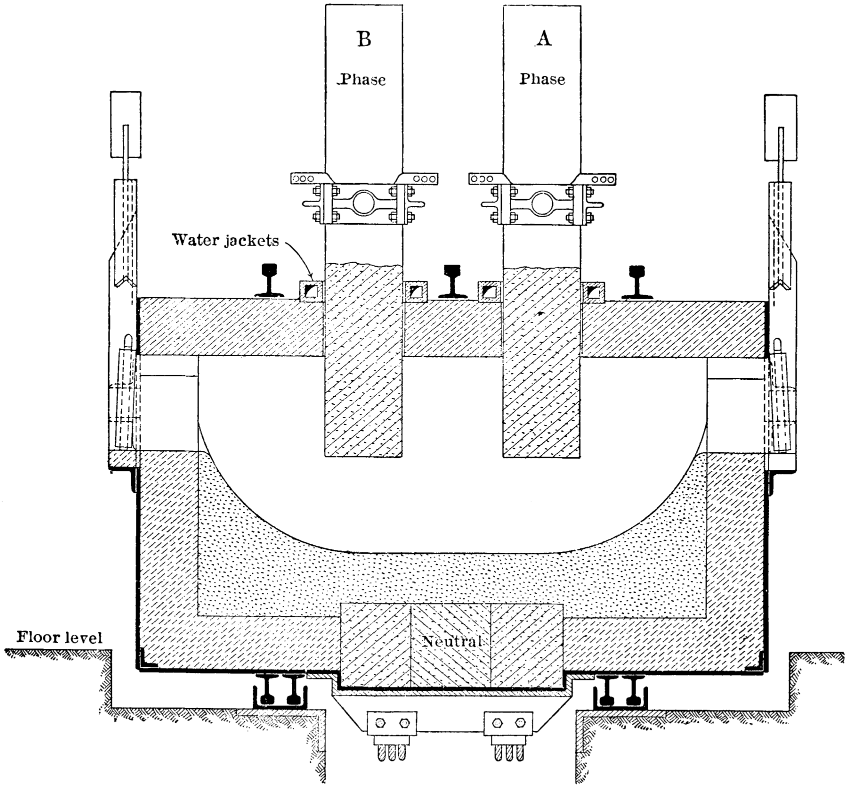

FIGURE 25.—Longitudinal elevation of 2.5-ton, two-phase Grönwall steel furnace, Sheffield, England.

THE RÖCHLING-RODENHAUSER FURNACE.

The Röchling-Rodenhauser electric steel furnace (fig. 27) was developed from the original Kjellin design in 1906 to meet the requirements for refining molten basic Bessemer steel. It combines two methods of electric heating—the ordinary heating by electric induction currents and heating by induction currents that are introduced into the molten bath through metal plates. It is the most widely adopted induction furnace of the present time, and the design is practically the same as the original. The Röchling-Rodenhauser furnace was the first induction furnace that could be heated with a current of ordinary frequency without having too low a power factor, as had the old design.

OTHER INDUCTION FURNACES.

Other induction furnaces are the Frick, the Hiorth, and the Paragon furnace of Harden. Several furnaces of the first two types have been built, but their adoption has not been widespread. Greene[a] has devised a combination induction converter which has not passed beyond the experimental stage.

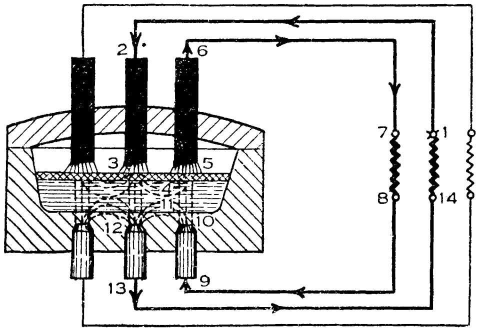

FIGURE 26.—Elevation of Nathusius three-phase steel furnace showing principle of operation.

GENERAL LINES OF DEVELOPMENT OF ELECTRIC STEEL FURNACES.

With the natural increase in size of units constructed there has been a marked tendency to use three-phase electric current in the

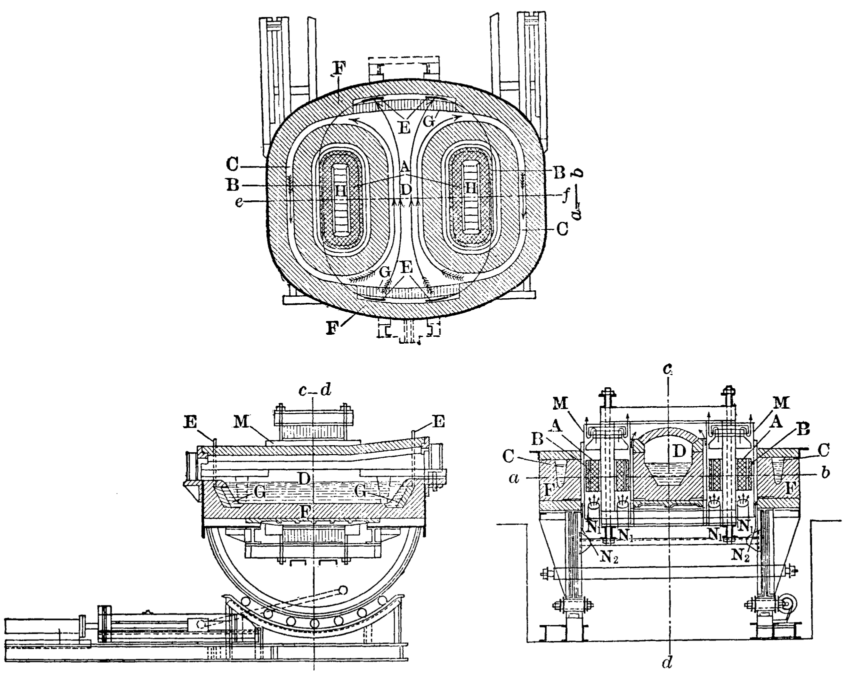

FIGURE 27.—Plan and elevation of 2-ton, single-phase, Röchling-Rodenhauser steel furnace, Volklingen, Germany. For explanation of lettering see p. 86.

larger furnaces of all types, except the induction furnace. Many of the recent furnaces have been designed especially with this in view

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[a] Greene, A. E., Electric steel processes as competitors of the Bessemer and open-hearth; Trans. Am. Electrochem. Soc., vol. 19, 1911, p. 233.

to save the expense of installing motor generator sets for transformation from three or two phase current to single-phase current. At present new generating units are invariably three-phase if the energy is to be transmitted a considerable distance. It is probable that a more even distribution of heat is obtained in a large furnace by the use of three-phase current. In induction furnaces it has been proved by experience that for units above 3 tons three-phase current does not give as good satisfaction as single-phase current, owing to the complicated nature of the electrical transforming part of the furnace.

Electrode consumption has been reduced considerably as a result of the production abroad of amorphous carbon electrodes in sizes up to 24 inches (61 cm.) in diameter, that screw into each other so that the butts are not wasted. Graphite electrodes of this design have been made in this country, but up to a recent date no domestic amorphous carbon electrodes threaded for continuous feeding were made. The strength and density of the carbon electrode are considerably greater than they were several years ago. The carbon electrode is used almost entirely by foreign electric-steel manufacturers, because of its greater cheapness.

Generally speaking electric steel furnaces were first operated by men not familiar with the steel industry, so that linings and roofs were not always properly constructed. The rather high cost item that resulted has been reduced considerably with the adoption of the electric furnace by established steel firms.

Under the hand of the steel manufacturer, the electric furnace seems to be gradually taking the form of the open-hearth furnace. The hearth proper of the Héroult furnace is like an open hearth, but the furnace is charged from the sides and front and is generally set back a short distance from the edge of the working floor. In the open-hearth furnace the charging door is on one side and the pouring spout on the opposite side, the furnace being level with the edge of the working floor. The electrode supports of the Héroult furnace as at present arranged prevent the use of a back charging door. The Girod furnaces at Ugine, however, are similar to the open-hearth furnace in these respects, as the electrodes are supported from the sides. A three-phase Héroult furnace now being constructed in England is to have the three electrodes suspended from the sides as in the Girod furnace, with a back charging door opposite the spout and close to the edge of the working floor. The Kjellin furnace is simply an annular crucible. The Röchling-Rodenhauser furnace has a rather large hearth in the center, and a charging door opposite the pouring spout.

The wider use of the electric process, together with the improvements mentioned, has resulted in a considerable increase in heating efficiency over the results obtained in 1904.

For a few years the induction furnace was developed as rapidly as the arc furnace, but during the past three years its use has not increased as rapidly. The reason for this will be discussed later.

PRESENT STATUS OF THE ELECTRIC STEEL INDUSTRY.

In 1904 there were 4 electric furnaces being used in Europe for the manufacture of steel, whereas to-day there are 114 electric furnaces producing steel in Europe and the United States and 30 others are in course of construction. As in other electrothermic processes, development has not been so rapid in the United States as in Europe. Only 14 furnaces are in this country. The average capacity per charge of the furnaces already built is 3.7 tons, whereas that of the furnaces under construction is 4.5 tons, an increase of 21.6 per cent. The total charge capacity of the furnaces now installed is about 250 tons per charge, and the total charge capacity of the furnaces under construction will be 170 tons per charge. The arc furnaces vary in capacity from 1 to 15 tons and require from 200 to 1,500 kw. for operation. A Héroult furnace of 25-ton capacity, requiring 3,000 kw., is nearly completed at Bruckhausen, Germany. The induction furnaces vary in capacity from 1 to 10 tons and require from 165 to 600 kw. for operation.

Of the 114 furnaces in operation 84 are arc furnaces and 30 are induction furnaces; of the 30 under construction, 26 are arc furnaces and 4 induction furnaces.

The following table gives the annual production of steel in electric furnaces, by countries, for the years 1908 to the first half of 1912.

TABLE 1.—*Yearly production of electric-furnace steel.*

Country.	1908			1909			1910			1911			1912, first half.
	Production.	Number of furnaces.	Change in production.	Production.	Number of furnaces.	Change in production.	Production.	Number of furnaces.	Change in production.	Production.	Number of furnaces.	Change in production.	
	Tons.		*Per cent.*	*Tons.*		*Per cent.*	*Tons.*		*Per cent.*	*Tons.*		*Per cent.*	*Tons.*
Germany and Luxemburg	19,536	8		17,773	8	— 9.0	36,188	13	+104.1	60,654	15	+ 67.8	
United States	55	1		13,762	4		52,141	7	+228.0	29,105	9	— 44.2	6,882
Austria-Hungary	4,333			9,048		+109.2	20,028		+120.8	22,867	10	+ 14.0	
France	2,686	7		6,515	12	+127.6	13,445	21	+106.2	13,850	21	+ 3.0	7,920
Sweden				591	11		431	12	— 27.0	2,034	13	+372.0	
Norway								1			1		
England											12		
Italy					5			2			4		
Switzerland											2		
Belgium											2		
Russia											1		
Total	26,610	16		47,039	40	+ 78.2	120,116	56	+155.4	126,476	90	5.22	

From Table 1 it may be seen that for a new process in so conservative an industry as iron and steel manufacture, progress has been very rapid since 1908. Germany leads all countries in the steady growth of the process and the total tonnage produced. Although in Germany the production of electric-furnace steel increased 67.8 per cent in 1911, in the United States it decreased 44.2 per cent. The decrease in this country was probably due to the conservatism of American steel makers, which has prevented the wide adoption of the process before experimental results have conclusively proved its merits. From present indications there will be a considerable increase in the production of electric-furnace steel in this country in the near future, although a very small tonnage, 6,882 tons, was reported by the American Iron and Steel Institute as the output for the first half of 1912.[a] Of the total production of electric-furnace steel in the United States in 1911, 27,227 tons were ingots and 1,878 tons castings. Of the total tonnage of electric-furnace steel made here in 1911, 6,700 tons were alloy steel and 462 tons were rolled into rails. The large production of steel in the United States and Germany in proportion to the number of furnaces operating is due to the use of molten Bessemer and open-hearth steel instead of cold scrap. The use of the latter almost entirely accounts for the comparatively small tonnage produced by France in proportion to the number of furnaces in operation. No figures were obtained for England, but it is probable that at least 10,000 tons of electric-furnace steel is manufactured in England. It is estimated that about 12 furnaces operate there, several of which receive hot-metal charges. Italy, Norway, Switzerland, Belgium, and Russia produce small tonnages also. The slight increase in the total electric-furnace steel production for 1911 over that produced in 1910 was caused by the big decrease in production in the United States.

In the first years of its development the electric process was considered as a competitor of the crucible process only for making high-class steel from scrap iron and scrap steel; but with the successful operation of larger furnaces the electric process is likely to become an important adjunct to the Bessemer and open-hearth processes as a means of superrefining the molten products that they yield. The electric process, however, does not appear to be destined to supersede either of these methods, as greater efficiency and economy are obtained by a combination of any two of the three processes as a duplex process. The success of recent experiments has obtained for the electric process a definite place as a superrefining method. In time preliminary refining will probably be done mainly in the Bessemer converter, the process being finished in the electric furnace or the open hearth. In Europe the electric-furnace process for making steel

[a] Iron Age, The world's output of electric steel; vol. 91, 1913, p. 304.

of the highest grades is rapidly superseding the old crucible method, because of its greater economy of operation and the possibility of using materials of lower grade.

ELECTRIC STEEL FURNACES.

In general electric furnaces in commercial use for the manufacture of steel may be divided into two groups—arc furnaces and induction furnaces. In the arc furnace the heating is caused by the arc, which may be between the electrode and the bath, or between two or more electrodes so arranged as to heat the metal by radiation only. In the induction furnace the heat is supplied by a current induced in the bath. The operation is similar to that of a step-down transformer, having a large number of primary turns and a single secondary turn, which is formed by the steel in the furnace.

ARC FURNACES.

THE HÉROULT FURNACE.

The Héroult electric steel furnace heads the list of electric furnaces in use in the iron and steel industry with 31 furnaces already built and 20 others in course of construction. The wide use of the Héroult furnace is due chiefly to its efficiency, simplicity of construction, and adaptability to many different uses. Also it was the pioneer electric steel furnace.

SINGLE-PHASE HÉROULT FURNACE.

The design of the 2½-ton, single-phase Héroult furnace has changed little from that (fig. 18) of the first Héroult furnace, which has been in operation at La Praz, France, continuously since 1900. The furnace consists of a shallow hearth of dolomite, similar to the open hearth, incased in a steel shell, and covered with a roof of silica brick. The 2½-ton Heroult furnace at Braintree, England, has the pouring spout in the center of one side, and two doors, one on each end of the furnace. There are two 14-inch carbon electrodes projecting into the furnace through the roof and held in place by a steel framework extending from the rear over the roof. The electric current arcs between each of the electrodes, which are connected in series, and the bath, thus passing through the bath. The Braintree furnace is operated with 300-kw. 25-cycle alternating current at 100 volts. The furnace is set on curved steel bars, the whole being on a concrete foundation, and is tilted by rotating a screw, operated by a 5-kw. electric motor. Springs are used on the bottom to keep the furnace from creeping.

The exterior of the 2½-ton furnace is 5 feet 6 inches wide, 7 feet 6 inches long, 4 feet 9 inches high to the top of the roof, and 9 feet

3 inches high to the top of the electrode holders. The furnace foundation is 2 feet 6 inches above the main floor of the foundry. The whole furnace is incased in plate steel $\frac{5}{8}$ inch thick.

In lining the furnace a mixture of tar and dolomite is tamped in around a sectional mold to a depth of 9 inches to form the bottom. The sides of the hearth slope about 60 degrees up to about 18 inches above the bottom. From here up to the roof, 15 inches, the lining is magnesite brick. The lining is 12 inches thick on the sides and 14 inches thick on the ends. The internal dimensions of the furnace are 4 feet 2 inches by 1 foot 8 inches at the bottom of the hearth, and 5 feet by 2 feet 7 inches at the top, with a depth of 31 inches. The doors are 9 by $10\frac{1}{2}$ inches. The customary roof for this type of furnace is silica brick, set so as to give a roof 12 inches thick. At Braintree considerable difficulty has been experienced with the roof and several kinds of brick have been tried, such as silica, magnesite, and bauxite. Bauxite brick were being used recently.

The electrodes are threaded for continuous feeding and are used in either 4 or 6 foot sections. Each of the two electrode holders consists of two vertical 9-inch channel irons that are set 5 inches apart and act as guides for two $\frac{3}{8}$-inch copper plates. These vertical copper plates are attached to a heavy horizontal copper plate that extends over the furnace and has a clamp tightened by a screw for supporting the electrodes. The electrodes may be raised or lowered by hand wheels at the rear or by automatic Thury regulators. In later furnaces the copper, that serves to support the electrode as well as conduct the current, is to be replaced by manganese steel supports and copper bus bars large enough to conduct the current. This will strengthen the holder and reduce the amount of copper, about 1 ton being necessary in the old design. The electrode holders are water cooled at the electrodes, and there are copper water jackets around the electrodes where they enter the roof.

The cost of a $2\frac{1}{2}$-ton Héroult electric steel furnace may be estimated as follows:

The furnace, automatic regulators, platform, transformers, switchboard, and other equipment will cost when completely installed about \$12,000 to \$15,000, exclusive of crane or buildings; allow an engineering fee of \$5,000, and \$350 per month and expenses for an expert to establish the operation of the furnace, making a total of about \$25,000. The royalty on tool steel produced would be from \$1 to \$3 per ton according to quantity, and on castings, billets, or ingots 50 cents per ton.

THREE-PHASE HÉROULT FURNACE.

With the use of three-phase electric current in the Héroult furnace of 15 tons capacity a slightly modified design has been made. Until recently the largest three-phase Héroult furnaces were the two in this country, one at South Chicago, Ill., and the other at Worcester, Mass., which are of identical design, but recently there has been erected a 25-ton three-phase Héroult furnace at Bruckhausen, Germany, and a 22-ton furnace is almost completed at the same plant.

The essential difference between the 15-ton, three-phase furnace at South Chicago, Ill.,[a] and the single phase 2.5-ton Héroult furnace is that in place of two electrodes there are three let down through the roof so that their ends form the vertices of an equilateral triangle, each side of which is 5 feet 2 inches long, one vertex of this triangle pointing toward the back of the furnace. The center of this triangle coincides with the center of the furnace. Each electrode is connected to a phase of a three-phase circuit.

A steel overhead structure supports the electrodes, the weight being directly supported by chains which run back over pulleys on the framework to the drums at the back of the furnace. The electrodes are kept in alignment by vertical guides. The chains are attached to three separate solid copper holders, which are bolted directly to the bus bars. In front these holders are split and joined with a right-and-left screw, which enables the holder to be opened or closed at will. The holders can be made to carry any size of electrode up to 24 inches diameter by use of contact blocks.

The electrode may be regulated by three hand regulators about 4 feet back of the furnace, or by automatic regulators. There is an individual motor for each electrode and a complete automatic device similar to the Thury regulator.

The furnace proper has a shallow hearth, as in the single-phase furnace, but is circular instead of rectangular. The outside dimensions are approximately that of a complete circle 13.5 feet in diameter, with two flattened portions at the front and back. The furnace shell is of plate steel 1 inch thick, riveted together.

