BULLETIN No. 3

RECENT ADVANCES

IN THE

CONSTRUCTION OF ELECTRIC FURNACES

FOR THE

PRODUCTION OF PIG IRON, STEEL, AND ZINC

BY

EUGENE HAANEL, Ph.D.

Director of Mines.

BULLETIN No. 3

RECENT ADVANCES

IN THE

CONSTRUCTION OF ELECTRIC FURNACES

FOR THE

PRODUCTION OF PIG IRON, STEEL, AND ZINC

BY

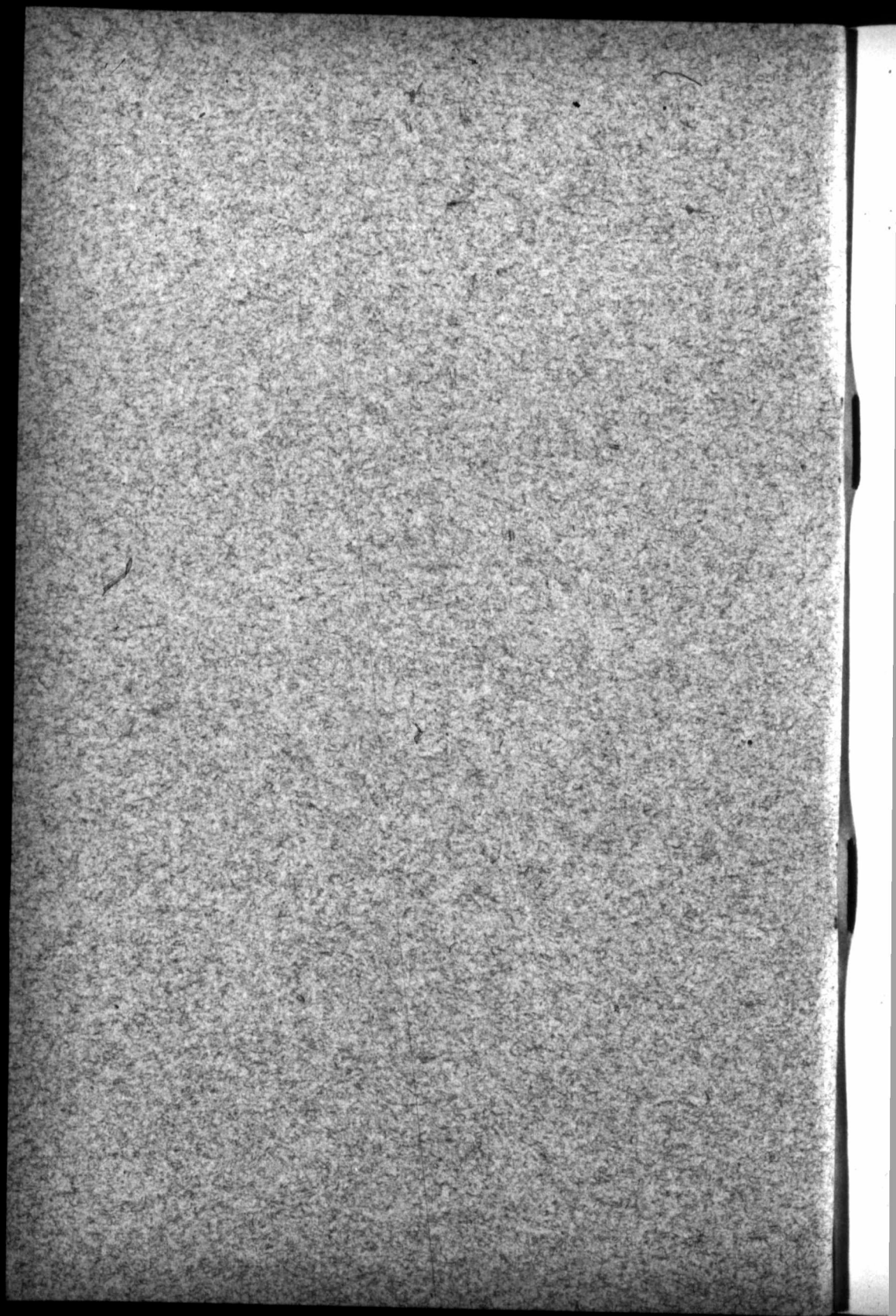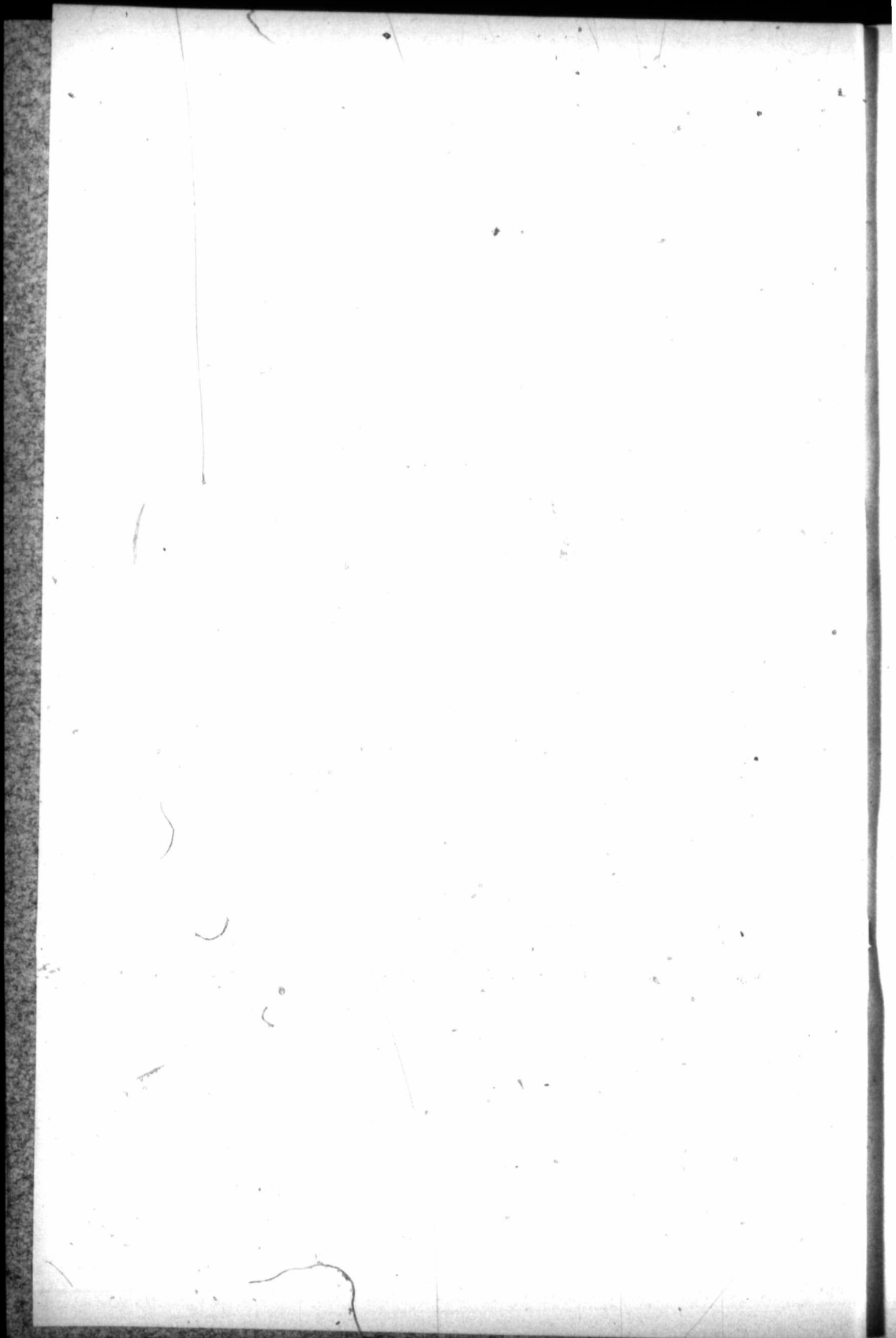## EUGENE HAANEL, Ph.D.

Director of Mines.

3146—1

No. 68

CONTENTS.

ILLUSTRATIONS.

Photograph.

Drawings.

3146—1½

RECENT ADVANCES

CONSTRUCTION OF ELECTRIC FURNACES

FOR THE

PRODUCTION OF PIG IRON, STEEL, AND ZINC

INTRODUCTORY

BY

EUGENE HAANEL, Ph.D.

Director of Mines.

I.

Steel Furnaces.

The extraordinary rapidity with which the development and perfection of electric furnaces for the production of steel has taken place since the publication of the Dominion Government 'Report of the Commission appointed to investigate the different electro-thermic processes for the smelting of iron ores, and the making of steel, in operation in Europe, in 1904,' will be manifest when it is stated that, only four electric furnaces of comparatively small capacity were then in existence in Europe; whereas in 1910—six years later—there are 67 in operation, 11 not working, and 36 in course of erection. The well-known technical journal, *Stahl und Eisen*, March 23, 1910, gives the following tabulated list of furnaces now working, or being installed:—

Present Status of the Electric Steel Industry.

(A) ARC FURNACES.

Number	Company	Working.	Not working.	Building.	Current.	Kilowatts.	Method of charging.	Application of product.
		Capacity in Kilograms.						
	Heroult System—*							
1	Stahlwerk, Richard Lindenberg, A. G., Remscheid-Hasten, Germany........	1,800	......	......	Single-phase alternating current.	400	Molten metal from O.H. furnace, also cold charge.	Tool steel, structural steel, war materials.
2	" "	3,000	......	......	"	520	"	
3	Bismarckhütte, Upper Silesia, Germany........	1,800	......	......	"	400	"	War material, high silicon dynamo steel, locomotive tires.
4	" "	3,000	......	......	"	540	"	
5	Mannesmannröhren Werke, Burbach, Germany	3,000	......	......	"	570	"	Drawn tubes steel castings.
6	Gewerkschaft 'Deutscher Kaiser,' Bruckhausen, Germany...............	......	......	6,000	"	800	Cold and molten open-hearth metal	Drawn tubes, rails, medium quality, all kinds.
7	" "	......	......	6,000	"	800		
8	Gebr. Böhler & Co., A. G., Kapfenberg, Austria	2,500	......	......	"	400	"	Tool steel, structural steel, war material
9	Kärntnerische Eisen und Stahl - Werks - Ges., Ferlach, Austria.........	5,000	......	......	"	765	Cold charge.	Rolled wire. Dynamo stampings, and fine sheets, steel castings.
10	Brüder Lapp, Rottenmann, Austria...............	6,000			"	785	"	
11	Georg Fischer, Schaffhausen, Switzerland.........	1,200	......	......	"	250	"	Steel castings.
12	Società Tubi Mannesmann, Dalmine, Italy..........	......	......	6,000	"	765	"	} Drawn tubes
13	" "	......	......	6,000	"	765	"	
14	Soc. Electrométallurgique Française, Froges, France	2,500			"	400	"	Tool steel.
15	Aciéries du Saut du Tarn, St. Juéry, France......	5,000			"	500	Molten open hearth metal	"
16	Usines Métallurgiques du Hainaut, Couillet, Belgium..................	......	......	5,000	"	400	"	Steel castings.
17	Edgar, Allen & Co., Sheffield, England...........	......	......	2,500	"	400	"	Tool steel.
18	Vickers, Sons & Maxim, Sheffield, England......	......	......	2,500	......	......	......	......
19	Obuchoff Steel Works, St. Petersburg, Russia.....	3,500			"	660	Molten open hearth metal	Shipb'lding.
20	Aktiebolaget Heroult Electriska Stal, Kortfors, Sweden...............	3,500			"	400	Cold charge.	Tool steel.
21	Holcomb Steel Company, Syracuse, N.Y..........	5,000	......	......	"	......	Molten pig iron.	"
22	Firth-Sterling Steel Company, McKeesport, Pa...	2,500	......	......	"	......	Molten O.H. metal.	"
23	" "	......	......	5,000	"	...	......	......

*Besides the pig iron production from three Héroult furnaces working at Welland and Sault Ste. Marie, Canada, and Héroult-on-the-Pitt, California.

(A) ARC FURNACES—*Continued.*

Number	Company	Capacity in Kilograms.			Current.	Kilowatts.	Method of charging.	Application of product.
		Working.	Not working.	Building.				
	Heroult System—							
24	Illinois Steel Company, South Chicago, Ill.	15,000			Direct current.	2,000	Molten Bessemer metal.	Railway material.
25	American Steel & Wire Company, Worcester, Mass.	15,000			"	2,000	"	Rolled wire
26	Electro Metals, Ltd., Welland, Ontario.	500						
27	" "			5,000				
28	Cia Mexicana di Acero y Productes Chimicos, Mexico.			4,000				
29	" "			4,000				
	Girod System--							
1	Cie des Forges et Aciéries Electriques Paul Girod, Ugine, France	1,800			Single-phase alternating current.	300		
2	" "	2,000 to 3,000			"	300 to 400		
3	" "	2,000 to 3,000			"	300 to 400	Cold charge.	Ordinary and special steels, steel castings.
4	" "	2,000 to 3,000			"	300 to 400		
5	" "	8,000 to 12,500			Direct current with 4 electrodes.	1,200		
6	" "	8,000 to 12,500			"	1,200		
7	Marrel Frères, Rive de Gier, France			5,000	Single-phase alternating current.	600	Cold and molten charge.	
8	Oehler & Co., Aarau, Switzerland	2,000			"	300	Cold and molten charge.	Steel castings.
9	Soc. John Cockerill, Seraing, Belgium.	3,000 to 4,000			"	450	Cold charge.	Ordinary and special steels
10	A. Stotz, Stuttgart-Kornwestheim, Germany	2,000			"	300	"	Steel castings.
11	Gutehoffnungshütte, Oberhausen, Germany			2,000 to 3,000	"	300 to 400	Cold and molten charge.	High quality steel.
12	Stahlwerk Becker, Krefeld, Germany			2,000 to 3,000	"	300 to 400	"	"
13	Fried. Krupp, A. G., Essen a. d. Ruhr, Germany			10,000 to 12,500				"