The furnace bottom is made of one row of magnesite brick laid on edge across the steel shell, over which is rammed dead-burned Spaeter magnesite to a depth of 12 inches at the center—its thinnest point. The side walls consist of two rows of magnesite bricks laid on end, giving a thickness of 18 inches up to the furnace roof. The roof is made of silica brick and is 12 inches thick. There is an 8-inch rise in the 10-foot span across the furnace.

The furnace has five doors, two on each side and one in front over the pouring spout, of cast iron lined with fire brick, 4½ inches thick. They are operated by steam pressure, with the exception of the one over the pouring spout, which is operated by hand with a counterbalance.

[a] Osborne, G. C., The 15-ton Héroult furnace at the South Chicago works of the Illinois Steel Co.: Trans. Am. Electrochem. Soc., vol. 19, 1911, p. 205.

The foundation is of concrete and extends 5 feet above the ground. On the foundation is a stationary rack 8 feet 9 inches long, upon which the furnace proper rests on a floating pinion fastened to the shell by rivets. The arc of this floating pinion has a radius of 10 feet, which gives the furnace a tilting angle of 29°. Attached to the extreme back of the furnace is an 18-inch plunger with a 4-foot stroke working in a cylinder attached to a hydraulic line of 500 pounds pressure per square inch, which gives a lifting power of about 45 tons. The furnace rights itself by its own weight after tilting.

For operation the furnace takes 1,200 to 1,500 kw., supplied by a three-phase current at about 90 volts, and having a frequency of 25 cycles.

THE GIROD FURNACE.

The main difference between the Girod electric steel furnace and the Héroult furnace is that the former has a hearth which conducts the electric current. There are in operation 16 Girod furnaces of 2.5 to 12 tons capacity and 5 are in course of construction. This type of furnace seems to be especially satisfactory in the refining of cold scrap steel because of the slight fluctuations in power demand.

SINGLE-PHASE GIROD FURNACE.

The single-phase furnace at Ugine, France[a] (fig. 28), has a shallow conducting hearth of dolomite with pieces of soft steel embedded in the dolomite near the periphery, and a carbon electrode passes through the roof. In the operation of the furnace current passes through the carbon electrode and through the steel bath, which touches the tops of the steel poles embedded in the hearth. The furnace is mounted on rollers and tilted by an electric motor. This furnace has a capacity of 2.5 to 3 tons and is operated with 300 kw. The voltage is 60 to 65 volts, and the frequency of the current is 25 cycles.

The hearth of the furnace is 3 feet square at the bottom and 6 feet square at the top. The roof is 31 inches above the hearth. The water-cooled steel electrodes (fig. 29), embedded in the hearth when new, project beyond the bottom of the hearth a short distance. There are 6 steel poles set on the circumference of a 31-inch circle. The floor of the hearth is made of dolomite and tar rammed in. The walls are magnesite brick; the roof is silica brick. The roof is insulated from the walls by a thin layer of asbestos. The whole hearth is encased in a $\frac{5}{8}$-inch steel shell and is set on a concrete foundation that extends 6 feet above the ground level. The furnace has one

[a] Borchers, W., Electric smelting with the Girod furnace: Trans. Am. Inst. Min. Eng., vol. 41, 1910, p. 120.

charging door at the rear and a pouring spout in front, and resembles the open-hearth furnace even more than the Héroult furnace does.

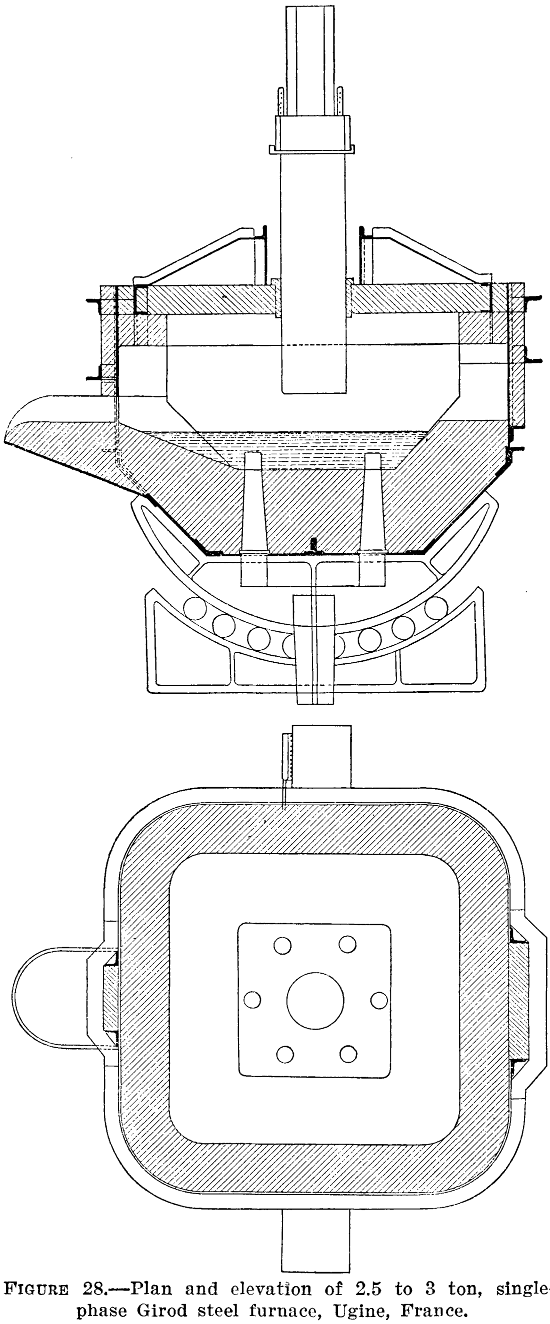

FIGURE 28.—Plan and elevation of 2.5 to 3 ton, single-phase Girod steel furnace, Ugine, France.

The 2.5-ton furnaces at Ugine are operated with carbon electrodes 14 inches in diameter and 5 feet long, some of which are threaded for continuous feeding. The means of supporting the electrode differs from the Héroult scheme in that the supporting steel structure is built over the furnace from the sides (fig. 22), making it possible to have a door at the rear. The crosspiece holds a water-cooled holder attached to the electrode. There is also a water jacket around the electrode where it passes through the roof. The crosspiece is raised or lowered by a screw at each end, the side structural work serving as a guide. The electrode may be adjusted by hand or by automatic control.

With a conducting-hearth furnace there is a considerable tendency to the presence of induced currents in the steel shell which reduce the power factor. Hence the arrangement of the electrical conductors is of great importance in the Girod furnace. Three methods have been used: (1) The shortest path from the motor-generator set to the carbon and steel electrode is used, so that all of the cables are on the side of the furnace that faces the motor generator. (2) The cable to the electrode is in two parallel sections, and the steel electrode is connected by the shortest path to the motor-generator set, so that each steel pole has a direct cable connection with the generator. (3) The third method is now being adopted for the latest furnaces of this type. The current is conducted to the carbon electrode in a manner similar to method 2, but whereas in methods 1 and 2 the bottom steel electrodes are insulated from the furnace body, in this method the steel electrodes are electrically connected to the furnace body; also the conductors are bus bars instead of cables attached to the steel shell of the furnace. These bus bars are arranged symmetrically around the furnace. This arrangement is shown in figure 22.[a] The advantages of this arrangement are: A better agitation of the bath due to the arc circling around the periphery of the carbon electrode, greater durability of roof and lining, a saving of 10 per cent of energy consumption, the use of copper bus bars instead of cables, lack of current interruptions due to rupture of the arc, and reduction of electrode consumption.

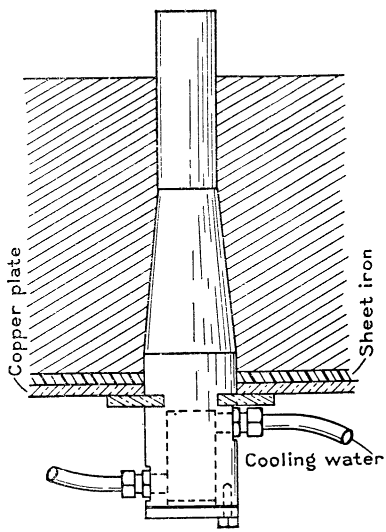

FIGURE 29.—Section of water-cooled steel electrode used in Girod furnace.

The cost of the metallic parts of a 2.5-ton Girod furnace, including electrode regulators, measuring instruments, tilting device, and conductors from the furnace to a dynamo or transformer near the furnace room, not including transforming or generating machinery and license fee, is estimated at about $3,000. The cost of a plant consisting of one 2.5-ton furnace for regular running and one furnace for reserve, with all appliances and smelter building, but without dynamo or transformer, is estimated to be approximately $40,000 to $50,000. The license fee is not included in this estimate.

THREE-PHASE GIROD FURNACE.

A section of the three-phase 10 to 25 ton Girod furnace is shown in figure 30. There are four upper carbon electrodes 14 inches in

[a] Mueller, A., The manufacture of steel in the Girod electric furnace: Metall. Chem. Eng., vol. 9, 1911, p. 581.

diameter, which with their connections constitute the essential difference between the single-phase and the three-phase furnace. On a three-phase circuit the Girod furnace is connected by the star con-

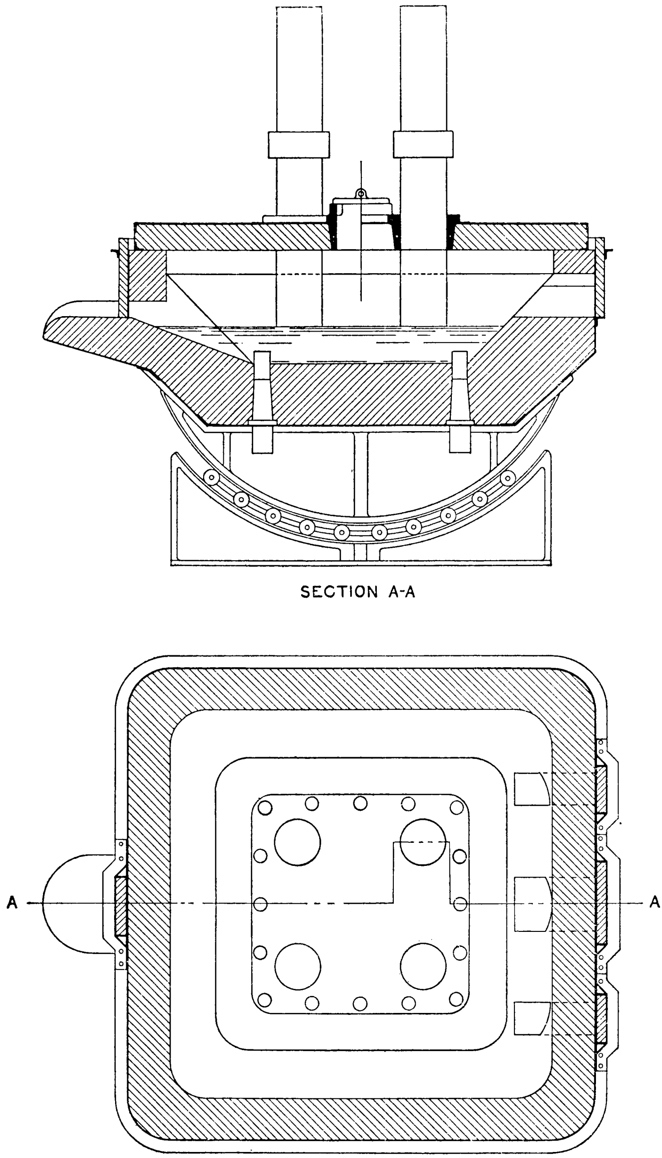

FIGURE 30.—Plan and elevation of 10 to 12.5 ton, three-phase Girod steel furnace, Ugine, France.

nection. Two of the carbon electrodes are each connected to a phase. The other two are connected in parallel with the third phase, while the hearth is connected so as to form the neutral point of the system.

There are 16 bottom electrodes of steel. The 12-ton furnace uses from 1,000 to 1,200 kw., supplied by a 25-cycle current at 70 to 75 volts.

The interior of the hearth of the 12-ton furnace is 4 feet square at the bottom, widening out to 10 feet at the top. The silica brick roof is set 3 feet 9 inches above the hearth of dolomite. The bottom is tamped in to a depth of 20 inches.

The furnace, with the exception that there are three charging doors at the rear instead of one, is similar to the single-phase 2.5-ton furnace. The four electrode holders are set two on a side, arranged as in the smaller furnaces.

The metallic parts of a 10 to 12.5 ton three-phase Girod furnace, including regulators for the electrodes, measuring instruments, tilting mechanism, and conductors from the furnace to a dynamo or transformer near the furnace room, but not transforming or generating machinery and license fee, cost about $6,000. A plant with one 12-ton furnace in reserve, including building, but without dynamo or transformer, is estimated to cost, license fee excluded, about $60,000 to $100,000.

THE STASSANO FURNACE.

The Stassano[a] electric steel furnace differs from other electric steel furnaces in that the electrical current does not pass through the metal or slag. All heating is by radiation from three horizontal arcs. The power consumption of the Stassano furnace is somewhat higher than that of some others, so that its use is limited to furnaces having a capacity of not more than 2 tons for making high-grade small steel castings. At present there are 16 Stassano furnaces in operation in sizes up to 2 tons capacity and one is in course of construction.

The Stassano furnace (figs. 19 and 20) has a circular hearth with a cylindrical melting chamber above. In the 1-ton furnace (figs. 19 and 20) the hearth is about 3 feet in diameter, with the roof 3 feet 6 inches above it. The furnace is incased in a steel shell with one door opposite the pouring spout. There are also openings for the three electrodes which project toward the center of the melting chamber. The movement of each electrode is controlled by a hydraulic piston. The source of power is connected by a rod with the end of each electrode, each of which is connected to a phase of a three-phase system. Each electrode holder and electrode are surrounded by a water jacket. In the 2-ton furnace carbon electrodes 3 inches in diameter and 4 or 5 feet long are used. The lining of the hearth is dolomite and tar, but the roof and sides are magnesite

[a] Stassano, E., The application of the electric furnace to siderurgy: Trans. Am. Electrochem. Soc., vol. 15, 1909, p. 63.

brick. The external dimensions of the 1-ton furnace are about 10 feet by 8 feet; the 2-ton furnace is 10 feet high and 10 feet in diameter.

The early type of Stassano furnace had a chamber beneath it (fig. 19) which contained a rotating mechanism for agitating the steel bath. This feature has not proved of great value, and is now abandoned in the more recent furnaces, which, like the Girod furnace, are set on rollers. Some furnaces recently erected at Newcastle on Tyne, England, by the Electroflex Steel Co. have a combination of the rotating and tilting motion.

A 1-ton Stassano furnace requires 200 kw. supplied by a 3-phase at 110 volts, having a frequency of 25 cycles. A 2-ton furnace uses about 400 kw. at 120 volts.

THE KELLER FURNACE.

The Keller[a] furnace (fig. 23) is very similar to the Girod furnace, as it has a conducting hearth of iron rods embedded in a refractory material. This type of furnace was the first to be used as a super-refining agent for steel that had been made by the old-established methods. There are in Europe three Keller furnaces, the capacities of which are 1 to 8 tons.

The Keller furnace consists of a conducting hearth surrounded by a steel water jacket, with a silica brick roof. The conducting hearth consists of iron bars 1 to 1½ inches diameter, set vertically 1 inch apart in an iron plate. These bars are surrounded by a mixture of magnesite and tar rammed in while hot. The bars are good conductors of electricity when the furnace is cold, and the magnesite also becomes a conductor when hot. The small furnaces have one carbon electrode and the larger ones have four electrodes. In both types the connections are similar to those of the Girod furnace. A feature of the Keller furnace plant, devised before the day of continuous feeding of electrodes, is the revolving arms, with extra electrodes for quick charging (fig. 23). An 8-ton Keller furnace is operated with 750 kw.

THE GRÖNWALL FURNACE.

In general external appearance the Grönwall[b] or Electro-Metals furnace (figs. 24 and 25) resembles the single-phase Héroult furnace. However, it uses two-phase current and has a conducting hearth. A noteworthy feature of this design is the steadiness of the load on the power line when cold scrap is worked, as the arcs are not connected in series. There are four Grönwall furnaces in operation.

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[a] Keller, C. A., A contribution to the study of electric furnaces as applied to the manufacture of iron and steel: Trans. Am. Electrochem. Soc., vol. 15, 1909, p. 87.

[b] Robertson, T. D., The Grönwall steel refining furnace: Metall. Chem. Eng., vol. 9, 1911, p. 573.

The current may be directly supplied as two-phase or transformed from three-phase to two-phase by the Scott connection of transformers. In the Electro-Metals furnace at Sheffield there are two 12-inch carbon electrodes projecting into the furnace through the roof, each of which is connected to a phase, the conducting hearth forming the neutral of the system. This conducting hearth consists of carbon paste rammed on the steel bottom of the furnace to a depth of 4 inches, over which is placed a mixture of dolomite and tar to a depth of 10 inches. In figures 24 and 25 the neutral point is a carbon block, but, as stated above, this has been recently changed at the Sheffield furnace. By this connection half of the power goes through one electrode and half through the other, each being independent of the other.

The furnace proper is rectangular in shape, like the Héroult furnace, the exterior being 6 feet 6 inches wide by 8 feet 10 inches long by 4 feet 11 inches high. There are two doors at the sides and a pouring spout, with the electrode holders, at the rear. The holders are of manganese steel, held tightly around the electrodes by wedges. At first, as shown in figure 25, current was led to the electrodes through these holders, but at present the electrodes are electrically connected with cables and two copper plates, $\frac{1}{4}$ inch thick and 6 inches wide, shaped so as to pass around the electrode. The furnace is tilted by hand by means of a screw device. Electrodes are adjusted by hand, although there is no technical reason why an automatic regulator should not be used. The lining of the sides is magnesite brick and the roof is silica brick. The use of water jackets around the electrodes has been discontinued. As now operated there is no water cooling of any part of the furnace. The furnace is set upon a concrete foundation, being tilted on the usual curved bars. The power required is 500 kw., the frequency of the current being 25 cycles; the voltage of the two carbon electrodes is 105, while between each electrode and the neutral point, the hearth, the voltage is about 75.

THE NATHUSIUS FURNACE.

The Nathusius[a] furnace (fig. 26) is three-phase and combines heating from above by arcs with resistance heating from below in the steel bath for the purpose of decreasing local heating by the arcs. The furnace is circular in form and is incased in a steel shell. There are three water-cooled carbon electrodes which project through the roof into the furnace above the surface of the charge, and three or a multiple of three water-cooled bottom electrodes of mild steel set in the hearth. Both upper and lower electrodes are arranged in a

[a] Nathusius, H., The refining of steel in the Nathusius electric furnace: Jour. Iron and Steel Inst., vol. 85, 1912, No. 1, p. 51.

triangle (p. 76). The electric connections are shown in figure 26. The electrodes are suspended by cables from overhead runways and are adjusted either automatically or by hand. On tilting, these electrodes are raised out of the furnace. The tilting mechanism is operated by an electric motor. Furnaces under 6-ton capacity are on trunnions, but with the larger sizes rollers are used. The 5-ton furnace at Friedenshütte, Germany, is normally operated with about 600 kw. Sixty-cycle current is used. The voltage between the upper electrodes is 110 volts, between the lower electrodes 10 volts, and between the upper and lower electrodes 61 volts. In addition to this 5-ton furnace the same company operates a 2 to 3 ton furnace for melting ferro-alloys.