Present Status of the Electric Steel Industry—*Continued.*

(A) ARC FURNACES—*Continued.*

Number.	Company.	Working.	Not Working.	Building.	Current.	Kilowatts.	Method of charging.	Application of Product.
		CAPACITY IN KILOGRAMS.						
	Girod System—							
14	Ternitzer Eisen und Stahlwerke, Schoeller & Co., Ternitz, Austria.			500	Single-phase alternating current.		Cold and molten charge.	Tool steel and high quality steel.
15	Danner & Co., Judenburg, Austria			1,800 to 2,000	"	300	Cold charge.	
16	Diosgyörer Sgl. Eisen und Stahlwerke, Diosgyör, Hungary.			2,000	"	300	"	
17	Unnamed American works			500	"	...	....	Tool steel.
	Stassano System—							
1	Forni Termoelettrici Stassano, Turin, Italy		100		Alternating current.	80	Cold charge.	Special steels
2	" "		400		"	80	"	
3	" "		1,000		Direct current.	200	"	Steel castings, automobile steel.
4	" "		1,000		"	200	"	
5	" "		800		"	150	"	
6	" "		5,000		"	800	"	
7	" "		5,000		"	800	"	
8	Royal Arsenal, Turin, Italy	800			"	150	"	Material for artillery and projectiles.
9	" "	800			"	150	"	
10	Rheinische Elektrostahlwerke G. m. b. H., Bonn, Germany	1,000			"	200	"	Steel castings, tool steel.
11	" "	1,000			"	200	"	
12	Leopold Gasser, St. Pölten, near Vienna	1,000			"	200	"	Steel castings and high quality steel.
13	" "			1,000	"	200	"	
	Keller System—							
1	Aciéries J. Holtzer, Unieux, France	8,000			Single-phase alternating current, four electrodes in pairs.	750	Molten O. H. metal.	High quality and war material, special steel, steel castings.
2	" "			1,500	Single-phase alternating current, one electrode.	200	Molten O. H. metal and cold charge.	High quality material, special and tool steel.
3	Sociéte des Etablissements Keller-Leleux, Livet, France	1,500			"	200	Cold charge.	High quality material, special steel, and steel castings.
4	" "	3,500			"	450	"	
5	" "	200			"	80	"	For experimental purposes.

Present Status of the Electric Steel Industry—*Continued.*

(A) ARC FURNACES—*Continued.*

Number.	Company.	Working.	Not working.	Building.	Current.	Kilowatts.	Method of charging.	Application of product.
		\ CAPACITY IN KILOGRAMS.						
	Keller System—							
6	Luxemburger Bergwerks und Saarbrücker Eisenhütten, A. G., Burbacherhütte, Saarbrücken, Germany.....	....	.....	3,500	Single-phase alternating current, one electrode and hearth electrode.	450	Molten basic metal.	Medium quality rails, structural steel.
	Chaplet System—							
1	Soc. des Hauts Fourneaux et Forges, Allevard, France........·.........	3,500	...	.....	Single-phase alternating current.	340	Cold charge.	Ordinary special steels
2	,, ,,	3,500	......	.....	,,	340	,,	,,
3	,, ,,	5,000	......	.....	,,	600	,,	,,
4	,, ,,	5,000	......	.....	,,	600	,,	,,
5	,, ,,	\.	......	5,000	.,	600	,,	,,
	Aktiebolaget Elektrometal, Ludvika (Sweden)*—							
1	Arvika, Sweden..........	1,000	.....	.....	Direct current.	175	Cold charge.	Temper steel
2	Hagfors, Sweden.........	500	......	......	Two-phase current.	125	,,	....
3	A. S. Norsk, Electrometal, Norway................	....	......	6,000	,,	736	Molten charge from electric smelting furnace.	....
4	St. John del Rey Mining Co., Brazil........ ...	......	......	2,000	,,	300	Cold charge.	....
	Co.'s System—							
1	A. Hickman, Staffordshire, England	300	.....	....		.. ..	....	....
	Co.'s System—							
1	Soc. An. des Aciéries et Forges, Firminy, France.	50	.....	....	....	....		Experimental furnace.
	Co.'s System—							
1	Scott Anderson, Sheffield, England............. ...	· 750	......	.....	....	......	....	....

* In addition, for the production of pig iron, the following furnaces on this system are operating : One furnace at Domnarfvet, Sweden, at work with a yearly production of 2,500 tons at a power of 400 kw. direct current ; in course of construction at the A. S. Norsk Elektrometal, Norway, two furnaces of 1850 kw. and a yearly production of 7,500 tons for each furnace; and one furnace of the same capacity at Trollhättan, Sweden.

Present Status of the Electric Steel Industry—*Continued.*

(B) INDUCTION FURNACES.

Number.	Company.	Working.	Not working.	Building.	Current.	Kilowatts.	Method of charging.	Application of product.
		CAPACITY IN KILOGRAMS.						
	System of the Gesellschaft für Elektrostahlanlagen m. b. H., Berlin-Nonnendamm, Ger. Kjellin.							
1 1	Fried. Krupp, A. G., Essen a. d. Ruhr, Germany	8,500			Single-phase alternating current.	750	Cold charge.	High quality steel.
2 2	Oberschlesische Eisenindustrie, A. G. Gleiwitz, Germany	1,500			"	180	"	"
3 3	Poldihütte, Kladno, Austria	4,000			"	400	Molten O. H. metal.	"
4 4	L. Braun's Sohne, Vöcklabruck, Austria	400			"	65	Cold charge.	"
5 5	Vickers, Sons & Maxim, Sheffield, England		1,500		"	230	"	"
6 6	" "		180		"	100	"	"
7 7	Wm. Jessop & Sons, Sheffield, England			1,800	"			
8 8	Alti Forni Gregorini, Lovere, Italy			1,800	"	250	"	"
9 9	Vidua de Urigoitia, è Hijà, Araya, Spain	1,500			"	330	Molten O. H. metal and cold charge.	Tool steels.
10 10	Eisenwerk Domnarfvet, Gysinge, Sweden	1,500			"	215	Cold charge.	High quality steel.
11 11	Sybry Searls, Ltd., Trollhättan, Sweden	2,000			"	175	"	"
12 12	General Electric Company, Schenectady, N. Y.	60			"	300	"	"
13 13	Irvington Smelting & Refining Co., Irvington, N. J.	300			"	50		
14 14	Electric Steel Company of Canada, Welland, Ontario	750			"	60		
						150	Cold charge.	Tool steel.
	System of the Gesellschaft für Élektrostahlanganen m. b. H., Berlin-Nonnendamm, Germany. Röchling-Rodenhauser.							
15 1	Röchlingsche Eisen und Stahlwerke, Volklingen, Germany	7,000			Single-phase alternating current.	750		
16 2	" "	2,000			Direct current.	275	Molten basic metal.	High quality material, rails, etc.
17 3	" "			2,000	"	275		
18 4	" "			2,000	"	275		
19 5	Pilger & Neidhardt, Frankfort, a. M., Germany			2,000	Single-phase alternating current.	275	Cold charge.	Steel castings.
20 6	Bergische Stahlindustrie, Remscheid, Germany	5,000			"	500	Molten O. H. metal.	High quality steel.

Present Status of the Electric Steel Industry—*Continued.*

(B) INDUCTION FURNACES—*Continued.*

Number.		Company.	Capacity in Kilograms.			Current.	Kilowatts.	Method of charging.	Application of product.
			Working.	Not working.	Building.				
21	7	Le Gallais, Metz & Co., Dommeldingen, Luxemburg	3,500	.....	......	Single-phase alternating current.	380	Molten pig iron from mixer.	
22	8	" "	3,500	.....	......	"	380	"	
23	9	" "	700	.....	......	"	100	"	High quality steel, steel castings.
24	10	" "	......	.....	1,500	Direct current.	275	"	
25	11	" "	......	.....	3,500	Single-phase alternating current.	380	"	
26	12	Aciéries de la Marine et d'Homecourt, St. Chamond, France	......	.....	3,000	Direct current.	350	Molten or cold charge.	High quality steel. Steel castings.
27	13	Aciéries Liègeoises, Bressoux-les-Liège, Belgium	......	1,000	.....	"	200	Cold charge.	War material.
28	14	Kronwerke Ziotooush, Russia	......	.....	1,000	"	175		
29	15	Richard Honey, Mexico			2,500	"	300	Molten pig iron with ore additions.	High quality steel.
		Kjellin Colby System—							
30	1	American Electric Furnace Company, Niagara Falls, N.Y	750	.....	......	Single-phase alternating current.	150	....	....
31	2	" "	100	.....	......		60	....	....
		Frick System—							
	1	Fried. Krupp, A. G. Essen n. d. Ruhr, Germany	10,000	.....	......	Single-phase alternating current.	750	...	
		Schneider System—							
	1	Schneider & Co., Creusot, France	1,000	.....	......	....	......	......	Experimental furnace.
		Hiorth System—							
	1	Norway	......	?	......	....	......	......	......
		Co.'s own System—							
	1	Forges de St. Jacques, Montluçon, France	?	.....	......	......	......	......	......