OTHER ELECTRIC STEEL FURNACES OF THE ARC TYPE.

Several other types of arc furnaces which have no especially novel feature are in operation at the plants where they were originally designed. The Chaplet furnace, used for the manufacture of ferro-alloys, the direct production of steel from ores and scrap, is similar in principle to the Héroult furnace, but has two separate chambers with an electrode in each. Four Chaplet furnaces are in operation in France. The Anderson furnace is also similar to the Héroult furnace, but has an electromagnet beneath it for the purpose of controlling the position of the arc. Five Anderson furnaces have been built in England. The Stobie two-phase furnace is very similar to the Grönwall furnace. There has also been designed a Stobie three-phase furnace. Four Stobie furnaces are being built at Newcastle, England. One three-phase Soderburg furnace, similar to the Girod furnace, is in operation. In the design of the Harden Paragon [a] furnace the bath is heated from above by arcs, and also from the sides and bottom by side plates in the lining.

INDUCTION FURNACES.

THE KJELLIN FURNACE.

The Kjellin furnace, the pioneer of induction steel-furnaces, is especially adapted to the melting of fine materials to obtain a high-grade steel. At present 9 of these furnaces are in operation, but the writer does not know of any others being erected.

The Kjellin [b] furnace (fig. 21) is in reality a transformer in which the bath of molten metal forms the secondary circuit. The magnetic

[a] Härdén, J., The Paragon electric furnace and recent developments in metallurgy: Met. and Chem. Eng., vol. 9, 1911, p. 595.

[b] Kjellin, F. A., The Kjellin and Röchling-Rodenhauser electric furnaces: Trans. Am. Electrochem. Soc., vol. 15, 1909, p. 173.

circuit C is built up of laminated sheet iron like the core of a transformer. The primary circuit is a coil consisting of a number of turns of insulated copper wire or tubing surrounding the magnetic circuit. The ring-shaped crucible B, made of suitable refractory materials, also surrounds the magnetic circuit, and when filled with molten metal forms the secondary circuit of the transformer. The annular crucible is supplied with covers.

If the coil be connected with the poles of an alternating current generator, the current passing through the coil excites a variable magnetic flux in the iron core, and the variation in the magnetic flux induces a current in the closed circuit formed by the molten metal in the crucible B. The ratio between the primary and secondary current is fixed by the number of turns of the primary, and the magnitude of the current in the steel is then almost the same as the primary current multiplied by the turns of the primary coil. Thus in a small furnace of this type a current of 500 volts and 280 amperes supplied to the coil induces a current of 7 volts and 24,000 amperes in the metallic bath. Before starting the furnace an iron ring must be placed in the crucible and melted down to form a bath, or the crucible must be filled with molten metal taken from another source. On continuous work it is customary to leave enough metal in the crucible to establish the bath. Kjellin furnaces have been built in sizes up to 8.5 tons capacity, requiring 750 kw.

THE RÖCHLING-RODENHAUSER FURNACE.

The Röchling-Rodenhauser furnace is an improvement of the Kjellin induction furnace designed especially for the refining of molten basic Bessemer steel and for use with currents of frequency ordinarily used in steel plants. The Kjellin furnace of 8 tons capacity required a current of not more than 5 cycles frequency or the power factor would drop below 0.6. The Röchling-Rodenhauser furnace is so designed as to have a power factor of 0.6 when using a frequency as high as 50 cycles. The furnace is the most widely used of the induction furnaces and is especially adapted to refining molten metal. Eighteen of these furnaces are already in operation and four are in course of construction.

The Röchling-Rodenhauser[a] furnace (fig. 27) has a hearth of very different shape from the Kjellin furnace, as it has a distinct open hearth which no other induction furnace possesses. Both single and three-phase current furnaces are constructed, the former having two grooves in which the metal is melted and the latter three. In either

[a] Rodenhauser, W., The electric furnace and electric process of steel making: Jour. Iron and Steel Inst., vol. 79, No. 1, 1909, p. 261.

furnace these grooves or heating channels, each of which corresponds to the annular hearth of the Kjellin furnace, open into a distinct open hearth, where all metallurgical operations, such as the addition of fluxes and alloys, take place. The grooves, which have a comparatively small cross section, form the secondary circuits in which the currents that heat the metal are induced.

Two side doors are provided in a single-phase furnace and three in a three-phase furnace. The furnace is set on rollers and is tilted by means of a hydraulic motor. One door has a spout for pouring. As the doors are slightly above the level of the bath, removing the slag is no more difficult than in the arc furnace, which is not the case with other induction furnaces.

In figure 27, HH represents the two legs of the transformer that are surrounded by primary coils A connected with the alternating-current circuit. Secondary currents are induced in the two closed circuits formed by the bath. These two circuits are connected by the hearth in the center so as to resemble the figure 8. The primary coils are so arranged that the induced currents have the same direction in the common part of the two circuits. The difference between this furnace and the ordinary induction furnace consists in the use of extra secondary coils BB surrounding the primary coils AA. The secondary coils are connected to metallic plates EE, covered by an electrically conducting mixture of lining material, G, which forms part of the lining of the furnace. The current from the secondaries passes through the plates, E, through the lining, G, and then through the main hearth, D.

This current used in combination with the current from the channels CC gives a better power factor than when the furnace is operated with the current from the channels only. Another advantage is that the magnetic leakage field surrounding the primary coils, which formerly had the effect of checking the primary current and decreasing the power factor, is now utilized for inducing currents in the extra secondaries.

The result is that the main hearth can be made of much larger cross section than before and that, nevertheless, even in big furnaces a good power factor can be maintained without the use of such a low frequency of the current as was necessary with the original induction furnace.

The single-phase furnace gives better satisfaction than the three-phase furnace because it is less complicated. Also, the strong circulation of the bath in the central hearth of the three-phase furnace causes great wear on the lining.

Röchling-Rodenhauser furnaces have been built in various sizes. The 8 to 10 ton single-phase furnace at Volklingen, Germany, takes 600 kw., supplied by a current of 4,000 to 5,000 volts with a frequency of 25 cycles. The 2 to 3 ton 3-phase furnace at the same place takes from 200 to 250 kw., supplied by a 400-volt current with a frequency of 50 cycles. The power load of these furnaces is very steady. The 2 to 3 ton furnace recently installed at Landsdowne, Pa., requires 300 kw., furnished by a 25-cycle current at 480 volts.

OTHER INDUCTION STEEL FURNACES.

The Frick furnace is very similar to the Kjellin furnace, differing from it only in slight details of design. The primary windings are placed above and below the annular ring instead of within it. One 12-ton Frick furnace is in operation in Germany.

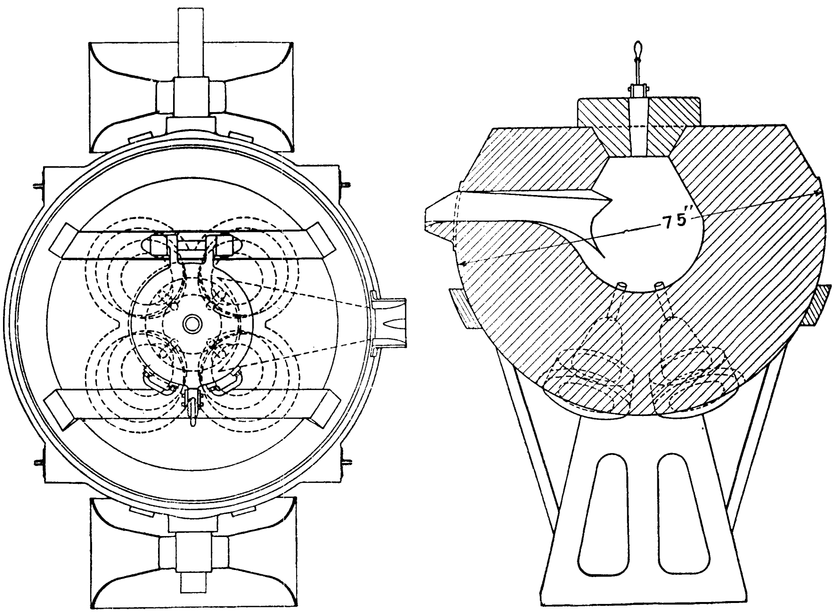

FIGURE 31.—Plan and elevation of Hering resistance furnace.

The Hiorth furnace is a further development of the Kjellin furnace, differing only in that the bath lies in two annular grooves instead of one, thus surrounding both sides of the primary coil. One tilting Hiorth furnace has been erected in Norway.

AN ELECTRICAL RESISTANCE FURNACE ADAPTABLE TO STEEL MANUFACTURE.

A resistance furnace based upon the "pinch effect" has been designed and operated on an experimental scale by Hering.[a] Although this furnace (fig. 31) is not in commercial operation as

[a] Hering, C., A new type of electric furnace: Trans. Am. Electrochem. Soc., vol. 19, 1911, p. 255.

yet for the production of steel, several are in the course of construction for this purpose, and small ones have been shown in operation. The following is a brief description of the principle on which this resistance furnace operates.

The "pinch phenomenon" is the local contraction of cross section of a liquid resistor through which electric current is passing and in which heat is being generated. In open channels this contraction or pinching often results in complete rupture, thereby limiting the temperature. This contraction is caused by an electromagnetic force that acts from the circumference to the center of the conductor and in a direction perpendicular to the axis.

If a conductor consists of a column of liquid metal in a vertical hole in a nonconducting material closed at the bottom by the electrode and opening at the top into the bath of metal in the hearth, then this force acts horizontally, and perpendicularly to the axis along the whole length, which results in an axial force that causes the liquid metal to flow out of the center of the open end. In the Hering furnace such a column is made the resistor in which the desired heat is generated by passing the current through the column by means of an electrode at the bottom. Two such resistors are placed in the bottom of a furnace of any desired shape for single-phase current and three for three-phase current. As this "pinch effect" can not now rupture the circuit, it expels the heated liquid rapidly from the holes and forces it against the blanket of slag, thereby continually renewing the surface exposed to the slag action, while the cooler liquid in the bottom of the hearth is sucked down into the hole near the circumference to be in turn heated and immediately expelled. The ejecting force increases as the square of the current and diminishes with an increase in the cross section of the conductor.

There is an active and systematic circulation of the liquid bath, and the temperature is very evenly distributed throughout the bath. As far as is known now, there is no temperature limit except that which causes failure of the refractory lining. The electrodes may be made of metal, and no adjustment of them is necessary; they are not consumed. The hottest liquid is in the center of the resistors. The rapid flow is not along the walls of the hole but in the center. The power factor can be made very high, and ordinary frequencies may be used.

The furnace can be operated with direct or alternating current of one, two, or three phase. The transformers in the latter case are attached directly to the bottom of the furnace, as the amperage is very high.

ELECTRIC STEEL MANUFACTURING PRACTICE.

There are two courses of procedure for steel manufacture in which the electric furnace has been used: Cold scrap iron and steel of either inferior or high-grade quality is melted and refined in an electric furnace with the production of steel of the highest grade equal to the best crucible steel; and molten steel, the product of either the acid or basic converters, or of the acid or basic open-hearth furnaces, is superrefined, or made into alloy steel, in an electric furnace.

MANUFACTURE OF STEEL FROM SCRAP IRON AND STEEL IN THE ELECTRIC FURNACE.

SOCIÉTÉ ÉLECTRO-MÉTALLURGIQUE FRANÇAISE, LA PRAZ, SAVOIE, FRANCE.

The plant of the Société Électro-Métallurgique Française, at La Praz, Savoy, France, has passed through many phases of the use of the electric furnace in metallurgical operations. The first product produced here by Héroult was aluminum, which was followed by calcium carbide, ferro-alloys, electrodes, and steel. To-day the plant uses 7,500 kilowatts for the production of aluminum, steel, and electrodes.

DESCRIPTION OF PLANT.

The principal products of the 2.5 to 3 ton Héroult furnace (fig. 18) in operation at La Praz are high carbon and alloy tool steels. The furnace is the original Héroult furnace examined by the Canadian commission. It differs from the furnace at Braintree in that the lining is thinner, giving a more shallow hearth. The hearth is ground dolomite and tar, the sides are magnesite brick, and the roof is silica brick. The two carbon electrodes are 14 inches square. The holders are of somewhat more simple design than those in the Braintree furnace (p. 94). They consist of two clamps of steel held together by a pin, being tightened by a wedge. Current is brought in by cables attached to pins in the ends of the electrodes and to the electrode holders. Electrodes are not threaded for continuous feeding. The holders and ports in the roof are water cooled. The electrodes may be regulated either by hand or automatically. Power is supplied by a single-phase alternator directly connected to the furnace about 30 feet away. The power required is 300 kw., and is supplied by a 33-cycle single-phase current, at 100 to 110 volts, giving 50 to 55 volts on each electrode.

PRACTICE AT PLANT.

The furnaces are charged with low-carbon steel or wrought-iron turnings and a part of the first refining flux. As the melting proceeds, all of the first flux, consisting of iron ore and lime, is added to remove the phosphorus. When this is accomplished the slag is completely removed from the furnace and a flux of lime added to remove the sulphur. The slag is completely deoxidized for the removal of sulphur by the addition of coke dust. The metal is finally carburized to the desired point by addition of carburite, and then poured into ingots.

The results of operations covering one week are given below. The number of heats is probably somewhat greater than the usual number, as at the time of the writer's visit the average was three in 24 hours. A noteworthy reduction of power consumption has been made over that of 1904, as the figure of December 24, 1911, was 528 kilowatt-hours per ton as compared to 840 kilowatt-hours per ton, of 1 per cent carbon steel, refined with two slags, for 1904, a reduction of 312 kilowatt-hours, or 37.1 per cent decrease. The electrode consumption of 18 kg. (39.6 pounds) in 1904 would probably approximately hold for to-day, as the methods have not been changed materially in that respect. The roof had stood 107 heats up to the week mentioned.

Results of operation of furnace for week ended Dec. 24, 1911.

Hours worked	126
Number of heats	26
Average hours per heat, including all repairs and charging	4 hours, 51 minutes.
Shortest heat	3 hours, 10 minutes.
Total weight teemed	66 tons.
Lowest power consumption, per ton, at furnace	459.2 kilowatt-hours.
Average power for week at furnace, per ton	528 kilowatt-hours.
Scrap, per cent	3
Clear ingots, per cent	93
Loss by oxidation, per cent	4

FINAL FORM OF PRODUCT.

The ingots cast at the furnace are reheated and reduced in rolls and hammered to 1 inch to ½ inch rods of circular or square cross section. The product is sold in this form. Samples of steels of the following composition were taken by the writer:

Tool steels produced in Héroult furnace, La Praz, France, 1912.

	No. of sample.			
	1	2	3	4
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Carbon	0.904	1.034	1.196	0.990
Silicon	.323	.201	.170	.700
Manganese	.236	.273	.210	.211
Sulphur	.008	.008	.009	.024
Phosphorus	.004	.006	.012	.007
Tungsten				19.407
Chromium				6.717

PLANT OF MESSRS. VICKERS, LTD., SHEFFIELD, ENGLAND.

A 2.5 to 3 ton single-phase Héroult furnace, similar to the furnace at Braintree, is being used in the manufacture of steel of crucible grade from cold scrap iron and steel at the River Don plant of Messrs. Vickers, Ltd., Sheffield, England. A new 8-ton three-phase Héroult furnace is being constructed, which will be directly connected to the main power circuit of the works and will take about 1,200 kw. The lining of rammed dolomite and tar, both on sides and bottom, will be thinner than usual, so that the nominal capacity will be 10 instead of 8 tons. The electrodes are to be supported by holders projecting over the roof from the sides. Charging doors will be placed in the rear instead of at the side, with the pouring spout at the front. The furnace will be set close to the edge of the working floor instead of 10 feet back, as is the case with the present 2.5-ton furnace. The erection of an electrode plant is also being considered.

DESCRIPTION OF PLANT.

The electric furnace, generator, and laboratory are placed in a steel frame building about 60 feet square, covered with corrugated iron. In one corner, at the rear of the furnace on the ground level, is the generator room. Above, on the furnace level, are the office and laboratory. The furnace is set on a concrete foundation extending about 6 feet above the ground with a steel platform about 20 feet square around it. The furnace is at the rear of this platform, leaving an open space of about 10 feet in front, in which there is a door that can be lifted for setting the ladle beneath the spout in pouring. The instrument board and Thury regulators are back of the furnace. In front of the platform is a pit 5 feet long, 20 feet wide, and 4 feet deep, where ingot molds are set for teeming. The remaining floor space is devoted to repairing and heating ladles, storing ingots, and piling scrap. There is an electric crane in front of the furnace platform.

The furnace differs in some details from the Braintree furnace. The bottom consists of a 4½-inch layer of magnesite brick laid on edge over the steel shell, above which tar and dolomite are rammed in to a depth of 7 inches, making a hearth 11.5 inches thick. This slopes up to a line on the sides above the slag line. When the furnace was first operated the walls were built of magnesite bricks laid to give a thickness of 9 inches. Because of the bricks spalling they have now been laid so as to give a wall 4½ inches thick. This, incidentally, has increased the capacity, so that the average charge is now 3 tons instead of 2.5 tons. The roof is silica brick. Carbon electrodes 16 inches in diameter and 4 feet long, and threaded for continuous feeding, are used. The electrodes are supported by a more simple holder than that of the Braintree furnace, consisting of bronze clamps surrounding the electrode, tightened in front by a horizontal bolt. The holder is similar to the older type, except for this feature, and that it is made entirely of manganese steel instead of copper and is not used for conducting current. Current is conducted by means of copper bus bars 4 inches wide and $\frac{7}{8}$ inch thick from cables at the rear of and beneath the furnace to the bronze holders around the electrodes. The furnace is tilted by means of a screw device that is operated by an electric motor. The electrode holders are water cooled, and there are copper water jackets around the electrode openings in the roof.

Power is delivered to the furnace about 20 feet from the generator by a single-phase alternating-current generator of 600 kw. capacity, operating at 100 to 110 volts and a frequency of 25 cycles. The alternator is directly connected to a 3-phase motor. The power is received from the main power plant of the works at 2,200 volts. The current consumption charged to the furnace is that shown on the primary side of the main 3-phase line, so that it includes all transforming and other losses. In the generator room there are also a power-factor meter and other meters on the secondary side. Current is conducted to the furnace bus bars by insulated copper cables. At the rear of the furnace are the Thury regulators, a wattmeter, a voltmeter on both electrodes and on each single electrode.

PRACTICE AT PLANT.

The electric-furnace operation consists in making high-grade steel for various purposes, such as tools and armament, out of scrap iron and steel turnings, some of which are impure ordinary carbon steel, while others contain valuable proportions of tungsten, chromium, and other expensive alloys. The furnace is operated at 100 volts, 50 volts per electrode, with a power consumption of 400 to 550 kw. For 15 to 45 minutes after charging, the electrodes are regulated by hand, but as soon as a pool of molten metal has formed in the bottom the Thury regulators are thrown in. The constant breaking of the circuit is very noticeable before the charge is completely melted. Sometimes one and sometimes two refining fluxes are used, depending upon the impurities present. The first flux is generally 40 kg. (88 pounds) of lime, 30 kg. (66 pounds) of hematite, and 20 kg. (44 pounds) of fluorspar. The second flux consists of 40 kg. (88 pounds) of lime and 20 kg. (44 pounds) of fluorspar, and is added only after complete dephosphorization by the first slag. To deoxidize the second slag for removing sulphur, coke dust is added. Sometimes pig iron, ferrosilicon, ferromanganese, and sand are used at the end of a run. Aluminum is thrown in the ladle bottom before pouring. A 3-ton ladle is used for teeming and is preheated before using. Part of the metal from one heat is cast by bottom casting into five 500-kilogram (1,100-pound) ingots, the balance of the charge being cast by top casting into 100-kilogram (220-pound) ingots. Of the metal charged, about 85 per cent is recovered in good ingots, 5 per cent in poor ingots, 3 per cent in scrap, and 7 per cent is oxidized.

Working with high-speed tool-steel scrap, the method of running a charge was as follows:

Results from a single charge.

Charge, steel scrap, tool-steel scrap, 2,800 kg. (6,160 pounds).

Slag added, 40 kg. (88 pounds) lime and 20 kg. (44 pounds) fluorspar.

No slag skimmed.

Additions at end, 6 kg. (13.2 pounds) of a deoxidizing mixture, 2 kg. (4.4 pounds) ferrosilicon, 0.5 kg. (1.1 pounds) aluminum. No coke dust added.

A gray slag.

Time, hours	$3\frac{1}{12}$
Total power on primary meter, kw	1,580
Kilowatt-hours per metric ton of sound ingots	542
Average power, kw	513

Composition of product:

	Per cent.
Carbon	0.60
Tungsten	4.57
Chromium	5.92
Manganese	.20
Silicon	.07
Phosphorus	.012
Sulphur	.052

It will be noted that the power consumption is higher in this case for an operation with one slag than at La Praz with two slags, but this may be explained by the fact that power charged to the furnace at Sheffield is read on the primary circuit and includes all losses; also results are figured to tons of sound ingots. The power factor averages about 0.85, but varied over a period of a year from 0.79 to 0.95.

The average length of a heat is 4 hours, but at times as many as 6 heats per 24 hours have been made, including charging and pouring. The electrode cost is about 75 cents per metric ton which, with electrodes at 4 cents a pound, gives a consumption of 18.7 pounds per ton. It takes about 20 minutes to add a new 4-foot section to an electrode already in the furnace. The electrodes wear uniformly around the holder and at joints, but if a joint is not properly made the electrode tends to wear to a point, and then must be broken off at the end. If a piece falls into the bath it is necessary to shut off the power while the piece is being removed. Between heats the power is off for 10 to 15 minutes. The furnace lining is then fettled with dolomite. For a period of six months' continuous operation the roofs lasted on the average 78 heats, but some have lasted as long as 120 heats.

Advocates of the conducting-hearth type of furnace have stated that it would be very difficult to melt out the charge of a Héroult furnace if frozen, but this does not appear to be the case. At this plant a 2.5-ton charge was frozen, owing to a breakdown of the generator, and stood cold for four days. The charge was melted in 12 hours with a power expenditure of 1,950 kilowatt-hours per ton. During the melting 0.2 ton more of metal was added, making 2.7 tons in the furnace. Of this 2.525 tons were tapped. For about 1½ hours the power on the furnace was only 250 kw. in order to heat the roof gradually.

For the complete operation of this plant seven men and two boys are necessary, as follows: A superintendent, assistant superintendent, melter, assistant melter, ladle man, floor man, one general laborer, and two boys in the laboratory.

LAKES & ELLIOT FOUNDRY, BRAINTREE, ENGLAND.

At the foundry of Lakes & Elliot, Braintree, England, a 2.5-ton, single-phase Héroult furnace is used in making steel of low carbon content for small castings for the automobile trade.

DESCRIPTION OF PLANT.

The furnace, which has already been described (p. 74), is placed in the main casting building of the foundry, close to one wall. At the rear in an adjoining building is a separate power plant for the furnace, consisting of a gas producer, a Westinghouse gas engine, and a single-phase 300-kilowatt generator which delivers a 25-cycle current to the furnace about 20 feet away at 110 volts. A 5-ton overhead electric crane is used for pouring and other purposes.

PRACTICE AT PLANT.

The scrap iron and steel used consists of a mixture of horseshoes, castings, foundry scrap, boiler punchings, and miscellaneous heavy steel scrap of small dimensions. Some pig iron is also used, which is placed between the electrodes and is claimed to assist in the steady operation of the furnace. The steel charged contains from 0.05 to 0.14 per cent carbon. A part of the iron ore and lime that form the dephosphorizing slag is laid upon the floor of the furnace before charging the scrap. This seems to protect the hearth from corrosion. The remainder of this flux is added during the melting period. After skimming the slag a desulphurizing flux of lime and fluorspar is used. The carbon is reduced to 0.06 per cent and recarburization is accomplished by means of powdered carbon. Some ferromanganese, ferrosilicon, ferrotitanium, and aluminum are added at the end of the run or upon pouring. The charge is poured into a 2.5-ton ladle, from which it is teemed into small shanks for casting into the molds, thus eliminating slag. The electrodes are regulated by hand for 1½ hours after starting the furnace until the bath is partly melted.

Owing to the thick lining used, charges of not over 2 tons can be made, and the average melt is not over 1.5 tons. The melt takes 4.5 to 11 hours, with an average of about 6 hours, depending upon the nature of the charge. Definite figures as to power consumption could not be obtained, but with 300 kw. on the furnace, it is probably from 800 to 1,000 kw. per ton. One charge is run on the day shift and one on the night shift, the furnace standing idle in the meantime. By this arrangement the furnace is empty 2 to 4 hours between melts.

The electrode consumption could not be obtained definitely; but two 5.5-foot sections of 14-inch electrodes will last for 14 melts. These sections weigh about 600 pounds, which with an average charge of 1.5 tons would give a consumption of 25.5 kg. (56 pounds) per ton. The cost of electrodes is about 3.95 cents per kg. (1.8 cents per pound) f. o. b. plant, or 4.95 cents per kg. (2.25 cents per pound) laid down at Braintree.

Considerable difficulty has been experienced at Braintree in getting a durable roof. Several kinds of brick, such as silica, bauxite, magnesite, and a mixture of magnesite and bauxite, have been tried. At present bauxite brick is being used. The roof lasts 14 to 28 heats, depending upon the nature of the charge. The walls are also attacked by the arc breaking against the sides after the charge has been melted. This, however, does not cause so much trouble when a slag is on the bath. Whenever the roof gives out the furnace is entirely relined.

In addition to these difficulties, the Thury regulators did not appear to be giving satisfaction, because they were continually getting out of adjustment. This was the only plant visited where this trouble was mentioned. It was stated that in building a new furnace automatic regulators would not be used, as there was no saving in labor and an increase in first cost by their use.

The effect of producing low-carbon steel upon the working of the furnace was plainly visible at this plant. At the Sheffield plant, which was operating almost entirely on medium or high carbon steel, the power consumption, electrode consumption, and wear on the lining were much lower than at this plant. This was due chiefly to the low-carbon product requiring a longer period in the furnace, and also because in making steel castings the temperature of the metal must be higher than in casting ingots. The power consumption is increased by the cooling of the furnace between melts. The electrode consumption was also probably increased because the holder clamps wore into the electrode, and the worn part spalled and burned to a point when it got down into the furnace. It will be recalled that this holder is of different type than that used on the older Héroult furnaces. The difficulty with the lining and roof was increased by the necessarily high temperature of the slag and metal. Also the writer believes that less difficulty in this respect would be experienced if the hearth was made more shallow and the lining thinner. This would prevent the "flaming arc," as the electrodes would be farther from the sides. The arc would be more concentrated beneath the electrode and less heat would be directly radiated to the roof.

PRODUCTS.

As previously stated, the product of this furnace is a soft steel containing on an average 0.14 per cent of carbon, the content varying between 0.10 per cent and 0.20 per cent. The manganese and silicon are varied according to the use to which the steel is to be put. Sulphur and phosphorus are kept below 0.03 per cent. The steel produced is equal in all respects to crucible steel maufactured at the same plant.

GIROD STEEL PLANT, UGINE, FRANCE.

The Girod steel plant at Ugine, France, is the first and largest complete steel plant built that uses electric power entirely for furnace purposes. In 1898 Girod began experimental work on the manufacture of ferro-alloys with a small 20-kilowatt furnace. To-day this manufacture has developed into an industry with an annual production valued at about $3,000,000 and using about 22,000 kw. for electric-furnace purposes during periods of high water in the streams. As previously stated, from the electric ferro-alloy furnace was developed the Girod electric furnace. The steel works were erected in 1909, and because of their uniqueness will be described in detail.

LOCATION.

The plant is situated in a place so remote from supplies of coal and raw material that only a product in which one of the chief requisites to commercial success was cheap power could be manufactured profitably there. Ugine is on the line of the Paris, Lyon & Marseilles Railroad between Annecy and Albertville, about 25 miles from Champbery. The plant is about half a mile from the main line, with which it is connected by an electric tramway for freight haulage, which is operated by the Girod company. The buildings are on the north bank of the River Arly.

POWER SUPPLY.

The total capacity of all the Girod power plants is about 28,000 kw., of which about 6,000 kw. is used at the steel plant. There is a possible development of 30,000 kw. more, a total of 58,000 kw. Not all of this is primary power, however; that is, power 24 hours a day, 365 days a year. The average cost of power from all sources is about $18.66 per kilowatt-year, or 0.2 cent per kilowatt-hour, based on a flat rate. There are three separate power plants, two on the Arly River and one on the Bonnant River. Some power is leased at times of low water. The power is delivered at the steel works at 45,000 volts and is stepped down to the desired voltage.

DESCRIPTION OF PLANT.

All buildings are of stone and cement construction. The stock house at the rear of the furnace house is 58 by 460 feet. It is used for the receipt and storage of steel scrap and furnace materials of all kinds. There are overhead traveling cranes and lifting magnetic cranes, used to unload carloads of scrap iron and steel.

The furnace and casting house is 70 by 550 feet. In it there are two 10 to 12.5 ton 3-phase Girod furnaces (fig. 30) and three 2.5 to 3 ton single-phase furnaces (fig. 28), which have already been described (pp. 77–78). The three small furnaces are operated with 300 kw. supplied by a 25-cycle current at 60 to 65 volts. The larger ones take 1,000 to 1,200 kw., using a 70 to 75 volt, 25-cycle current. The furnaces are placed on a concrete foundation about 6 feet above the ground floor. The working floor of the furnace is concrete, and the furnaces are set at its edge as in an open-hearth plant. The plant is arranged for a production up to 200 tons a day. One of the smaller furnaces is used entirely for small casting work. The other two produce high-priced alloy steels. The two 10 to 12.5 ton furnaces are used for making carbon steels and the more common alloy steels. In front of the furnace platform are casting pits, one end being used entirely for foundry work. The furnace house is provided with two 2-ton traveling electric cranes and two 12-ton traveling electric cranes.

The rolling-mill building is 90 by 250 feet and contains 1 train of three-high rolls capable of rolling ingots 20 inches in diameter and 400 kg. (880 pounds) in weight to rods 5 inches in diameter. Another three-high mill rolls rods 13 inches in diameter to smaller rods of round, square, and other shapes. The trains are driven by a 600-kw. 3-phase motor. This building also contains 2 producer-gas fired furnaces for preheating ingots.

A large forging shop 70 by 250 feet contains 9 hammers operated by compressed air. The largest hammer weighs 5,000 kg. (11,000 pounds) and the others weigh from 1,000 kg. (2,200 pounds) to 100 kg. (220 pounds). A second forging shop contains one 1,000-ton forging press, 1 forging hammer weighing 10 tons, and 3 stamps with falling hammers, weighing, respectively, 3 tons, 2 tons, and

1 ton. In the first shop rough forgings are made, primarily for automobile machinery, shaftings, gears, tool-steel rods and projectiles.

A tempering shop 50 by 200 feet contains furnaces for tempering, annealing, and hardening large forged or cast-steel pieces. An annealing shop 33 by 67 feet contains several furnaces.

The steel foundry contains a carpenter shop for making patterns, a sand-separating plant, molding machines, molding frames, drying and heating ovens, and a sand-blast jet for cleaning finished castings. The foundry is able to produce 10 tons of steel castings daily, but castings weighing 20 tons have been cast.

The power house at the plant, which is 50 by 115 feet, is equipped with 4 electrically driven compressors and 2 rotary converters.

The warehouse for finished products is 50 by 325 feet, and is made especially large because of the variety of products, and also because it is necessary to carry common shapes over in stock during low-water periods.

In addition to the buildings mentioned there are a furnace-transformer house, a sand-storage house, a drying-oven house, an assembly shop, a machine shop, a storage house for the rolling mills, a pattern warehouse, general stores, a well-equipped physical and chemical laboratory, and an office building.

REFINING PRACTICE.

The refining of cold scrap at the Ugine plant[a] is typical of electric-furnace practice in work of this nature, and is here described in detail. Almost any grade of scrap steel or scrap wrought iron is charged into the Ugine furnaces, the mean proportions of carbon, silicon, manganese, sulphur, and phosphorus in the charge being as follows:

Average proportions of carbon, silicon, manganese, sulphur, and phosphorus in charge.

	Per cent.
Carbon	0.3 to 0.4
Silicon	.1 to .3
Manganese	.6 to .8
Sulphur	.07 to .120
Phosphorus	.07 to .12

The refining operation can be divided into two periods, the oxidation period, in which phosphorus is removed from the metal, and the deoxidation period, with the elimination of sulphur.

After the furnace has been charged with cold scrap, an oxidizing flux of lime and iron ore is added. The proportions vary with the charge and product desired, but a mixture commonly used is 80 kg.

[a] Girod, P., Studies in the electrometallurgy of ferro-alloys and steels: Trans. Faraday Soc., vol. 6, 1911, p. 172; The electric steel furnace in foundry practice: Metall. Chem. Eng., vol. 10, 1912, p. 663; Borchers, W., Electric smelting with the Girod furnace: Trans. Am. Inst. Min. Eng., vol. 41, 1910, p. 120.

(176 pounds) of lime and from 220 to 250 kg. (485 to 550 pounds) of iron ore. Oxidation of the impurities in the metal begins as soon as the scrap becomes pasty, so that by the time the charge is completely melted the carbon, silicon, manganese, and phosphorus contents of the metal are usually reduced to less than 0.1 per cent each. If this is not the case, the slag is withdrawn by tilting the furnace backwards and another flux of the same composition is added. To cleanse the bath of the last traces of the phosphorous-bearing slag and any phosphorus in the metal, lime is added and the resulting slag removed. This is repeated as often as may be necessary. In this first period the temperature is gradually increased, but the oxidation takes place largely at a low temperature.

When the oxidizing and cleansing slag has been removed, the first deoxidation of the bath is effected by adding reducing agents such as ferrosilicon or ferromanganese, but these alloys are added in such a proportion as not to remain in the bath, serving merely as deoxidizing agents. If a high-carbon steel is to be made, recarburization takes place at this point.

The bath is then covered with a flux consisting of about 5 parts lime, 1 part silica sand, 1 part fluorspar, and a little petroleum coke. In this period the furnace must be tightly closed. For proper deoxidation and desulphurization of the bath all iron oxide in the slag must be reduced. This is done with petroleum coke and deoxidizing alloys such as ferrosilicon, silicomanganese, ferrosilico-manganese-aluminum, or even silicon-aluminum. These alloys act energetically and form fluid slags which rise to the surface.

When the slag is completely deoxidized, which is shown by its being white and disintegrating to a powder in air, any desulphurization not completed in the first period is finished by the passage of the sulphur to the slag as calcium sulphide, the chemistry of the process will be described later (p. 124). Carburizing materials are added for finishing the metal, as well as other alloys to bring the steel to the desired composition. If any of the slag from the first period has been left in the furnace, the phosphorus in it will be reduced in the second period, passing into the steel. The average analysis of the final white slag is as follows:

Average composition of final slag.

	Per cent.
CaO	74.85
SiO_2	13.20
FeO	.13
MnO	Traces.
Fe_2O_3	None.
Al_2O_3	1.75
MgO	4.22
P_2O_5	.09
S	1.20

The power consumption recorded at the terminals of the furnace, including melting, refining, and finishing a charge of cold scrap is estimated by Girod at about 850 kilowatt-hours per ton of metal tapped for a 2.5 to 3 ton furnace; at 750 kilowatt-hours per ton of metal tapped for a 10 to 12 ton furnace. The power consumption varies with the charge and product required. A power factor of 0.80 to 0.88 is maintained.

The electrode consumption is stated to be 8 to 9 kg. (17.6 to 19.8 pounds) for a 2.5 to 3 ton furnace, and 8 to 10 kg. (17.6 to 22 pounds) for a 10 to 12 ton furnace. These figures are based on the use of electrodes made at the Girod plant, not designed for continuous feeding, so that this item might be considerably reduced.

Dolomite-and-tar hearths are used. The life of a lining is 90 to 100 heats for a furnace of 10 to 12 tons and about 120 heats for the 2.5 to 3 ton furnace. At the end of that time the side walls are repaired. All burned or oxidized parts of the walls are scraped. About 4 to 6 inches of the bottom is taken up and retamped with a new layer of dolomite. Care is taken to leave the bottom electrodes clear. The roof of the furnace is made of silica brick and stands on an average 50 heats for the 10 to 12 ton furnace and 70 heats for the 2.5 to 3 ton furnace.

The output of metal is 90 to 96 per cent of the charge, depending upon the nature of the metal charged.

A 2.5 to 3 ton furnace requires for operation 1 melter, 1 assistant, and 1 boy; the 10 to 12 ton furnace 1 melter, 2 assistants, and 1 boy. This does not include foremen, cranemen, ladle men, and other laborers.

PRODUCTS OF THE FURNACE.

An idea of the charges, power consumption, and wide variety of products made at Ugine may be obtained from the following record [a] of the operation of this furnace:

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[a] Girod, P., op. cit., and Borchers, W., op. cit.

Operation and products of 2.5 to 3 ton Girod furnace.