(C) COMBINED ARC AND RESISTANCE FURNACES.

Number.		Company.	Capacity in Kilograms.			Current.	Kilowatts.	Method of charging.	Application of product.
			Working.	Not working.	Building.				
		Nathusius System—							
	1	Oberschlesische Eisenbahn-Bedarfs, A. G., Friedenshütte, Germany	5,000	.....	......	Three-phase alternating current.	750	Molten metal from converter or O. H. furnace.	Soft and hard quality steels.
	2	" "	1,000	.....	......	"	250	Solid or molten basic O. H. metal.	For experimental work

II.

Iron Ore Smelting Furnaces.

The development of the electric furnace for steel making, as indicated by the foregoing list, has been far more rapid than was the adoption of either the open-hearth furnace, or Bessemer converter—which were introduced, 1855 and 1856, respectively. Nothing has been done in Canada towards the utilization of the electro-thermic process for the smelting of iron ores, since the experiments at Sault Ste. Marie, in 1906; but in Sweden, where the conditions—as regards iron ores, and the absence of coal—are very similar to those existing in Canada, the enterprise and progress made has been most praiseworthy. Swedish engineers are, at the present time, leading the van in the practical application of the economics demonstrated by our Canadian experiments.

With commendable enterprise, a syndicate of engineers and capitalists has not hesitated to take technical and financial risks in an endeavour to solve the problem of placing the electric smelting of refractory iron ores on a commercial basis. So far, the best results have been achieved in connexion with the Domnarfvet furnace—see my Report (No. 32) on an investigation of an Electric Shaft Furnace, at Domnarfvet, Sweden, 1908-9; now in its second edition. Since the publication of that report, considerable improvement has been made towards the perfection of the furnace. A communication received (April 29, 1910) from Mr. A. Grönwall, electrical and metallurgical engineer, Ludvika, Sweden—one of the inventors of the Domnarfvet furnace—contains the following statement:—

'We are glad now to be able to inform you that we have had a very fine success these last months with our electric shaft furnace. The furnace in Domnarfvet was put in work again on March 1, without having been rebuilt. Consequently the furnace is still made for 800 horse-power. The only alteration being made, was by introducing the circulating gas around the electrodes, inside the water-cooled boxes. By this device, the loss of heat, which had before arisen through the heating of the water, is prevented; since the gas absorbs a good deal of heat which is being led down into the furnace. Further, the water-jackets are now made of a non-magnetic material, which prevents a considerable loss of electric energy. As a consequence, the output has been increased to such an extent that now, by a charge of 55 per cent Fe—when producing grey iron— 6,283·11 pounds pig iron per horse-power year is obtained; and when producing white pig iron, 6,613·8 pounds per horse-power year. The furnace has been continuously working, and acts satisfactorily.'

So marked has been the impression created throughout Sweden by the success at Domnarfvet—for the utilization of the lower grade iron ores of the country is of national importance—that the matter is now being taken up by the Swedish government in the public interest, as the following extract from one of the leading Swedish journals will show. In order to make the discussion intelligible, it may be as well to state that the government controls all the more

important water-powers, and has established a department to administer these powers, namely, the Royal Waterfall Commission, of which Colonel P. V. Hansen is chief director. On April 26, 1910, a proposal was introduced into parliament. asking that a large water-power at Porjus, in the northern Province of Norrbotten, be utilized for the electrification of a railway, and for electric smelting. The translation of the published report in the Stockholm *Daily News*, Wednesday, April 27, 1910, begins with an interrogation:—

'But would it be possible to find a market for this water-power, away up in Norrbotten (68° N)? Colonel Hansen replied to this question in a most optimistic answer, and was supported by two authorities whom he cited: one was General Manager E. J. Ljungberg,[1] who stated that after the experiments at Domnarfvet the *electric smelting of iron ore could be considered practically and economically solved*, and that it was already proposed to venture upon a production of 100,000 tons of electric steel at that place. At Kiruna, and Gellivare—continued General Manager Ljungberg—there were very large deposits of iron ore unsuitable for exportation, but which could be used advantageously for electric smelting.

'Chief Engineer Brinnell[2] had spoken to the same effect, and forcibly emphasized the significance of the proposal as regards Norrbotten; and urged the government to see to it that an abundant supply of electric energy is available at the lowest possible cost, so that the power could be used for the electric smelting of iron ores.

'How great the desire in the country is, for the acquisition of power for the last named purpose, is evidenced by the numerous inquiries received from the various ironworks in Bergslagen, as to the possibility of obtaining power from Alfkarleby waterfall. Colonel Hansen, in reply, said he hoped to accomplish this next session, by a proposition to Parliament, which he trusted would be endorsed by the House. With these general considerations before them, the Waterfall Commission had not hesitated to recommend the Porjus scheme.

'In his closing speech, Colonel Hansen expressed his conviction that, the enactment of the proposal before Parliament would benefit not only the Province of Norrbotten, but all Sweden.

'The national, economic, farsighted proposals of the Chief Director of the Royal Waterfall Commission made a deep impression upon the assembly. His speech was greeted with enthusiastic applause by the members of the House generally; in which the Minister of the Interior did not fail to join.'

Advices dated April 29, show that the water-power at Porjus, controlled by the government, and which it is proposed to exploit straightway, is capable of developing 300,000 horse-power; while another of like capacity, at Vakkokoski, will be developed in the near future. We thus see that water-power capable of developing 600,000 horse-power is about to be rendered available by the government: a large part of which is to be utilized in the exploitation of one of the largest iron ore fields in Sweden.

[1] Director of the largest and most influential industrial company in Sweden: the 'Stora Kopparbergs Berslags Aktiebolag.'
[2] Chief Engineer of the Jern-Kontorets of Stockholm, Sweden.

The Domnarfvet furnace, which was officially investigated by the Mines Branch during December, 1908, was started again on May 7, 1909, and continued in operation—with short intermissions—until July 30. An exhaustive report on the performance of the furnace during this three months run has been made by Mr. Lars Yngstrom, for the Jern-Kontorets Annaler. (See translation in Appendix I.)

A second commercial plant for the production of pig iron and steel, by the electro-thermic process, is being established at Tysse, Norway. This installation will consist of two electric shaft furnaces of the Domnarfvet type, for the reduction of iron ores—each of 2,500 horse-power capacity: and two steel furnaces of the resistance type, each of 600 horse-power capacity, together with a rolling mill for billets and flat iron. The plant is to be extended later on by four additional electric shaft furnaces, and two more steel furnaces of even greater capacity than 600 horse-power.