Quality of steel manufactured.	Desired proportions of—						Time of starting.	Charge.				Time of pouring.	Production in ingots of 350 kg.	Total production.	Incomplete analysis of metal obtained.								Electrical energy consumed per ton.
	C.	Si.	Mn.	Ni.	Cr.	Va.		Scrap.	Turnings.	Ore.	Lime.				C.	Si.	Mn.	S.	P.	Ni.	Cr.	Va.	
								Kg.	*Kg.*	*Kg.*	*Kg.*			*Kg.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Kw.-hrs.*
Tool steel	0.90	0.30	0.30	.....	.....	.....	7 a. m.	1,800	200	100	60	11.10 a. m.	5½	1,725	0.845	0.27	0.31	0.019	0.013	.....	.....	.....	900
Nickel-chrome steel.	.30	.20	.35	2.8	0.6	.....	11.40 a. m.	2,000	200	100	60	6.00 p. m.	6	2,100	.277	.153	.358	.016	.008	2.86	0.51	.....	950
Nickel steel	.15	.20	.35	5.0	.....	.....	12.25 a. m.	2,300	200	120	70	7.00 a. m.	6½	2,275	.156	.194	.380	.012	.012	5.18	.....	.....	950
Nickel-chrome-vanadium steel.	.30	.15	.45	3.0	1.0	0.30	7.30 a. m.	2,500	200	120	70	2.15 p. m.	7	2,450	.297	.120	.473	.010	.005	3.22	1.06	0.23	900
Steel for shell plugs	.30	.20	.40	.....	.....	.....	3.10 p. m.	2,500	200	120	70	10.40 p. m.	6¾	2,370	.312	.176	.420	.006	.013	.....	.....	.....	900
Extra soft steel	.10	.20	.30	.....	.....	.....	11.00 p. m.	2,800	300	200	70	7.00 a. m.	(*a*)	2,775	.097	.190	.317	.014	.012	.....	.....	.....	925

a 7 castings.

FOUNDRY OF MÖNKEMÖLLER & CO., BONN, GERMANY.

At the foundry of Mönkemöller & Co., Bonn, Germany, three Stassano furnaces (figs. 19, 20) are producing low-carbon steel for high-grade steel castings and one additional Stassano furnace of 2-ton capacity is being built. The Stassano furnace in small units is better adapted to this use than to any other.

DESCRIPTION OF PLANT.

There are two 1-ton furnaces, each requiring 200 kw., supplied by a current at 110 volts with a frequency of 25 cycles, and one 2-ton furnace taking 400 kw. at 120 volts; the frequency is 25 cycles. The two small furnaces are of essentially the same construction as shown in figures 19 and 20, having the rotating mechanism. The larger one differs only in that it is set on rollers for tilting. The details of construction are as given in the description of the Stassano furnace.

FOUNDRY PRACTICE.

Scrap steel of various sizes and grades is used as a raw material. This is charged to a point directly beneath the three arcs. The desulphurizing and dephosphorizing operations are in general about the same as at other plants.

It takes about three to four hours to melt the charge and from four to five hours for complete melting and refining. The loss of heat in the water cooling of the electrodes is about 14 per cent. The electrodes consumption is very high, owing to failure to use up stumps. The repair cost is also high. The magnesite brick roof lasts from 80 to 100 heats; the whole furnace must then be relined. The power consumption is about 800 to 1,000 kilowatt-hours per ton. A power factor of from 0.85 to 0.90 is maintained. Power is supplied by a public-service corporation at a cost of about 1 cent per kilowatt-hour. The electrodes are regulated hydraulically, but not automatically, as a man watches the meter for changes all the time.

The metal is poured from the furnace into a 1 or 2 ton ladle, from which it is poured into small shanks for casting. All three furnaces are on the main casting floor of the foundry. Most of the castings made are of small size. The steel has an average content of 0.8 to 0.18 per cent carbon, 0.03 per cent sulphur, and 0.06 per cent phosphorus. Occasionally tool steels, with or without the addition of alloys, are made. The process is said to be much cheaper than the crucible method and gives a better product.

SHEFFIELD ANNEALING WORKS, SHEFFIELD, ENGLAND.

At the Sheffield Annealing Works, Sheffield, England, a 2 to 2½ ton Grönwall furnace is in use for the production of steel from scrap.

The chief product is alloy steel, which is cast into ingots and further treated at another works. The scrap steel used consists for the greater part of small pieces of tool scrap and other alloy scrap.

DESCRIPTION OF PLANT.

The furnace (figs. 24, 25) has been described. At some future time the cables to the electrodes are to be replaced by bus bars. The furnace foundation is set level with the ground, with a pit in front for teeming. The building is not well arranged for electric furnace work; the ventilation is very poor. Two annealing furnaces are adjacent to the casting pit.

The two-phase current is received from the main line of the municipal power system at 2,000 volts, with a frequency of 25 cycles, the cost being about 1 cent per kilowatt-hour. An integrating wattmeter, from which the power is charged to the furnace and from which power figures are taken, is placed on the primary side of the circuit where the line enters the building. The meter is followed in the circuit by choke coils to the two transformers. These transformers can be adjusted to give 50, 60, 70, or 80 volts on the secondary circuit. The usual voltage is 75 volts. The neutral point is connected to the bottom of the furnace and a phase is connected to each electrode. The secondary switchboard has a power-factor meter, which can be thrown into any leg, as well as a voltmeter, with the same adjustment. On the switchboard there is also one ammeter set in the neutral. On the back of the furnace there are two ammeters, one to each phase, by means of which two men regulate the electrodes.

PLANT PRACTICE.

The furnace is operated only 12 hours a day, so that more than two charges are never run in one day; also, in the wintertime, it is necessary not to draw too heavily on the power system late in the afternoon when the load on the city lines begins to get heavy. Such operation, of course, is not economical with respect to power consumption, as the furnace cools overnight. Constant change of temperature in the furnace also increases the wear on the lining and the electrodes.

At the time the furnace was inspected it was charged with steel scrap containing 0.40 per cent carbon, 1 to 2 per cent tungsten, and about 1 to 2 per cent chromium. The object of the run was melting with some refining and the casting of ingots. The charge melted in 2 hours and 15 minutes, during which period 560 kilowatt-hours per ton were expended, and was poured in 4 hours and 5 minutes, with a total expenditure of energy of 902 kilowatt-hours per ton. Thus 62 per cent of the energy consumed was used for melting. During the melting stage the amperage was held at 4,000 amperes, or about

500 kw. was on the furnace, while during the refining period this was reduced to 2,500 to 3,000 amperes and about 200 to 300 kw. Often only about 1,500 amperes are on toward the end, but at the very end the temperature is raised to keep the slag fluid. This is said to protect the roof, which seems to be more attacked during the last half hour than any other time. During the melting period a mixture composed of 100 pounds of lime, 30 pounds fluorspar, and 20 pounds of silica was added in two parts. None was added after the melting period, but as soon as the alloy was hot anthracite coal dust was used for deoxidation. In 1½ hours the slag became white. At the end of 3 hours and 50 minutes samples of metal and slag were taken. The slag was white. Analysis of the steel showed a carbon content of 0.39 per cent. While the analysis was being made more coal was shoveled in to prevent reoxidation of the slag. Another sample of slag was taken and the charge poured into a 2.5-ton ladle that had been preheated. From the ladle it was teemed by top-casting into ingots. About 20 pounds of 50 per cent ferrosilicon were placed in the spout before pouring, and 20 to 30 pounds of 80 per cent ferromanganese were added to the charge in the furnace. The weight of metal tapped was 2.1 tons. Some aluminum was added to the tops of the ingot molds.

The electrode consumption is about 20 pounds per ton, at a cost of about 4 cents a pound. Under the poor operating conditions the silica roof lasts about 20 heats. The conducting bottom had been in 60 heats at the time of inspection and was still in good condition.

The furnace force consists of a superintendent, a chemist, a melter, two assistant melters, a ladle man, and one general laborer.

PLANT OF CRUCIBLE STEEL CASTING CO., LANSDOWNE, PA.

At Lansdowne, Pa., the Crucible[a] Steel Casting Co. has recently built the first Röchling-Rodenhauser steel furnace to be used commercially in the United States. It is used for producing steel for castings from cold scrap.

The current used is single-phase and the furnace is of 2 tons capacity, similar to the furnace shown in figure 27. It is situated 200 feet from the generator, on an operating platform. The lining is a mixture of magnesite and tar and is tamped by hand. The roof is magnesite brick. A motor-driven blower supplies the air for cooling the transformer coils for the furnace.

A 300-kilowatt generator supplies a 25-cycle single-phase current at 480 volts, and is directly driven by a 2-cylinder oil engine. The power cost is estimated at 0.7 cents per kilowatt-hour.

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[a] Von Bauer, C. H., The Röchling-Rodenhauser furnace of the Crucible Steel Casting Co., Lansdowne, Pa.: Iron Trade Rev., vol. 53, 1913, p. 153.

The furnace is charged while hot with cold scrap, some molten steel from the previous run being left in the furnace. At present it is operated only 12 hours a day, making two melts in that period. The general refining process is the same as in other electric steel furnaces. The length of run varies from four to six hours and the power consumption from 800 to 900 kilowatt-hours per ton. Steel has been produced of the following composition—0.30 per cent carbon, 0.30 per cent silicon, 0.49 per cent manganese, 0.03 per cent phosphorus, and 0.03 per cent sulphur.

SUPERREFINING OF MOLTEN STEEL IN THE ELECTRIC FURNACE.

PLANT OF ILLINOIS STEEL CO., SOUTH CHICAGO, ILL.

The 15-ton 3-phase Héroult [a] furnace at the South Chicago works of the Illinois Steel Co. until recently was one of the two largest electric furnaces in operation for the manufacture of steel. A wide variety of products was made in an attempt to learn what could be done with the electric furnace. The furnace was primarily intended for the refining of molten Bessemer steel, but some cold scrap has been treated.

DESCRIPTION OF PLANT.

The Héroult furnace at South Chicago has already been described. The steel operating platform of the furnace is about 9 feet above the ground level. Around the furnace on this platform, at convenient points, bins are placed for the materials used in furnace operation. The front part of the furnace platform opens to allow a ladle to be hung in position when steel is poured.

Power for the furnace is supplied by the central plant of the works. Dynamos are driven by reciprocating gas engines, reciprocating steam engines, and high-pressure and low-pressure turbines. Blast-furnace gas is used in the gas engines and under boilers. The power cost is about 0.5 cent per kilowatt-hour. The 25-cycle 3-phase current is stepped down at the furnace from 2,200 volts by three 750-kilowatt transformers. These transformers are arranged so that the number of turns in the primary may be altered to give a secondary voltage of 80, 90, 100, or 110 volts. The usual voltage is 90 volts.

The pouring platform, 30 feet long, enables eight molds to be placed in position for pouring. The furnace is served by a 50-ton crane.

PLANT PRACTICE.

Bessemer pig iron is full blown, in a 15-ton Bessemer converter, in 8 to 12 minutes. The analysis of the Bessemer metal shows 0.05 to

[a] Osborne, G. C., The 15-ton Héroult furnace at the South Chicago works of the Illinois Steel Co.: Trans. Am. Electrochem. Soc., vol. 19, 1911, p. 205; The South Chicago electric furnace plant of the U. S. Steel Corp.: Met. and Chem. Eng., vol. 8, 1910, p. 179.

0.10 per cent carbon, 0.005 to 0.015 per cent silicon, 0.05 to 0.10 per cent manganese, 0.035 to 0.07 per cent sulphur, and about 0.095 per cent phosphorus. It is then poured directly from the converter to a transfer ladle and drawn to the electric furnace building, about one-fourth of a mile away. As a precaution against the possible formation of a skull in the ladle, the Bessemer charge is blown hotter than in ordinary Bessemer practice.

When the ladle is received at the electric furnace it is lifted by a crane and tilted; the silicious slag is removed by hand rabbling. The metal is then poured into the electric furnace through a spout. The cleaning of the slag and the charging take 5 to 10 minutes. As the metal pours into the furnace the helper shovels iron oxide and lime through the furnace doors to produce a basic oxidizing slag for the removal of phosphorus. In about 30 minutes the furnace is tilted forward and the slag removed in 5 to 10 minutes by hand rabbling. The quantities of carbon, silicon, manganese, and phosphorus have been reduced to a low point in this period.

In the second or deoxidizing stage which now begins sulphur is eliminated as much as possible. The recarburizing agent is added, followed by lime and fluorspar to keep the mass fluid. In about 15 minutes this second slag is fluid, and finely divided coke dust, the deoxidizer, is thrown on top of the slag, forming a reducing atmosphere, as shown by the formation of calcium carbide beneath the electrodes. Thereafter there is a dead melting in a reducing atmosphere. The slag is basic and fluid and contains considerable calcium carbide. It will be seen that the refining practice with molten metal is quite similar to that with cold scrap.

Tests are taken to show the condition of the steel. A small cylindrical test piece is poured and then flattened under a steam hammer at the furnace. If the forged sample appears to be satisfactory, the bath is tapped. The furnace electrodes are raised, and the charge is poured into a ladle, from which it is teemed into ingots.

The quantity of material used in a typical charge is given in the following charge sheet:

Charge sheet of 15-ton Héroult furnace, South Chicago, Ill.

Materials used.	Pounds.	Pounds per tons of 2,240 pounds.
Bessemer blown metal	30,000	....
Scale	700	52.3
Ferromanganese, 80 per cent pure	200	14.9
Ferrosilicon, 10 per cent pure	60	4.5
Ferrosilicon, 50 per cent pure	80	6.0
Recarbonizing agent	130	9.7
Fluorspar	400	29.9
Coke dust	200	14.9
Lime, first slag	600	45.0
Lime, second slag	600	45.0
Dolomite lining	400	29.9
Magnesite lining	25	1.8

The time consumed in the different operations is divided as follows:

	a. m.
Previous heat tapped	7.00
Metal ordered for	7.15
Metal received	7.15
Fettling begun	7.17
Current on	7.27
Removal of slag begun	8.00
Removal of slag finished	8.11
Tapped	8.48

Time of heat, 1 hour 21 minutes.

The temperature of the Bessemer metal poured into the electric furnace is almost 1,500° C., whereas that of the steel poured from the furnace is about 1,495° C. At the close of a run the furnace temperature drops from about 1,500° C. to 1,300° C. during the 15 minutes necessary to patch the lining for the next run.

On an average 12 heats are made daily. During a series of experiments in which both dephosphorization and desulphurization took place, the average power consumption was 198 kilowatt-hours per long ton. When desulphurization alone was carried on, the average power consumption was 105.9 kilowatt-hours per long ton. The power factor of the furnace varies from 0.80 to 0.90.

The hearth is fettled after each run with dolomite, from 10 to 30 pounds of dolomite being used per ton of steel. The hearth proper consists of 4 parts dead-burned, ground magnesite mixed with 1 part basic open-hearth slag. To this mixture tar enough is added to make the mass plastic for tamping. After being tamped, the furnace is heated with a wood fire for 48 hours; it is then filled with coke, the current turned on, and the bottom fluxed into place. This bottom and the side walls last a long time. A silica-brick roof withstands about a week's use and is repaired or replaced during the regular weekly shutdown. The roof has then been subjected to about 72 heats, although some roofs have stood 129 heats. A new roof is always kept in reserve.

Extensive tests have been made with various kinds of electrodes. The average consumption of either amorphous carbon or graphite electrodes is given as about 6 pounds per ton of steel. As in cold-scrap refining processes, the electrodes are regulated by hand during the first few minutes of a run.

PRODUCTS.

This furnace has produced a greater variety of steel than any electric furnace in operation, the product including high-grade alloy steel, high-grade carbon steel, and ordinary carbon steel. From the ordinary carbon steel produced, rails of a dozen different sections, billets of all sizes and grades, plates of all sizes and grades, structural shapes, castings, both small and large, and high and low carbon, and forgings of all sizes have been manufactured. Among the alloy steels made are nickel, nickel-chrome, chrome, manganese, and silicon steels. Some steel has been made from cold scrap.

The main characteristics of the steels produced in the furnace are a comparative freedom from oxidation and from segregation and a higher tensile strength and slightly higher ductility than that of open-hearth or Bessemer steel of the same chemical composition up to 0.4 per cent carbon, where the difference becomes less apparent.

PLANT OF AMERICAN STEEL & WIRE CO., WORCESTER, MASS.

A 15-ton, three-phase Héroult furnace similar to the South Chicago furnace was in operation until recently at Worcester, Mass., for the production of steel for wire from basic open-hearth steel. Owing, presumably, to difficulty in drawing the comparatively high-carbon steel into wire the furnace is not operated regularly at present. The furnace is similar in construction to the furnace at South Chicago. A current of 12,000 volts is received and is transformed to about 110 volts or less at the plant, according to the voltage desired for the furnace. There are three 750-kilowatt transformers, and the furnace is connected to the transformers by bus bars. Electrode regulators similar to those at South Chicago are used. The cost of power is 0.6 to 0.8 cents per kilowatt-hour.

The process is desulphurizing only and hence requires less time than at that at South Chicago. The procedure of one run was as is stated below. The charge of molten basic open-hearth steel contained 0.18 per cent carbon, 0.22 per cent manganese, 0.02 per cent silicon, 0.02 per cent phosphorus, and 0.027 per cent sulphur. As the 12 to 15 ton charge was poured into the electric furnace about 280 pounds of electrode dust were added. Charging took about 5 minutes. When the furnace was charged a mixture made of 700 pounds lime, 350 pounds fluorspar, and 50 pounds of coke was added. In about 30 or 35 minutes 120 pounds of fluorspar were rabbled in. This was followed in 10 minutes by 30 pounds more of fluorspar. About an hour after the charging was completed a sample was taken. One of these contained 0.50 per cent carbon, 0.12 per cent manganese, and 0.019 per cent sulphur. Ferromanganese and pig iron were then added. About 10 minutes after the first sample had been collected another was taken, which contained 0.45 per cent carbon, 0.45 per cent manganese, and 0.02 per cent sulphur. The slag at this time was tested for calcium carbide, then ferrosilicon, sand, and lime were added. The current was then turned off and the charge poured into a ladle and cast into ingots. The finished product contained

0.54 per cent carbon, 0.47 per cent manganese, 0.157 per cent silicon, 0.022 per cent of phosphorus, and 0.015 per cent of sulphur.

The average current strength for a run was 12,310 amperes; the power factor was 0.696; the voltage was 76.2, 97.7, and 73.3 volts; and the power 396, 451, and 404 kw. to the respective phases. The sum of the kilowatts on the three phases was 1,253 kw. and the average length of a run was 1.41 hours, making the total power consumption 1,746 kilowatt-hours. The average power consumption per ton of metal poured is about 152 kilowatt-hours.

The temperature of the steel when charged is about 1,454° C. The temperature of the slag is 1,524° C. The steel is tapped at a lower temperature than it is charged.

The total losses in bus bars, electrodes, and transformers is 6.53 per cent of the current measured at the switchboard. About 2 per cent of this loss is in the transformers. The loss by conduction through the walls is 5.57 per cent of the total power supplied the furnace.

GUTEHOFFNUNGSHÜTTE WORKS, OBERHAUSEN, GERMANY.

An extensive test[a] has been conducted at Oberhausen, Germany, on the Girod electric furnace (fig. 32) for the refining of steel from molten basic open-hearth metal.

DESCRIPTION OF PLANT.

The Girod furnace installed here is from 2.5 to 3 ton capacity (fig. 22) and is similar to the usual type of Girod furnace.

The single-phase current is supplied by a motor-generator set consisting of a 3,000-volt, 95-ampere, 575-kilowatt, three-phase induction motor driving a single-phase 75-volt, 6,700-ampere, 25-cycle, 500-kilowatt generator. The power factor is 0.8. These machines, as well as all conductors carrying high-tension currents, are placed in a room adjoining the furnace. The loss in transforming from three-phase to singe-phase current is about 14 per cent. On the furnace switchboard there are ammeters and voltmeters in the low-tension circuit, with a wattmeter in the primary circuit. The excitation-current regulator for the furnace voltage, the manual and automatic regulator for the electrodes, and the device for tilting the furnace are all controlled from the switchboard.