Mr. Boholm, of Trondhjem, Norway, writes that he is arranging for the erection of an electric smelting and steel manufacturing plant in northern Norway, for the treatment of ores from his own mines, and has applied to the Mines Branch for a metallurgist to act as chief of staff.

An announcement has also been made that a syndicate—financed in Great Britain— is being formed for the erection near Bombay, India, of an electro-metallurgical plant for the manufacture of wheels, tyres, axles, springs, etc., for the Indian railways. The rolling mill is expected to be ready for service in March next, and the entire plant is to be operated by electricity.

In Appendix II is a description of the 'Frick' electric reduction furnace, which is designed on similar lines to those of the Domnarfvet furnace; the distinguishing feature being the sheet-easing lined with coal, which environs each electrode, to protect them from the oxidizing effect of the ore and mechanical friction of the descending stock: thus greatly increasing their life, at the same time effectively preserving the lining of the furnace.

A 5 ton 'Frick' electric steel tilting furnace, of 1,000 horse-power, has been in operation at the Krupp works, Essen, Germany, since November, 1904. As shown on Plate I, p. 58, this furnace is of the induction or transformer type, single-phase alternating current, 5,000 volts. A lucid and interesting description, supplemented by valuable practical data as to its working, together with a description of his electric, steel refining furnace for the purification of steel made in the open-hearth furnace, or Bessemer converter, has been prepared by the inventor, Mr. Otto Frick, and will be found in Appendix III.

III.

Electric Furnaces for the Reduction of Spelter and Zinc Oxide.

SPELTER FURNACES.

In the Annual Summary Report for 1908, I mentioned two electro-thermic processes for the production of spelter: namely, the plant at Trollhatten, Sweden, and the demonstration plant now being erected in London, England— both of which were invented by Dr. De Laval; but differ in principle, and in con-
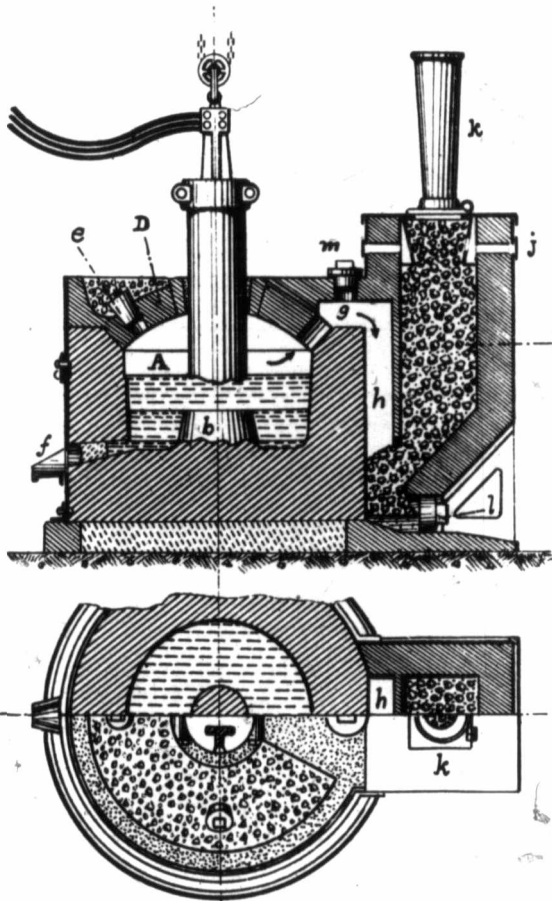

Fig. 1.
Côte-Pierron Electric Zinc Furnace and Condenser.

struction. Since then, particulars have been received of a third process (invented by Messrs. Côte and Pierron, France), which, it is claimed, is of special economic advantage in dealing with composite zinc-lead ores; since it effects a practically complete separation of the zinc from the lead.

Côte-Pierron Process.

In this process, advantage has been taken of the well-known fact that sulphur has a greater chemical affinity for iron than for zinc. At a relatively low temperature the reaction takes place in accordance with the equation:—

$$ZnS + Fe = FeS + Zn.$$

The furnace (Fig. 1) consists of a sheet metal cylinder, the sides and bottom of which are lined with graphite. The top—arched over with refractory brick—is pierced by two openings: one in the centre, for the admission of a cylindrical, carbon electrode; and the other—which can be closed by a plug—is eccentrically situated, for charging the furnace. The wall of the furnace is extended beyond the lower part of the arch where the feeding hole is located; and the extra surface thus formed is covered with the charge, which, in this way, is dried and preheated prior to admission to the furnace. A slagging hole in the side of the furnace and at an appropriate distance from the bottom of the crucible, permits the discharge of molten slag, and fused metal other than zinc. A conical, graphite electrode projects above the bottom of the crucible. On the wall of the furnace opposite the slag-hole, and at the eave of the arch, the furnace communicates with the condensing apparatus by means of a canal formed of refractory material—entering at its lowest point. The condensing apparatus consists of a cylindrical shaft of firebrick filled with pieces of carbon; and provided at its base with a door through which the spelter is tapped. Provision is made at the top of the furnace for giving access to the canal, in order to clean it when found necessary. The condenser is charged with pieces of carbon by means of a stack on top—which is always kept filled. Just below the stack, and at a short distance above the top of the furnace, the condenser is provided on each side with openings, for the admission of atmospheric air, whenever necessary to render the carbon incandescent.

The following is a brief description of the method of charging and operating the furnace:—

MODE OF WORKING.

The charge is placed in the depression around the charging orifice—which is closed. The electrode, inserted through the roof, is lowered into contact with the lower electrode. The current is then passed through the electrode and the heat generated is—by radiation—imparted to the crucible. The tapping hole in the condenser, through which the spelter is cast, is kept open during the operation. When the crucible has acquired the proper temperature, the tapping hole is plugged, and the charge is rapidly pushed through the charging hole in the arched roof—which is quickly closed again. The charge, heated by contact with the electrode, rapidly increases in temperature until the lead runs out of the tapping hole, which has been opened for the purpose. When all the lead that can be dissociated from the charge has run out of the furnace, the tapping door of the condenser and tapping hole of the furnace are closed; the electrode is gradually raised; and the heating of the charge is effected by arc and resistance. The iron now combines with the sulphur of the zinc blende, forming iron sulphide: releasing the zinc in the form of vapour, which passes out of the furnace down

the vertical canal into the condenser, imparting its heat to the carbon in the condenser. The zinc vapour is liquified in the form of drops which, trickling down, accumulate in the chamber at the bottom of the condenser. To prevent the formation of zinc powder the carbon in the condenser is kept at a red heat. The appearance of white clouds at the top of the condenser stack is evidence of imperfect condensation: requiring immediate regulation of heat in the condenser.

Iron is, to some extent, volatile; hence, to prevent the spelter from becoming contaminated by the iron, sufficient slag should be provided to protect the molten metals. At the close of the reaction, the slag and sulphide of iron are tapped.

The sulphide of iron may be sold as a by-product, or if deemed sufficiently economic, regenerated. It requires 1,800 pounds of iron to produce one ton (2,000 pounds) of zinc.

For the production of pure zinc oxide from crude low-grade ore, the process is modified. Instead of using iron to absorb the sulphur of the zinc blende, burnt lime and carbon are substituted; the reaction taking place in the furnace is shown by the following equation:—

$$ZnS + CaO = CaS + Co + Zn.$$
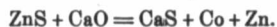
The zinc vapours which pass into the combustion chamber are burnt to oxide, which is conveyed by metallic tubes into large storage chambers.

DE LAVAL ZINC PROCESS, 1909.

A plant, intended to demonstrate the applicability and economy of a new process for the production of zinc from its ores, is being erected in London, England, by the Laval-Ferguson Syndicate.

The process is as follows:—

The ores, fluxes, and fuels are ground separately, passed through a fine mesh, mixed in proper proportions, and delivered in the form of a dust cloud into the apex of what is termed a cyclone furnace. Passing into the furnace they are met by a tangential cyclone current of air under high pressure, and at a high temperature. This current prevents the rapid settling of the charge, and the volatile metals are converted from sulphides into oxides, in the form of fumes, which are withdrawn by suction from the furnace. The non-volatile metals, on account of their gravity, are projected against the walls of the furnace, where, on account of the intense heat generated, they are fused, and trickle down the walls into the crucible at the bottom of the furnace.

The hot oxide fumes of zinc and lead, and the sulphur dioxide formed, pass through a cooling apparatus into the bag-house, where the lead and zinc oxides are deposited; while the sulphur dioxide is drawn by suction through the suspended bags into the sulphur recovery plant.

The further treatment of the mixed oxides is effected within what are termed by the inventor, ' Cyclone producers,' or, in electric furnaces. No description of either of these furnaces is available.

3146—2

The carbon monoxide resulting from the reduction of the oxides, is employed for power purposes; and the deoxidation of the sulphur dioxide. By this latter process the sulphur is recovered from the sulphur dioxide in the solid form.

The following is selected from a number of cost sheets giving the analysis and cost of ores treated by this method:—

Average analysis of a Broken Hill zinc ore:—

Zn, 16; Pb, 18; Fe, 5; S, 15; Si, 40 per cent; Ag, 12 ozs.

Cost:—

Treatment 100 tons at 12s....	£60
Grinding by power derived from carbon monoxide produced..	1
Labour: 12 men at 10s...	6
Furnace renewals..	9
Coal for heating and reducing 30 tons in cyclone producers[1] at £1 10s...	45
Flux: 50 tons at 14s...	21
	£142
To cover depreciation: say..	18
	£160

Cost: £1 12s. per ton of ore.

Product:—

Zn	16 − 1·5	= 14·5	tons at £16..	£232
Pb	18 − 2	= 16	tons at £10..	160
S	15 − 1	= 14	tons at £4..	56
Ag	1,200 ozs. at 2s. per oz..			120
				£568
Less freight to Europe of 30 tons of metal at £2.. ..				60
				£508

Daily profit, say = £330, on treatment of 100 tons of ore.

Cost of metal, $\dfrac{£220}{30·5} = £7$ per ton.

The foregoing calculation looks alluring, but as no experimental run has yet been made with this process, actual results of prospective trial runs will be awaited with interest.

---

[1] Cost of electric energy and carbon for reduction if electric furnace is employed, not given.

APPENDIX I.

REPORT ON THE EXPERIMENTS CONDUCTED AT DOMNARFVET, SWEDEN, IN THE SMELTING OF IRON ORE BY THE ELECTRO-THERMIC PROCESS.

BY

Lars Yngström, M.E.

(Translated from ' Bihangtill Jern-Kontorets Annaler, 1909,' by
E. Lindeman, M.E.)

It has long been known that iron can be produced from iron ore in the electric furnace, when carbon is added for the reduction of the ore and the requisite fluxing material for the making of a suitable slag of the gangue minerals. We have heard how, on a number of occasions, a few tons of pig iron have been made from iron ore in electric furnaces, designed for the production of ferro-alloys or steel, but this has been done more as an experiment than as a regular proceeding.

The question of reducing iron ore to iron by aid of electricity, is of special interest to the countries which have large iron ore resources, and which, further, in their waterfalls, afford an opportunity of generating cheap electric power. Lack of domestic coal makes the solution of the problem of still greater importance. On account of all this, the problem of the reduction of iron ore by the electro-thermic process has received great attention in Sweden.

Experiments have been carried on, during the past few years, at the iron works of Domnarfvet, for the purpose of constructing a suitable electric furnace for a continuous production of pig iron.

Now that these experiments seem to have been crowned with success, a report on the instructive data obtained and the results should be of interest.

Theoretical Investigation of the Problem.

It might be advisable to begin with a calculation of the amount of carbon and electric energy which are theoretically required for producing one ton[1] of pig iron in the electric furnace.

We know that the object of the use of the electric current is to replace part of the carbon which is required for the smelting of the charge in the blast furnace.

The amount of this carbon varies with the content of CO_2 and CO in the flue gases, i.e., the higher the content of CO_2 in the flue gases, the less the consumption of carbon. For the actual reduction of the ore, a specific amount of carbon is always required.

---

[1] The metric ton of 1,000 kilograms is used throughout this article.
3146—2½

We will first calculate how much carbon and electric energy are required to produce one ton of pig iron of the following composition:—

Fe = 96 per cent.
C = 3 "
Si = 1 "
Mn, P, S, Cu, trace.

Let the ore used in the charge be magnetite, and assume the iron content to be 60 per cent of the charge, i.e., ore + calcined lime; and further, let us assume that the departing flue gases contain 30 per cent CO_2 and have a temperature of 200° C.

The thermal calculation given below is based on the following constants:—

In reducing 1 kg. Fe from Fe_3O_4, 1,650 calories are absorbed.
" 1 kg. Fe from Fe_2O_3, 1,800 " " "
" 1 kg. Si from SiO_2, 7,830 " " "
In oxidizing 1 kg. C to CO_2, 8,080 " " developed.
" 1 kg. C to CO, 2,470 " " "

In melting and superheating 1 kg. of pig iron, 280 calories are required.
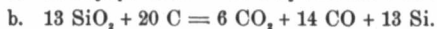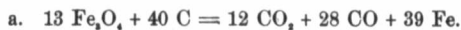In melting and superheating 1 kg. of slag[1], 595 calories are required.
Specific heat of dry furnace gas per kg., 0·245 calories.

It is further assumed that the temperature of the charge, when it enters the furnace, is 0° C, that the ore is free from water and CO_2, and that the lime is calcined.

I. *Calculation of the Consumption of Carbon.*

(Chemically pure C per 1,000 kgs. of pig iron.)

Formulæ of reaction:—

a. $13\ Fe_3O_4 + 40\ C = 12\ CO_2 + 28\ CO + 39\ Fe.$
b. $13\ SiO_2 + 20\ C = 6\ CO_2 + 14\ CO + 13\ Si.$

According to formula a, 960 kgs. Fe are obtained from 1,325·71 kgs. Fe_3O_4, and for this reduction 210·99 kgs. C are required, when 576·70 kgs. of gases $(CO_2 + CO)$ are formed.

According to formula b, 10 kgs. Si are obtained from 21·43 kgs. SiO_2, and for this reduction 6·59 kgs. C are required, when 18·02 kgs. gases $(CO_2 + CO)$ are formed.

Total amount of carbon required:—

In reduction 960 kgs. Fe.. . . . . 210·99 kgs. C.
In reduction 10 kgs. Si.. . . . . 6·59 "
In combination of carbon.. . . . . 30·00 "

247·58 "

[1]This figure seems somewhat high, but it has been considered convenient to add about 100 calories to the figure usually given in metallurgical papers, partly on account of the high temperature of the slag, and partly because in the electric furnace we might have to consider a certain amount of carbide formed in the slag.

II. *Calculation of the Amount of Slag.*

The charge, i.e., ore + lime, contains 60 per cent Fe. Then to get 960 kgs. Fe, a charge of 1,600 kgs. is required. This corresponds to 1,325·71 kgs. Fe_3O_4.