REFINING PRACTICE.

In continuous operation it is possible at this plant to run 8 heats in 24 hours, a total of 25 tons of steel. The basic open-hearth furnaces

[a] Mueller, A., The manufacture of steel in the Girod electric furnace: Metall. Chem. Eng., vol. 9, 1911, p. 581.

are tapped only every four hours, so that the electric furnace can not be operated continually. The furnace is charged by means of a 23-foot launder extending from the open hearth. During the charging process the current is 4,000 to 6,000 amperes. After the charging

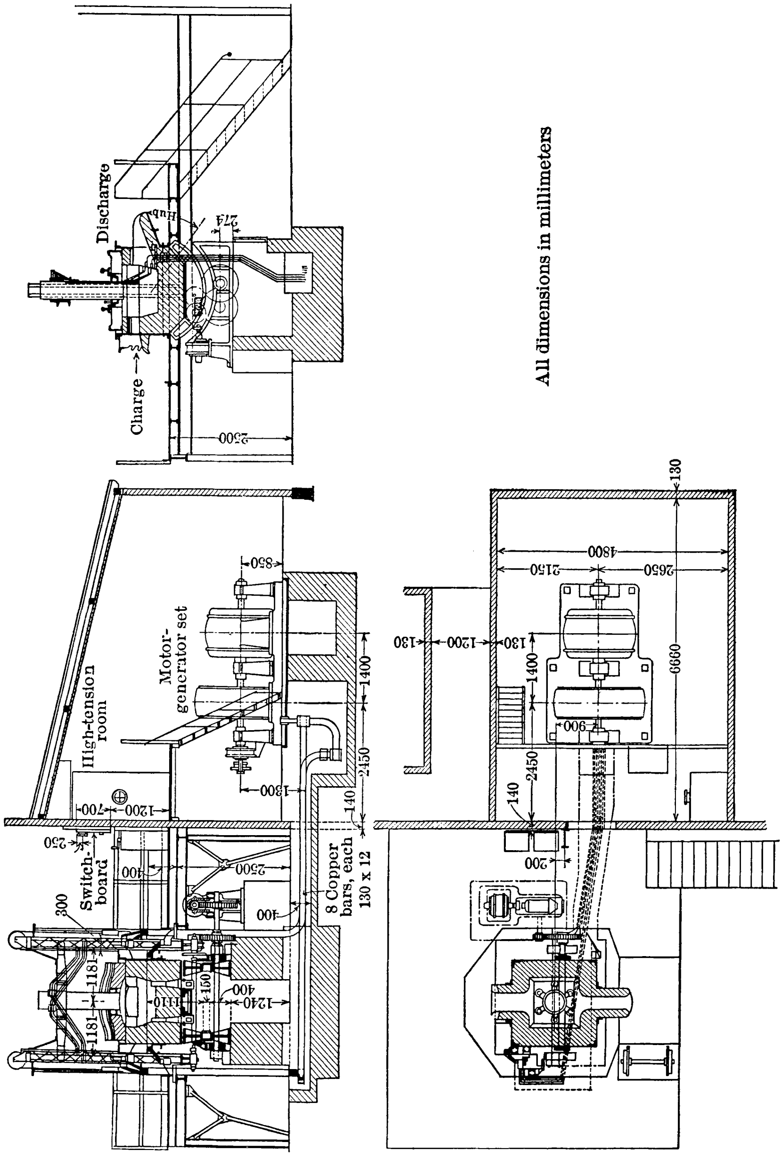

FIGURE 32.—Arrangement of electric-furnace steel plant, Oberhausen, Germany.

launder has been removed from the furnace the flux of ore and lime for oxidizing is shoveled into the furnace. The usual practice is followed for oxidation and deoxidation. The results of tests to determine oxidation and deoxidation of impurities is given below.

Figure 33 shows diagrammatically the chemical reactions during a heat in the Girod furnace and illustrates the changes of the carbon, manganese, phosphorus, sulphur, and silicon contents.

The results of the analyses of 19 samples are here plotted. Sample 1 is that of the charge, sample 2 was taken after addition of 15 kg. (33 pounds) of ore, sample 3 after addition of 50 kg. (110 pounds) of ore. Samples 4 and 5 were also taken during the oxidation period, sample 5 being taken just before removal of the oxidation slag. Samples 6 to 19 were taken during the deoxidation period. Sample 6 was taken after the addition of 16 kg. (35 pounds) of Girod carbons and 5 kg. (11 pounds) of ferromanganese; sample 7 after the addition of 12 kg. (26.5 pounds) of ferrosilicon (50 per cent Si) and 40 kg.

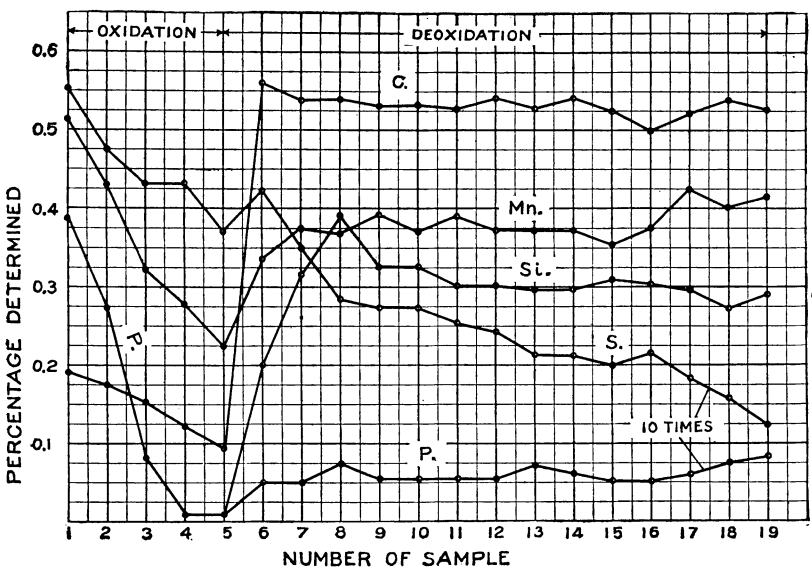

FIGURE 33.—Results of analyses of 19 samples of metal during one heat.

(88 pounds) of refining slag; sample 8 after the addition of 4 kg. (8.8 pounds) of ferrosilicon; sample 9 after the addition of 20 kg. (44 pounds) of refining slag; sample 10 after the addition of 3 kg. (6.6 pounds) of ferrosilicon; sample 11 after addition of 2 kg. (4.4 pounds) of powdered petroleum coke; sample 12 after the addition of 1 kg. (2.2 pounds) of ferromanganese (80 per cent Mn); sample 13 after the addition of 8 kg. (17.6 pounds) of lime; nothing was added when samples 14 and 15 were taken; sample 16 was taken after the addition of 10 kg. (22 pounds) of lime and fluorspar and 2 kg. (4.4 pounds) of powdered petroleum coke; and sample 17 after addition of 2 kg. (4.4 pounds) of ferromanganese. Nothing was added after that, sample 19 being the last.

The oxidation period must be preceded in many cases by a melting period of a length corresponding to the interval between charges. A longer interval causes the steel to solidify in parts. During this time ore is added gradually to the bath in the furnace.

The carbon oxidizes slowly in spite of the high temperature in the furnace. The curves shown in figure 33 are based on data obtained from a heat in which 0.10 per cent carbon was oxidized in 55 minutes, the amount oxidized being equivalent to 53 per cent of the original carbon content. Although the manganese was present in a more concentrated state than the carbon, only 58 per cent of the original manganese content was oxidized in the same time. The amount oxidized is equal to a decrease in manganese from 0.52 to 0.22 per cent.

Phosphorus can be more completely removed than the other impurities since the proportion of the oxidizing agent can be governed at will and the slag can be kept very basic, and these conditions facilitate the removal of phosphorus. As decarburization progresses the phosphorus content decreases steadily, the low temperature of the bath favoring the oxidation of phosphorus. The third sample taken (fig. 33), after a charge of 50 kg. (110 pounds) of ore had been added, contained only 0.008 per cent phosphorus, against 0.039 per cent in the first, a reduction of 80 per cent. Practically all the phosphorus is removed before slagging proceeds.

As shown in figure 33, the sulphur content decreases from 0.055 per cent to 0.037 per cent during oxidation, the decrease being 33 per cent. Wüst claims that slag containing ferrous oxide dissolves iron sulphide to a certain extent. In stronger concentration it reacts with ferrous oxide, according to the equation:

$$FeS+2FeO=3Fe+SO_2.$$

The sulphur dioxide escapes and can be clearly recognized. But a part of the sulphur may still remain dissolved in the slag together with free ferrous oxide, as is shown by the sulphur in the oxidation slags. The average decrease in sulphur content during the oxidation period is 26 per cent.

The oxidation slag is drawn off, and the last trace of phosphorus is removed from the bath by mixing lime with it. This method avoids rephosphorization of the bath by the carbon and silicon additions in the following period. One slag is sufficient to remove all the phosphorus except traces.

The deoxidizing slag is produced by adding to the bath about 20 kg. (44 pounds) of lime, 3 kg. (6.6 pounds) of sand, and a like quantity of fluorspar, and also 1 kg. (2.2 pounds) of ferrosilicon (50 per cent silicon) per ton of steel. This slag dissolves the ferrous oxide that has been forming on the unprotected surface of the metal and thereby becomes black.

The reduction of the ferrous oxide in the slag is indispensable for the deoxidation and desulphurization of the bath. For this deoxidation the silicon from the added ferrosilicon is not sufficient, and 1 to 2 kg. (2 to 4 pounds) of powdered petroleum coke are added to insure complete deoxidation. The slag obtained disintegrates in the air quickly to a white powder, indicating that the ferrous oxide has been reduced to traces.

With high-carbon products, petroleum coke or waste pieces of carbon electrode are added in proper proportion to the bath as required for purposes of carburization prior to the formation of the deoxidation slag. As soon as the slag is readily fluid and free from oxide, ferromanganese, ferrosilicon, and other alloys are added.

The addition of these alloys which are often impure may increase the phosphorus and sulphur content considerably. Thus, in figure 33 sample 6 shows that the phosphorus has increased from traces to 0.08 per cent, owing to the addition of ferromanganese with a phosphorus content of 0.4 per cent. The chemical composition of the slag at different periods of the melt follows:

Composition of slags.

Constituent.	Oxidizing slag.	Deoxidizing slag.		Finishing slag.
		After carburization.	After main charge.	
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
CaO	41.69	59.50	69.45	75.85
SiO_2	9.58	26.78	17.90	13.20
FeO	28.36	1.02	.27	.13
MnO	.99	1.44	.52	Trace.
S	.62	.39	.90	1.22
Fe_2O_3	6.43	.23	....	....
Al_2O_3	1.73	1.67	1.27	1.73
MgO	6.99	5.54	5.78	4.22
P_2O_5	1.47	.07	.12	.09
Oxide of bases	.20	.20	.22	.22
Oxide of acids	9	15	10	8
Appearance of slag	Black and streaky.	Grayish brown sand.	White sand.	White powder.

The sulphur is removed in three ways: During oxidation, through the formation of sulphur dioxide by the action of slag rich in ferrous oxide; in the deoxidation period, through the action of the white slag, free from ferrous oxide; and through the union of silicon with sulphur, forming silicon sulphide.

The quiet melting of a cold scrap-steel charge has been recognized as a great advantage of the Girod furnace. Figure 34 shows the fluctuations of the kilowatt consumption as traced by a recording wattmeter, starting with a liquid charge. The regulation of voltage and current is almost always automatic; hand regulation, with the automatic regulator disconnected, is used only during the beginning of a run. In figure 34 the letters represent the time of the operations as given: A, tapping; B, C, and D, additions of flux; E, carburization; F, slagging; G, slag readily fluid; H, bath boiling; I, additions of ore; J, slag not fluid; K, charging.

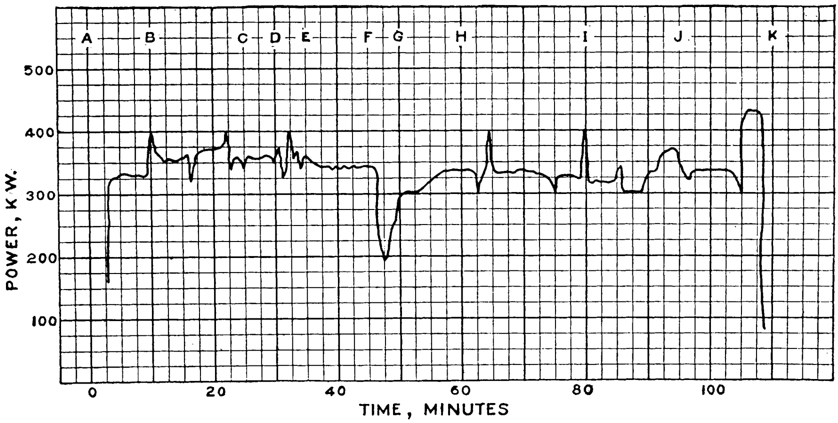

FIGURE 34.—Power fluctuations of 2.5-ton, single-phase, Girod steel furnace during a heat.

The size of the furnace, the duration of the intervals between successive heats, the cooling of the furnace during these intervals, the condition of the charge, the quality of steel desired, and other factors all affect the energy consumption decidedly.

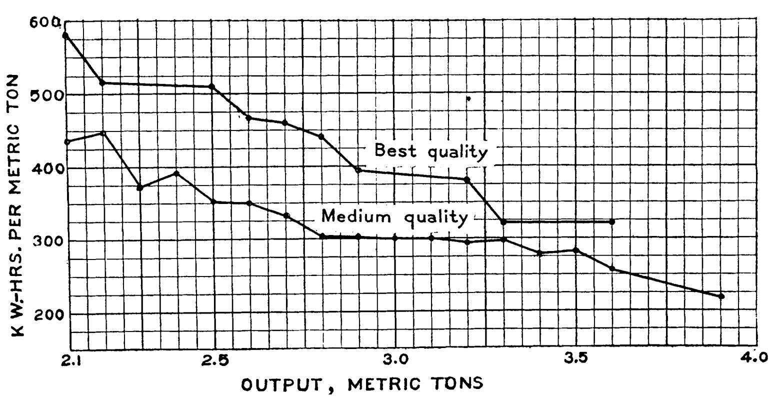

FIGURE 35.—Specific-energy consumption as function of weight of charge, Girod furnace.

Figure 35 shows the influence of the weight of charge on the specific-energy consumption per ton. The results are averages taken from 500 successive heats, including some of alloy steels. The energy consumption depends a great deal on the weight of the charge and decreases in large furnaces.

The loss of heat through radiation and conduction and the fluctuations of temperature decrease with increasing size of furnaces, the temperature being much more easily regulated in large furnaces than in small ones.

The minimum economical weight of charge is about 2,800 kg. (fig. 35), the specific-energy consumption not changing materially with increasing weight up to 3,300 kg.

The specific-energy consumption depends still more on the temperature of the furnace, and this depends greatly on the duration of the intervals between charges. The fall of temperature after tapping is rapid compared with that of an open-hearth furnace, the temperature of which decreases to only 1,000° C. in 25 hours and decreases after-

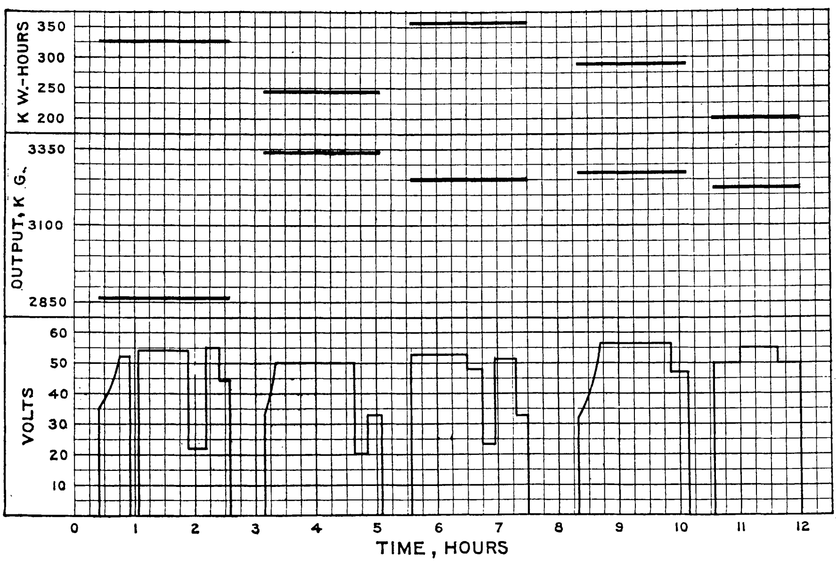

FIGURE 36.—Voltage, output, and power consumption for 2.5-ton, single-phase, Girod steel furnace.

wards at the rate of 20° C. per hour. Under such conditions it is possible to get a high thermal efficiency with the Girod furnace only by charging it, at the latest, 20 minutes after the last tapping. The temperature of the interior of the furnace is then still about 1,300° C. The energy consumption per ton is then 188 kilowatt-hours for medium-grade steels and 270 kilowatt-hours for high-grade steels (fig. 36).

Under favorable conditions it was possible in a Girod 3-ton furnace to refine 3,654 kg. (8,039 pounds) of steel with an energy consumption of 158 kilowatt-hours per ton, including refining by oxidation, deoxidation, and desulphurization. Large Girod furnaces give more favorable results, as they can be charged immediately after tapping, while they are at a temperature of 200° C. higher.

The silica brick roof of the furnace lasts for 60 to 70 heats. The walls are attacked most at the slag line. This is fettled between charges. After 120 heats it is necessary to reline the walls. The hearth bottom is also repaired then, as by that time it has sunk about 2 inches in the center. The hearth does not have to be pulled out when it is repaired.

The heat loss due to cooling of the bottom electrodes is 1.01 per cent of the energy consumption, and in producing 3.5 tons of steel the cooling of these electrodes consumes about 2.9 kilowatt-hours per ton of steel poured. The heat lost in cooling the silica roof around the carbon electrode is 3.65 per cent of the total energy supplied. With a production of 3.5 tons, 10.5 kilowatt-hours per ton would be lost in cooling the upper electrode.

PRODUCTS.

The analyses, tests, and uses for some of the products of this Girod furnace follow. Similar products can be made in any commercial electric steel furnace.

Analyses, tensile strength, and uses of various electric steels.

Va.	W.	Cr.	Ni.	C.	Mn.	P.	S.	Si.	Tensile strength.			Use.
									Weight per square millimeter.	Elongation on 200-millimeter bar.	Reduction of cross section.	
P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Kg.*	*P. ct.*	*P. ct.*	
......	......	......	......	0.13	0.54	Tr.	0.014	0.16	41.2	30	65.6	Angle.
......	......	......	......	.13	.70	0.018	.020	.08	43	31	62.3	Do.
......	......	......	......	.19	.56	Tr.	.010	.13	47	31	55	Do.
......	......	......	......	.22	.90	.010	.017	.25	58	27.5	52.8	Iron.
......	......	......	......	.25	.88	Tr.	.017	.26	60	23.5	49.1	I-beam.
......	......	......	......	.33	.74	.010	.010	.20	65	19	42	Engine and machine parts.
......	......	......	......	.64	.62	.010	Tr.	.47	86	13.2	23.5	Square blocks.
......	......	......	......	.53	.68	.008	.010	.37	86.9	12.8	30.3	Flat steel bars.
......	......	......	......	.57	.70	Tr.	.008	.40	89.4	10.7	21.4	Do.
......	......	......	......	.72	.42	.020	.010	.34	97.1	6	23.8	Dies.
......	......	......	......	.82	.48	.006	.010	.25	99.5	5.8	20.1	Punches.
......	......	......	......	.70	.72	.010	.010	.36	83.8	11.5	19.8	Tramway car-wheel tires.
......	......	......	......	.47	.78	.010	.012	.24	71.5	17.5	32.9	Railway car-wheel tires.
......	......	......	......	.36	.78	.013	.010	.17	64	19	40.7	Axles.
......	......	......	......	.48	.78	.007	.019	.28	74.4	13.3	24.9	Locomotive wheel tires.
......	......	......	......	.52	.78	.015	.018	.19	78.7	11.1	20.5	Do.
......	......	......	......	.48	.84	.007	.018	.23	72	17.7	44	Shafting.
......	......	......	......	......	......	......	......	......	72	16.5	45.2	Do.
......	......	......	1.89	.26	.78	Tr.	.012	.12	61.8	23.5	48.6	Spindles.
......	......	......	1.98	.20	.72	.012	.018	.13	54	22	58.6	Do.
......	......	1.04	......	1.02	.58	Tr.	.012	.16	......	......	......	Knives, shears, chisels.
......	1.50	.92	......	.49	.82	.012	Tr.	.32	79.7	15	40.4	Tools.
0.19	......	.85	......	.46	.60	Tr.	.012	.22	79.6	10.2	32.9	Pieces for forging.
......	......	......	......	......	......	......	......	......	62.1	33	59.5	Quenched at 700° C. in oil.
......	......	......	......	......	......	......	......	......	59.6	36	63.8	Quenched at 700° C. in water.
......	......	......	......	.68	.32	.010	.010	.23	93.3	9	18.8	Rolls for making grooved rail.

WORKS AT VOLKLINGEN, GERMANY.

Two Röchling-Rodenhauser furnaces at Volklingen, Germany, are in operation for the refining of molten basic Bessemer steel, with the production of steel varying in grade from rail steel to high-priced tool steel. At this plant the Röchling-Rodenhauser furnace was developed from the original Kjellin design.

One of the furnaces is of 8 to 10 tons capacity (fig. 27), taking 600 kw., supplied by a 25-cycle single-phase current at a voltage of 4,000 to 5,000 volts. The 2 to 3 ton three-phase furnace requires 200 to 250 kw. at a pressure of 400 volts on a 50-cycle circuit. The details of these furnaces have been previously described.

METHOD OF RELINING FURNACES.

In relining the furnaces the furnace castings are first protected by layers of fire brick, which serve as the principal protection against radiation losses and rarely require replacement. On the fire brick a layer of a mixture of calcined dolomite and tar is rammed to the level of the hearth bottom. Cast iron templates are then set and dolomite mixture is rammed behind them on the sides. After the templates are removed, the walls are finished with dolomite brick.

The lining is dried by placing cast-iron rings in the channels and heating the rings by the passage of current. When the tar in the mixture is burned out the roof is put on and molten pig iron is charged to complete the sintering of the hearth.

The time required for relining a 3-ton furnace is as follows: Removing old lining and ramming in new, 24 hours; burning out tar with hot rings, 6 hours; completing the sintering of the lining, 6 hours—total, 36 hours. During burning and sintering about 230 kilowatt-hours are consumed. Such a lining stands on the average 55 charges, or 360 to 500 tons of hot metal, according to the steel produced.

REFINING PRACTICE.

The molten metal charged into the furnaces at Volklingen from the basic Bessemer converters contains 0.1 per cent carbon, 0.5 per cent manganese, 0.08 per cent sulphur, and 0.08 per cent phosphorus. At times molten basic open-hearth steel that has been refined, containing about 1.22 per cent carbon, 0.38 per cent manganese, and 0.209 per cent silicon, is put in the electric furnace to allow removal of gases, to adjust the carbon content and to add alloys.

Dephosphorizing and desulphurizing are carried on as in the arc furnace, but not at so high a temperature, although the temperature is sufficient for the purpose, and is more evenly distributed through the charge. Also most of the desulphurizing is caused by the action of ferrosilicon and lime on ferrous sulphide, as the temperature is not high enough to permit the formation of calcium carbide. Hence more ferrosilicon is charged in the induction furnace than in the arc furnace.

The furnace is started cold, rings of steel are placed in the channels, and molten metal is poured on them. The voltage of the secondary current, through the pole plates, is higher than usual at the start in order to warm the hearth more quickly and make it conducting. Formerly it was customary to pass current through the furnace on Sunday to keep it hot, but now the doors are closed and the current is shut off entirely. After the furnace has stood 30 hours part of the current is turned on and the amount is gradually increased until in 4 to 6 hours the furnace is at working temperature. After each run the furnace is practically emptied. In using cold scrap about two-thirds of the charge is molten steel and the rest is cold scrap.

With hot metal the length of a heat varies from 1 hour 15 minutes to 3 hours. With a cold charge the time required is 3 to 6 hours. To produce a rail steel containing 0.5 per cent carbon, 0.8 per cent manganese, 0.04 per cent sulphur, and 0.05 per cent phosphorus, about 100 to 125 kilowatt-hours per ton are necessary with a hot charge of Bessemer metal. For high-grade steel containing 0.05 per cent carbon, 0.25 per cent manganese, and trace of sulphur and phosphorus, the power consumption is about 300 kilowatt-hours per ton. The power factor averages about 0.60 with both the single and the 3-phase furnaces. With cold scrap the power consumption is claimed to be 580 kilowatt-hours per ton. The power cost at Volklingen is about 1.5 cents per kilowatt-hour.

PRODUCTS.

Steel of many grades has been made at Volklingen in the induction furnace, including high-grade tool, alloy, and rail steels. Some of the mild-steel products and the power consumption are as follows:

Mild-steel products of Röchling-Rodenhauser furnace.

	C.	Si.	Mn.	P.	S.	Time.		Power consumption per ton.	Total energy consumed.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Hours.*	*Minutes.*	*Kw.-hrs.*	*Kw.*
Charged		0.028	0.534	0.037	0.081	1			
Poured		.022	.307	.005	.057		50	250	628
Charged		.034	.478	.060	.077	2			
Poured		.018	.309	.011	.053		25	274	685
Charged	0.128	.032	.590	.064	.085	1			
Poured		.140	.618	.020	.065		45	235	587
Charged	.116	.018	.679	.054	.097	2			
Poured		.122	.695	.028	.098		5	282	705

PLANT OF LA GALLAIS METZ & CO., DOMMELDINGEN, LUXEMBURG.

At Dommeldingen, Luxemburg, is the largest installation of Röchling-Rodenhauser furnaces in operation. There are three single-phase 3½-ton furnaces, similar to the one shown in figure 27, and one three-phase 2.5-ton furnace. The single-phase furnaces take 350 to 400 kw. at 3,500 volts, 50 cycles. The three-phase furnace requires 275 kw. at 500 volts, 50 cycles. The power factor of the single-phase furnace averages about 0.6, and that of the three-phase furnace is sometimes as high as 0.7.

Pig iron is made into steel in a gas-heated 20-ton tilting furnace. When 3.5 tons of the steel is transferred to an electric furnace for further refining it is replaced by 3.5 tons of pig iron. The gas furnace acts as an oxidizing mixer. The steel in the gas furnace has 0.26 per cent carbon, 0.082 per cent phosphorus, and 0.03 per cent sulphur. For ordinary castings the steel is in the electric furnace about 2 hours, for the best machinery castings 3 to 3½ hours.

The three-phase furnace was not in use at time of inspection, as faulty design had resulted in poor operation.

Some of the results obtained in practice at Dommeldingen were as follows:

Results obtained from furnace practice at Dommeldingen.

Sample.	Chromium content.	C, Si, Mn, P, and S content.				
		Carbon.	Silicon.	Manganese.	Phosphorus.	Sulphur.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Pig iron	....	3.50	0.60	1.20	1.80	0.12
Mixture from gas furnace	....	1.62	....	.66	.46	.035
Tappings from gas furnace	....	.26	....	.30	.08	.030
Steel from electric furnace	....	.35	....	....	....	....
Castings	....	.40	.25	.50	.020	.010
Hard fine steel	....	.85	.23	.26	.011	.009
Chrome steel	0.87	1.17	.19	.16	.014	.009

CHARACTERISTICS OF OPERATION OF ELECTRIC STEEL FURNACES.

DESIGN.

From what has been said it is clear that electric steel furnaces vary widely in design, but they may be divided into two general classes, arc furnaces and induction furnaces. The general features of the operation of the furnaces in a class are similar. Steel of about the same grade can be made in any of the commercial electric furnaces, but from their design some furnaces are better adapted to one purpose than to another. In general the power consumption and efficiencies of the various types are about the same. Hence the choice of the type of furnace for a specific purpose should be determined by the factors of the individual case.

Several general points should be considered in choosing the type of furnace. In comparing the arc and the induction furnace it should be remembered that the arc furnace is better adapted to melting cold scrap than is the induction furnace, because the latter must be charged with molten metal at the start to insure quick and regular heats. The power factor of the induction furnace is lower than that of the arc furnace and is much lower than that of most public power service lines. Hence, an induction furnace that might be a satisfactory load on a private plant carrying no other load, on a public line might lower the power factor of the whole system to an objectionable degree. If an induction furnace is built where power must be obtained from a public service line, the company operating the furnace may be required to put in a motor-generator set at its own expense. In general, the induction furnace makes a more steady demand on the central power plant than the arc furnace, because there is no constant breaking of the arc which may cause fluctuations.

In choosing an arc furnace for refining cold scrap it seems that the load on the power line is more satisfactory, if the furnace is of the conducting-hearth type with several upper electrodes in parallel rather than of the type with two arcs in series with the bath. This is because the arc breaks less frequently in the former than in the latter. For continuous steady operation on either cold scrap or molten steel, one furnace is probably about as good as the other as regards mechanical features, power consumption, and heat losses, although some consider the water-cooled electrodes of the conducting hearth and broken hearth to be objectionable. An arc furnace in which heating is by radiation of the arc has a higher power consumption than the other types. Electrode consumption and repair cost are also higher.

POWER CONSUMPTION.

The power consumption of furnaces depends so much upon the materials being treated, the process of operation, and the product desired that no satisfactory comparisons can be made. Also, the point in the circuit at which the reading is taken for figuring the basis of power consumption may be so variously selected that one furnace may show a much lower power consumption than the other when it should show about the same. With cold scrap the power consumption of the various arc furnaces varies from 459 to 1,200 kilowatt-hours per ton. Aside from the points mentioned, this wide variety of results may be due to the amount of refining done. Furnaces in which only one refining slag is used take about 600 kilowatt-hours per ton on an average, while if two slags are used 800 to 1,000 kilowatt-hours per ton are necessary. Power consumption per ton of metal is also influenced by the size of the furnace. For example, a 10 to 12 ton Girod furnace uses about 12 per cent less power per ton than a 2.5 to 3 ton furnace of the same type.

In refining molten steel in the electric furnace, the power consumption has varied from 100 to 300 kilowatt-hours per ton. Rail steel of this class takes about 100 kilowatt-hours per ton when one slag only is necessary and about 200 kilowatt-hours per ton with two slags in a 15-ton furnace. Tool steel is made from molten metal in a 2 to 3 ton furnace with a power consumption of 150 to 300 kilowatt-hours per ton.

POWER FACTOR.

The power factor is the ratio of the number of effective watts in an alternating-current circuit to the number of volts multiplied by the number of amperes. Any self-induction in the circuit causes a difference in phase between the electromotive force or voltage and the current or amperage, and the current will thus lead or lag behind the voltage; that is, the two do not reach their maxima at the same moment. An amount of energy equal to the number of amperes multiplied by the number of volts is surging through the circuit, but, as the electromotive force and current do not reach their maxima together, the product does not represent the effective energy that is usefully consumed at the receiving end.

The generators have to supply the total wattage and the line has to conduct it. Hence to offset a low power factor large generators and thick conductors must be used. For example, a power factor of 0.5, or 50 per cent, means that conductors of double size must be used to get the same number of effective watts as with a power factor of 1, and it also means that generators of double capacity must be used to produce the same useful output. In such a case there would still be objection raised by the power company, for the voltage regulation of the line and generators would be poor, and the low power factor would act as a brake on the circuit, throwing back on it all power not effectively used and causing the generating machinery to heat. If the company using a furnace with a low power factor generates its own power, it must consider the increased capital investment on account of larger generating capacity.

If the ordinary loads of a central power station are considered, an operating power factor above 0.95 will be obtained only when practically all of the load consists of synchronous motors or rotary converters that may be operated with a power factor of about 1. The power factor for a plant having a large proportion of induction motors is about 0.70. Hence in operating several electric furnaces the necessity of keeping the power factor of the single unit as much above 0.80 as possible is evident or the power factor of the whole plant may drop below 0.70.

Without discussing the causes in furnace design that influence the power factor, it may be said that there are three ways of reducing the trouble. One is to reduce the frequency of the alternating current, but, although this should be considered when a new plant is to be erected, in an established works such a change means new electrical machinery of special design and higher cost. A more practical way is to increase the resistance of the furnace, which results in a higher working voltage and a higher power factor. The third method is to decrease the quantity of iron surrounding the brickwork of the furnace as much as possible, as this iron causes the formation of lines of force that tend to lower the power factor. Tie-rods and buck staves may be made of nonmagnetic special steel, or a strip of copper may be inserted to break the continuity of the iron surrounding the circuit.

The effect of frequency has been mentioned. It is for this reason that most electric steel furnaces are operated with a current having a frequency of 25 cycles rather than with the 60-cycle current ordinarily used in commercial practice. Up to the time of the design of the combination induction furnace the great drawback to the induction furnace as originally built was the necessity of using a current with a frequency as low as 5 to 15 cycles in order to obtain a power factor over 0.5. With the combination induction furnace a power factor of 0.6 can be obtained with a frequency of 25 cycles.

The power factor of a furnace decreases if the size is increased and the voltage and frequency remain the same. For instance, the power factor of a 25-ton single-phase Héroult furnace varies from 0.85 to 0.95 with a current frequency of 25 cycles and a voltage of 110 volts, whereas in a 15-ton three-phase furnace the power factor is 0.70 to 0.80 with a current frequency of 25 cycles and a voltage of 90 volts.

The power factor of the combination induction furnace varies from 0.60 in an 8 to 10 ton furnace, single-phase, frequency 25 cycles, to 0.70 in the 3-ton furnace, three-phase, frequency either 25 or 50 cycles. The power factor of the 1.5-ton induction furnace is about 0.5, using a current with a frequency of 15 cycles. The power factor of induction furnaces, owing to the large proportion of iron used, decreases rapidly with increase in size, so that it would seem that this might prevent an increase in size over 8 to 12 tons.

In general the arc furnace with the conducting hearth tends to have a slightly lower power factor than the arc furnace with the upper electrodes in series and a nonconducting hearth. The power factor of all designs of commercial electric steel furnaces of the arc type is above 0.70 for the sizes over 5 tons, and above 0.80 for the smaller sizes.

ELECTRODES.

With improved methods of making amorphous-carbon electrodes the electrode consumption of electric steel furnaces has been considerably reduced. The manufacture of electrodes with threads for continuous feeding has reduced the stumpage loss, which was formerly as much as 50 per cent in some cases, and the electrodes are now much more uniform in character. Threaded amorphous carbon electrodes of foreign manufacture sell for about 2 to 3 cents per pound f. o. b. at the maker's plant. Domestic electrodes sell at about the same price but are not made threaded for continuous feeding. The use of graphite electrodes for steel furnaces is not economical because of the high cost per pound and because the consumption per ton of steel produced is almost as large as that of amorphous-carbon electrodes. The manufacturers of graphite electrodes claim that the gain in electrical conductivity offsets the higher cost, although the losses by heat conductivity would be greater unless the graphite electrodes were carefully designed.

For melting and refining cold scrap the consumption of amorphous-carbon electrodes varies from 15 to 50 pounds per ton. The consumption seems to be considerably higher in furnaces of the nonconducting-hearth type with two electrodes than in the conducting-hearth type with one electrode. The difference is probably due to the additional electrode, for in conducting-hearth furnaces of larger size having two to four electrodes the consumption per ton is greater than in the single-electrode furnace. In furnaces used for refining molten steel the wear on the electrodes is not as great and the consumption is much lower, being 6 to 12 pounds per ton.

THE LINING.

The rate of wear of the lining varies so much that it is almost impossible to state general figures. The furnace bottom will last 200 to 400 heats on cold charges and indefinitely on hot metal. The sides are repaired about every 100 heats but are not completely torn out. In most furnaces the hearth has a dolomite bottom and magnesite brick on the sides. The roof is generally silica brick, and, in an arc furnace, lasts 40 to 120 heats. In the arc furnaces operating under the best conditions the roof lasts about 70 heats. In furnaces with magnesite hearth, sides, and roof the lining cost per ton of metal is high. In some of the more recent furnaces the lining on the sides is about half as thick as that formerly used. The thinner lining increases the capacity and does not seem to affect the conduction losses enough to increase decidedly the power cost per ton of output. The hearth lining of an induction furnace lasts about 55 heats and the roof an indefinite period.

ESSENTIAL FEATURES OF REFINING IN AN ELECTRIC FURNACE.

The general process of refining steel in the electric furnace, as has been stated, comprises oxidation, followed by reduction or deoxidation. Owing to the nature of the heat supply, it is possible to have the atmosphere oxidizing, reducing, or neutral. This is not possible in the open-hearth furnace owing to the gases introduced for heating.

The function of slags[a] in refining steel in electric furnaces is somewhat different from that in refining in open-hearth furnaces. First, all oxygen introduced into the electric furnace must be in the solid form, whereas the open hearth has an unlimited supply in the air admitted. Oxidation can be conducted in an ordinary open-hearth furnace as in an electric furnace, except that the higher temperature of the latter hastens the melt. Deoxidation in which carbon is the chief agent can be performed only in the electric furnace.

During the oxidizing period sulphur is removed only to a small degree in the open-hearth furnace but much more efficiently in the electric furnace, especially when manganese ore is used. It is likely that part of the sulphur forms sulphur dioxide and passes off with the gases. The phosphorus is eliminated in the oxidizing period, just as in the open-hearth furnace.

Sulphur is removed in four ways: (1) As calcium sulphide, formed by the action of lime and carbon on ferrous sulphide at the high temperature of the arc furnace; (2) as calcium sulphide from the reaction of lime, ferrous sulphide, and calcium carbide at the higher temperatures of the arc furnace; (3) as calcium sulphide through the reaction of lime, ferrous sulphide, and silicon at the lower slag temperatures of the induction furnace; and (4) as iron sulphide from the action of ferrous oxide on calcium sulphide. The chemical reactions are as follows:

(1) $FeS+CaO+C=Fe+CaS+CO$.