Remaining slag making substances.. .. .. 274·29 kgs.
Amount of SiO_2 to be deducted.. .. .. 21·43 "

Total slag per ton of pig iron.. .. .. 252·86 "

III. *Calculation of the Amount of Gas Evolved.*

According to I a, the amount of CO_2 + CO is.. .. 576·70 kgs.
According to I b, the amount of CO_2 + CO is.. .. 18·02 "

Total gas per ton of pig iron.. .. .. 594·72 "

IV. *Heat of Combustion of Carbon.*

When one kg. of C combines with O to form a gas mixture which volumetrically contains 30 per cent CO_2 and 70 per cent CO, $0·3 \times 8,080 + 0·7 \times 2,470 = 4,153$ kilogram calories are developed.

V. *Balance Sheet of Heat.*

Amount of heat required:—

To reduce 960 kgs. Fe from Fe_3O_4, $960 \times 1,650$.. .. .. .. = 1,584,000 calories.
To reduce 10 kgs. Si from SiO_2, $10 \times 7,830$.. .. .. = 78,300 "
To melt and superheat 1,000 kgs. of pig iron, $1,000 \times 280$· = 280,000 "
To melt and superheat 252·86 kgs. of slag, $252·86 \times 595$.. = 150,452 "
To raise the temperature of 594·72 kgs. CO_2 + CO to
  200° C, $200 \times 0·245$.. .. .. = 29,142 "

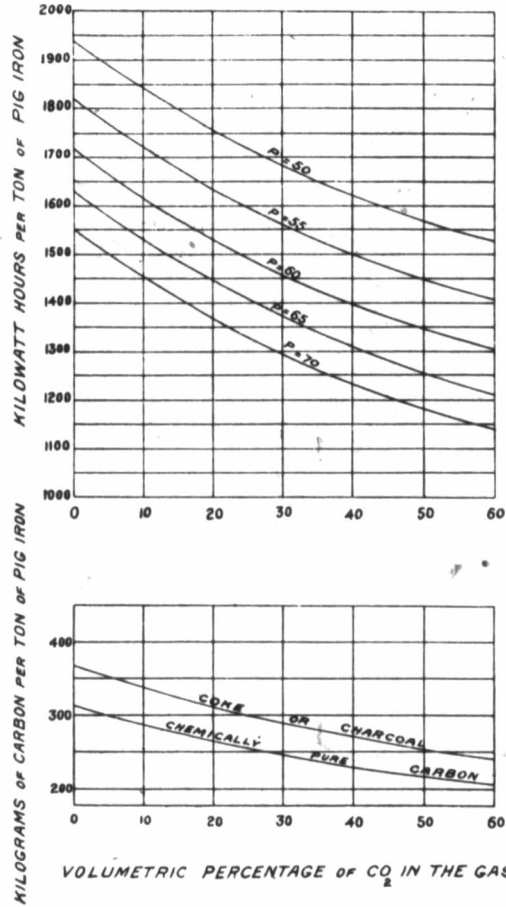Total.. .. .. 2,121,894 "

Amount of heat supplied:—

By the combustion of 217·58 kgs. C, $217·58 \times 4,153$.. .. = 903,610 calories.
Amount of heat to be furnished by the electric current.. = 1,218,284 "

Total.. .. .. 2,121,894 "

The theoretical amount of electric power required per ton of pig iron is, therefore:—

$$\frac{1,218,284}{857} = 1,420 \text{ kilowatt hours.}$$

Figs. 2 and 3.

The graphic tables (see Figs. 2 and 3) have been prepared according to the above method of calculation. In these tables the carbon content of the coke has been assumed to be the same as that of the charcoal, and the chemical composition as follows:—
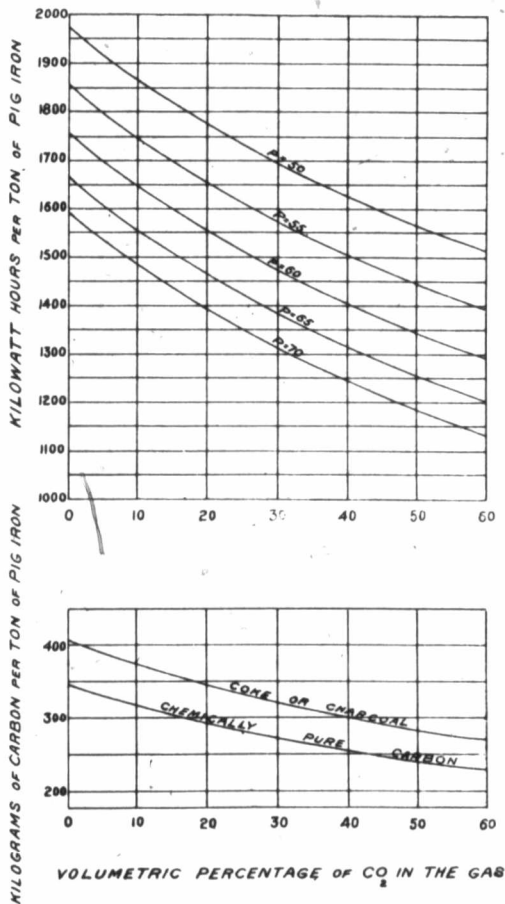
Coke:—

C. . . . . 85 per cent.

H_2O. . . . . 5 "

Ash. . . . . 10 "

Charcoal:—

C................................. 85 per cent
H₂O............................... 12 "
Ash............................... 3 "

Figs. 2 and 3 are applicable, when the iron occurs in the ores as Fe_3O_4; Figs. 4 and 5 when it is found as Fe_2O_3.

CARBON AND ELECTRIC ENERGY REQUIRED IN SMELTING HEMATITE

Figs. 4 and 5.

On the abscissa the volumetric percentages of CO_2 are scaled from 0 to 60 per cent.

The ordinates of the upper table give in kilowatt hours the electric energy which is theoretically required per ton of pig iron, when coke or charcoal is used.

The ordinates of the low table give in kilograms per ton of pig iron the amount of chemically pure carbon, coke, or charcoal required to reduce the ore.[1]

$P =$ iron content of the charge (ore + lime).

To produce one ton of pig iron of the above-mentioned composition, there are required, according to these tables, 248 kgs. of chemically pure carbon, or 292 kgs. of coke or charcoal, and 1,460 kilowatt hours, which corresponds to a production of 4·4 tons of pig iron per electric horse-power year (365 days). This is, however, under assumption that the CO_2 content of the flue gases is 30 per cent, that the ore is magnetite (Fe_3O_4), and that the charge contains 60 per cent Fe.

Description of the Plant.

The experiments at Domnarfvet commenced in the spring of 1907, and have been going on since then, with several interruptions, partly due to the rebuilding of the trial furnaces, and in part to the lack of water at the power station.
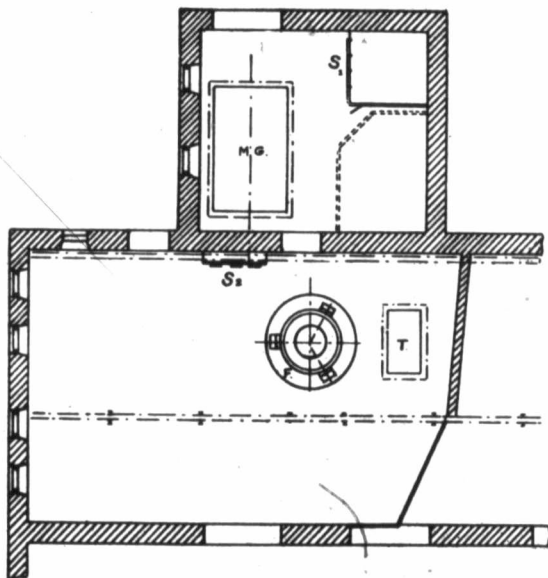
M.G. MOTOR-GENERATOR
S₁ SWITCHBOARD FOR M.G.
S₂ SWITCHBOARD FOR FURNACE.
T. TRANSFORMER.
F. FURNACE.