(2) $3\ FeS+2\ CaO+CaC_2=3\ Fe+3\ CaS+2\ CO$.

(3) $2\ FeS+2\ CaO+Si=2\ Fe+2\ CaS+SiO_2$.

(4) $CaS+FeO=FeS+CaO$.

The final reaction is reversible, acting from left to right in an atmosphere even slightly oxidizing, whereas the action is from right to left in the first three reactions.

From the equations it may be seen that in both the induction and the arc furnace the formation of a highly basic slag is essential, but desulphurization in the former, owing to its lower temperature, is brought about chiefly by the reducing action of silicon upon the oxides, whereas in the latter the reducing agent is carbon at a higher temperature.

[a] Ambery, R., Slags in electric steel refining: Metall. Chem. Eng., vol. 10, 1912, p. 601.

In the arc furnace complete deoxidation is recognized by the presence of calcium carbide in the slag. When deoxidation of the bath is complete the contents of the electric furnace represent the nearest approach to ideal equilibrium between different chemical compounds that has ever been accomplished in large metallurgical operations. In the converter and the open hearth the metals are under the action of air and gas, in the crucible the metal takes up carbon and silicon, whereas in the electric furnace the action of the metal on the basic lining is very slight and there is no exchange of elements between metal and slag, except that if the dephosphorizing slag of the oxidizing period has not been completely removed before deoxidization begins some of the phosphorus in this slag and some in the new slag will be reduced. This last point must be carefully watched in all refining in the electric furnace.

Although the induction furnace can not attain the high temperature necessary for desulphurizing by use of calcium carbide as can arc furnaces, the results obtained in refining practice are about equal.

COST OF PRODUCING STEEL IN THE ELECTRIC FURNACE.

The cost of making steel in the electric furnace varies with local conditions. The cost of power does not enter so largely into the final cost as it does in some other electrometallurgical processes, especially the refining of molten steel. Plants are operating successfully under a power cost of 1 cent per kilowatt-hour in localities where material can be obtained at the price common to other processes. Plants such as the one at Ugine, France, have been established in remote localities, where the cost of power is very low, 0.2 cent per kilowatt-hour, but the cost of material is high.

COST OF PRODUCING STEEL IN THE GIROD FURNACE.

Girod[a] estimated in 1912 the cost of producing steel from cold scrap in the Girod furnace at Ugine as follows:

Cost of refining steel from cold scrap in Girod furnace at Ugine.

Item.	2.5 to 3 ton furnace.		10 to 12 ton furnace.	
Raw materials:				
Scrap, 1,100 kg., at $15 per ton	$16.50		$16.50	
Slag	.46		.46	
Deoxidizing and recarburizing additions	.70		.70	
Producing cost:		$17.66		$17.66
Electric power, 850 and 750 kilowatt-hours, at 0.2 cent per kilowatt-hour	3.40		3.00	
Electrodes, at $64 per ton	.60		.70	
Wages	.60		.30	
Maintenance and repairs	2.40		1.60	
		7.00		5.60
Total cost per ton of steel		24.66		23.26

[a] Girod, P., The electric steel furnace in foundry practice: Metall. Chem. Eng., vol 10, 1912, p. 663.

Girod estimated the cost of producing steel from molten steel at the same plant as follows:

Cost of refining steel from molten charge in Girod furnace at Ugine.

Item.	2.5 to 3 ton furnace.		10 to 12 ton furnace.	
Raw materials:				
Liquid steel, 4 per cent loss in heating, 1,040 kg., at $16 per ton	$16.64		$16.64	
Slags	.40		.40	
Deoxidizing additions	.70		.70	
		$17.75		$17.75
Producing cost:				
Electric power, 275 and 300 kilowatt-hours, at 0.2 cent per kilowatt-hour	1.10		.80	
Electrodes, at $64 per ton	.25		.25	
Wages, 8 heats per 24 hours	.20		.20	
Maintenance and repairs	.80		.50	
		2.35		1.75
Total cost per ton of steel		20.09		19.49

The estimates of Girod do not include expense for ingots, molds, superintendence, laboratory, amortization, general charges, or royalty charge. These figures apply only to conditions such as prevail at Ugine, where power is very cheap and the cost of material is high.

COST OF PRODUCING STEEL IN THE GRÖNWALL FURNACE, SHEFFIELD, ENGLAND.

The Electro-Metals Co., owners of the Grönwall patents, estimated the cost of production in 1912 for a 2-ton Grönwall furnace operating at Sheffield, England, as follows:

Cost of refining steel from molten charge, Grönwall furnace.

Item.	Without dephosphorizing.		With dephosphorizing.	
Number of charges per week	40		30	
Tons per week	80		60	
Cost per ton of steel:				
Power at 0.5 cent per kilowatt-hour		$1.00		$1.25
Repair of roof		.16		.20
Dolomite (100 pounds per charge)		.17		.17
Electrodes, at 4 cents per pound		.18		.22
Sundries		.14		.16
Royalty		1.50		1.50
		3.15		3.50

The items of labor, amortization, interest, raw materials, and general charges are omitted from the estimate given above. The figures refer to the production of steel with a sulphur and a phosphorus content below 0.02 per cent.

COST OF PRODUCING STEEL IN RÖCHLING-RODENHAUSER FURNACES.

Kjellin[a] in 1909 estimated the cost of production of high-grade steel for castings at Volklingen, Germany. The cost under German

[a] Kjellin, F. A., Induction and combination furnaces: Trans. Am. Electrochem. Soc., vol. 15, 1909, p. 172.

conditions with a 7-ton, three-phase Röchling-Rodenhauser furnace, using fluid basic Bessemer steel made at Volklingen, is estimated by Kjellin[a] as follows:

Cost of producing steel for castings in a 3-phase Röchling-Rodenhauser furnace, from molten metal.

	Cost per ton of steel.
Lining:	
Raw materials	$0.304
Wages	.043
Heating up furnace:	
2,000 kilowatt-hours at 2.17 cents for 160 tons	.272
Refining:	
300 kilowatt-hours per ton at 2.17 cents per kilowatt-hour	6.52
Wages	.425
Materials:	
Mill scale, 20 kg	.082
Lime, 30 kg	.087
Ferrosilicon, 6.5 kg	.485
Ferromanganese, 4 kg	.214
Power for cooling arrangements	.196
Repairs	.194
Total	8.822

To this must be added interest and the depreciation of the plant. Assuming 5 per cent interest and 10 per cent depreciation on $13,380, the approximate cost of the plant, gives $2,000 per year, which for 300 working days would give 41.2 cents per ton, so that the conversion of the fluid product from the basic converter into steel that can replace crucible steel for steel castings will cost $9.23 per ton exclusive of the cost of the molten steel charged. This cost is figured on a basis of three men operating the furnace.

Cost of producing rail steel in a 3-phase Röchling-Rodenhauser furnace, from fluid steel.

	Cost per ton of product.
Raw materials, steel at $15.54 per ton, and all fluxes	$16.56
Power at 0.58 cent per kilowatt-hour:	
Heating up	.02
Refining	.72
Wages:	
For furnace	.16
For lining	.008
Lining materials	.072
Tools	.097
Repairs	.194
Amortization and interest	.168
Licenses	.582
Total	18.62

This estimate includes all items. If the cost of molten steel be disregarded, the refining cost, with power at 0.58 cent per kilowatt-hour, will be $3.08 per ton.

[a] Loc. cit.

The cost of making casting steel of the composition given on page 105, from cold scrap in the Röchling-Rodenhauser furnace, at Lansdown, Pa., is estimated by the Crucible Steel Casting Co.,[a] as follows:

Cost of producing steel from cold scrap in the Röchling-Rodenhauser Furnace at Lansdowne, Pa.

	Cost per long ton of product.	
Scrap	$14.50	
Oxidation loss, about 2 per cent	.29	
		$14.79
Power, 844 kilowatt-hours at 0.7 cent per kilowatt-hour	5.91	
Fluxes	.76	
Ore	.05	
Labor	1.50	
Tools, repairs, and bottom	.76	
Air-cooling transformers	.12	
Conversion cost		9.10
Interest, 5 per cent; depreciation, 10 per cent per ton		1.50
Cost of 1 gross ton (2,240 pounds) electric steel ready to pour		25.39

PROPERTIES OF ELECTRIC-FURNACE STEEL.

For many years all high-grade steels were manufactured by the crucible process, but since the advent of the electric furnace there has been a gradual adoption of that furnace for refining steel. For the complete refining of the highest grades of steel the use of the electric furnace is now thoroughly established in Europe. Any product that can be made by the crucible process can be made by the electric furnace, and in most cases with cheaper raw materials and at a lower cost. In the electric furnace complex alloy steels can be made with precision. The high temperatures attainable facilitate the reactions and alloys need not be used so largely for the purpose of removing gas. Very low carbon steels can be kept fluid at the high temperatures. Steels free from impurities and of great value for electrical apparatus can be made. With the electric furnace large castings can be made from one furnace, whereas in the crucible process steel from several crucibles must be used. For small castings, which require a very high grade metal free from slags and oxides, electrically refined steel is especially adapted. The electric furnace gives a metal of low or high carbon content as desired, hot enough to pour into thin molds and still free from slags and gases.

There is now a tendency among consumers of rail and structural steel to require a higher-grade steel at an increased price rather than steel of acid Bessemer or even of basic open-hearth grade at a lower price. With the high cost of power that now prevails throughout the steel centers of the United States the electric furnace can not

[a] Von Baur, C. H., "The Röchling-Rodenhauser furnace of the Crucible Steel Casting Co., Lansdowne, Pa.: Metall. Chem. Eng., vol. 11, 1913, p. 113.

compete profitably with either the acid Bessemer or the basic open-hearth process in manufacturing steel of like grade from pig iron. It is in combination with either of these processes that the electric furnace seems destined to be prominent in steel manufacture. The cost of superrefining in the electric furnace the molten steel from either of these processes, exclusive of the cost of the molten steel, varies from $1.50 to $2.25 per ton, depending on the cost of power and the impurities to be removed.

Experiments conducted by the United States Steel Corporation[a] during the past four years show that, as compared with the acid Bessemer and basic open-hearth processes, the electric process has the following advantages: A more complete removal of oxygen; the absence of oxides caused by the addition of silicon, manganese, etc.; the production of steel ingots of 8 tons weight and smaller that are practically free from segregation; reduction of the sulphur content to 0.005 per cent if desired; reduction of the phosphorus content to 0.005 per cent, as in the basic open-hearth process, but with complete removal of oxygen.

Acid Bessemer steel has been refined in the basic electric furnace, yielding steel of the following composition: Carbon, 0.55 per cent; manganese, 0.137 per cent; silicon, 0.13 per cent; sulphur, 0.017 per cent; and phosphorus, 0.022 per cent. Rails made from this steel are comparatively soft, but show less wear than Bessemer rails in the same track and subjected to the same service. About 5,600 tons of standard electric steel rails from electric-furnace steel have been in service in the United States for the past two years. These rails have been subjected to all sorts of weather and to temperatures as low as —52° F. It seems that rails made by the basic electric process can be made softer than by either the acid Bessemer or basic open-hearth processes and yet show highly satisfactory wearing qualities.

No steel rails made by the basic electric process in service in this country have yet broken. Electric-furnace steel of a given tensile strength has a slightly greater elongation than basic open-hearth steel and is somewhat denser than basic open-hearth or acid Bessemer steel.

Below are given the averages of some comparative tests of rails from steel made in a Röchling-Rodenhauser furnace and Bessemer rails. The tests were made at Volklingen, Germany, for the Prussian State Railway.

[a] Clark, E. B., Various types and applications of electric steel furnaces: Metall. Chem. Eng., vol. 10, 1912, p. 373.

Comparison of steel rails made in Röchling-Rodenhauser furnace with basic Bessemer steel rails.

Kind of steel.	Carbon.	Silicon.	Manganese.	Phosphorus.	Sulphur.	Tensile strength per square inch.	Elongation.	Contraction.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Pounds.*	*Per cent.*	*Per cent.*
Electric	0.54	0.21	0.984	0.056	0.042	119,000	15.4	24.1
Bessemer	.36	....	1.127	.073	....	97,000	17.6	26.2

The results of some comparative tests, made at South Chicago, of electric-furnace steel for plates and basic open-hearth steel for plates were as follows:

Average ultimate strength and elongation of electric and open-hearth plate steels.[a]

Electric.			Open-hearth.		
Carbon content.	Ultimate strength per square inch.	Elongation on 2 inches.	Carbon content.	Ultimate strength per square inch.	Elongation on 2 inches.
Per cent.	*Pounds.*	*Per cent.*	*Per cent.*	*Pounds.*	*Per cent.*
0.08	59,194	27.25	0.08	51,690	32.00
.12	64,080	26.05	.12	56,510	29.70
.16	69,220	25.25	.16	52,901	28.61
.20	72,853	22.82	.20	58,294	28.82
.24	69,540	23.12	.24	63,560	26.25

[a] Osborne, G. C., The 15-ton Héroult furnace at the South Chicago works of the Illinois Steel Co.: Trans. Am. Electrochem. Soc., vol. 19, 1911, p. 221.

The results show a 15.5 per cent increase in ultimate strength and 11.3 per cent decrease in elongation for electric steel, as compared with open-hearth plate steel of approximately the same chemical composition.

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SUGGESTIONS FOR A DUPLEX PROCESS FOR MAKING STEEL.

Inasmuch as greater capacity and efficiency can probably be obtained by working an open-hearth furnace and an electric furnace in conjunction, the following description and the costs of working a 5-ton tilting basic open-hearth furnace and a 2½-ton electric furnace in this manner, as obtained from data furnished by Electro-Metals, Ltd., of London, England, are submitted here.

Although a 5-ton open-hearth furnace is rather small for keeping a 2½-ton electric furnace working at full capacity, yet the following method of procedure would give the maximum efficiency with the given plant, and serves to illustrate the point.

The open-hearth furnace should be charged at the beginning of the week, say at 12 p. m. Sunday. The charge under the special circumstances will consist of 4 tons of scrap and 1½ tons of pig iron, with the usual fluxes. This being the first charge, it will probably be ready to tap into the electric furnace at 6 a. m. Previous to this time the electric furnace has been heated with coke and with current and is ready to take a charge of hot metal.

At 6 a. m. 2½ tons of partly refined metal are drawn from the open-hearth furnace and put in the electric furnace. The open-hearth furnace is then recharged by putting pig and scrap on the banks and slopes of the furnace and allowing the cold material to come to almost a fusing temperature. Then, when the new material is hot enough it should be pushed into the bath and worked in the usual manner. The metal should be fit to tap in three to four hours.

Meanwhile it has taken about one hour to heat the crude fluid metal and to dephosphorize it, two hours more being taken to desulphurize the charge, so that by 9 a. m. it would be ready to tap, and by 9.15 the electric furnace would be ready to take another charge.

It is quite possible that the open-hearth furnace may not be ready for another hour or more. If this be the case, about 1 ton of cold scrap may be charged into the electric furnace and melted, by which time the open-hearth furnace will be ready to tap. This time it will be necessary to tap only 1½ tons of metal into the electric furnace. Owing to the small recharge in the open-hearth furnace the charge will be completely melted and perhaps partly refined by the time the electric furnace has finished its work. The electric furnace then being ready again at, say, 12.30, a 2½-ton charge of very hot refined metal will be tapped into it immediately, with no waste of time.

This method of assisting the open-hearth furnace can be carried out when necessary; perhaps at every alternate charge. One will see that the process presents these advantages:

The ton of scrap melted in the electric furnace will not need any pig iron to accompany it, as would be the case in the open-hearth furnace. That means that one-fourth ton of pig iron at $45 per ton is replaced by one-fourth ton of scrap at $5 per ton. Here is a clear saving of $10, which will pay for melting the ton of metal in the electric furnace many times over.

Although an "assisted" charge will take, say, 3½ hours to work, the resulting gain of time for the open-hearth furnace will reduce the time of the succeeding electric-furnace charge to less than 2½ hours and may even eliminate the dephosphorizing period in the electric furnace and thus reduce the time taken there to 2 hours.

The output by this method will be as follows:

One charge of 2½ tons could be run every 3½ hours, making 7 charges in 24 hours, or 42 casts per week of 6 days. This makes a weekly production of 105 tons, or a yearly production of 5,040 tons, allowing 48 weeks per year.

The cost of the process would be as follows:

Cost of producing steel by duplex process.

	Cost per ton.
Average power consumption, 420 kilowatt-hours, at 1.3 cents per kilowatt-hour	$5.46
Electrodes	.56
Slags	.62
Repairs to roof and lining	.66
Labor, 3 men each shift	.87
	8.17

It should be noted that there is a saving of $2 on every ton passing through the electric furnace by this method, owing to the use of scrap instead of pig iron.

DUPLEX PROCESS FOR LARGER FURNACE.

If the capacity of the open-hearth furnace be increased from 5 tons to, say, 7½ tons, then it may be found that the following method of increasing the output can be employed.

The open-hearth furnace should be charged with, say, 8 tons of scrap and pig iron. The phosphorus is then reduced to the proper limit, after which a 2½-ton charge can be transferred to the electric furnace for completion of the process. The electric furnace will be ready again in 2 hours for another charge.

It should be quite possible to recharge the open-hearth furnace and have the bath dephosphorized again by the time the charge in the electric furnace is finished. In this way a charge should be ready every 2 to 2½ hours.

The output will be as follows:

One charge of 2 tons could be run every 2 hours, making 12 charges in 24 hours, or 72 casts per week of 6 days. Therefore 130 to 140 tons would be produced in one week, or 6,200 to 6,700 tons in a year, allowing 48 working weeks to a year.

The cost of producing steel by this method would be as follows:

Cost of producing steel in duplex process, using 7½-ton furnace.

	Per ton of product.
Power consumption, 300 kilowatt-hours per ton, at 1.3 cent per kilowatt-hour	$3.90
Electrodes	.50
Slags	.37
Repairs to roof and lining	.56
Labor, 3 men each shift	.75
	6.08

COST OF OPERATING AN ELECTRIC FURNACE ALONE.

For comparison with the foregoing schemes, the following figures for making steel in the electric furnace alone are given:

In a 2½-ton electric furnace 1 cast can be made in 6 hours, or 4 casts in a day, making an output of 24 casts, or 60 tons per week. On a basis of 48 working weeks in a year, the yearly output will be 48 times 60, or 2,880 tons.

The cost of producing steel in the simple electric process would be as follows:

Cost of producing steel in 2½-ton electric furnace.

	Cost per ton.
Power, 950 kilowatt-hours per ton, at 1.3 cents per kilowatt-hour	$12.35
Electrodes	.87
Slags	.62
Repairs, roof, lining, and dolomite	.87
Labor, 3 men per shift	1.50
	16.21

Although the cost of operation is greater than that of the open-hearth, the cost per ton of the metal charged in the electric furnace is much less than that used in the open-hearth furnace, and this saving in cost should more than counterbalance the extra cost of working the electric furnace, not to mention the increased quality of the product.

A 5-ton electric furnace used for melting and refining would turn out 1 charge of 5 tons in 6 hours, or 4 casts in 24 hours. Twenty-four casts of 5 tons each, or 120 tons, would be produced in one week of six working days. The yearly production would be 5,760 tons, allowing 48 working weeks to a year.

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