Fig. 6.
Plan of Domnarfvet Furnace Plant.

The experimental plant is installed in an old building adjoining the Bessemer plant. Fig. 6 shows the plan of the same.

---

[1] The heat absorbed by the water and ash of the fuel is assumed to be supplied by the electric current.

The machinery, specially constructed for the experimental trials, consists of a three-phase synchronous motor of about 900 horse-power, which is supplied with a 60 cycle current of 7,000 volts from the three-phase cable line of the iron works.

S.M.   SYNCHRONOUS MOTOR. 900 H.P.
A.S.M. ASYNCHRONOUS STARTING MOTOR
T.G.   THREE PHASE GENERATOR
E.   EXCITER
E.B.   EXCITING BUS BARS
F.R.   FIELD RESISTANCE
S.R.   STARTING RESISTANCE
F.W.   FUSE WIRE
A.S.   AMPEREMETER SHUNT
T.T.   TENSION TRANSFORMER
C.T.   CURRENT TRANSFORMER
V.R.   VOLTMETER REVERSER
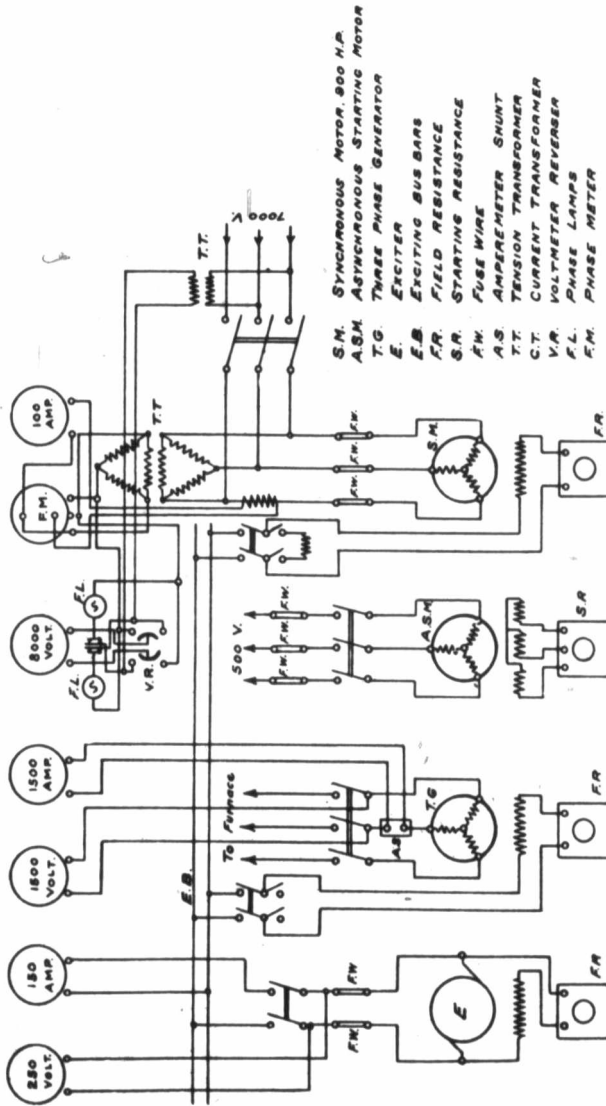F.L.   PHASE LAMPS
E.M.   PHASE METER

Fig. 7.
Arrangement of switchboard connexions.

This motor is directly coupled to a three-phase generator, which supplies current to the transformers erected in the immediate vicinity of the furnace. The three-

phase current of the generator is of 25 cycle, and its voltage is adjustable by small steps from 300 to 1,200 volts.

By means of this wide regulation it was possible to determine the most suitable voltage to be employed in furnaces of different construction and operating under various conditions. The fields of both the synchronous motor and the generator are excited by a current of 220 volts from a direct current generator, 20 kw. capacity, directly coupled to the system. To start the system, a three-phase asynchronous motor, also directly coupled, is employed. This is fed with a current transformed down to 500 volts. In order to control the machinery, there are up-to-date instruments, the arrangement of which may be seen from the diagrams of connexion shown in Fig. 7.
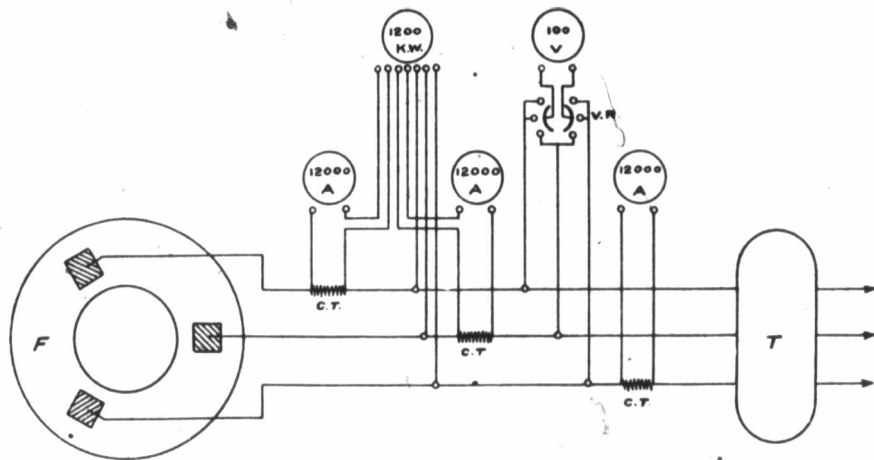
F FURNACE
T TRANSFORMER
C.T. CURRENT TRANSFORMER
K.W. KILOWATT METER
V.R. VOLTMETER REVERSER
V. VOLTMETER
A AMPEREMETER

Fig. 8.
Arrangement of furnace electrical connexions.

The current is led from the switchboard through copper bars, laid down in cement channels in the floor, to the transformers erected in the immediate vicinity of the furnace. The total capacity of these transformers is 1,500 K.V.A., with a transformation ratio of 14:1. By regulating the voltage of the generator, the low voltage of the transformers can be altered in small intervals from 20 to 80 volts. The transformers are cooled by air supplied under pressure from two electric blowers erected in their immediate vicinity. In order to control the operations a switchboard is placed conveniently near the furnace. On this the following instruments are mounted:—

One three-phase precision wattmeter for differently loaded phases.

Three ampere meters, one for each phase.

One volt meter, with reverser.

The ampere meters and the wattmeter are connected with the current system by means of transformers. The volt meter and the terminals of the wattmeter are directly connected to the conducting bars. Fig. 8 shows the diagram of connexion.

The wheels by which the electrodes are adjusted are placed immediately under the instruments in such a manner that the wheel and the ampere meter opposite each other belong to the same phase.

Experiments with Different Furnaces.

The first smelting experiments were made in an electric furnace constructed according to certain patents obtained by Messrs. Grönwall, Lindblad, and Stalhane. These gentlemen, who are the founders of the company, Electrometall,
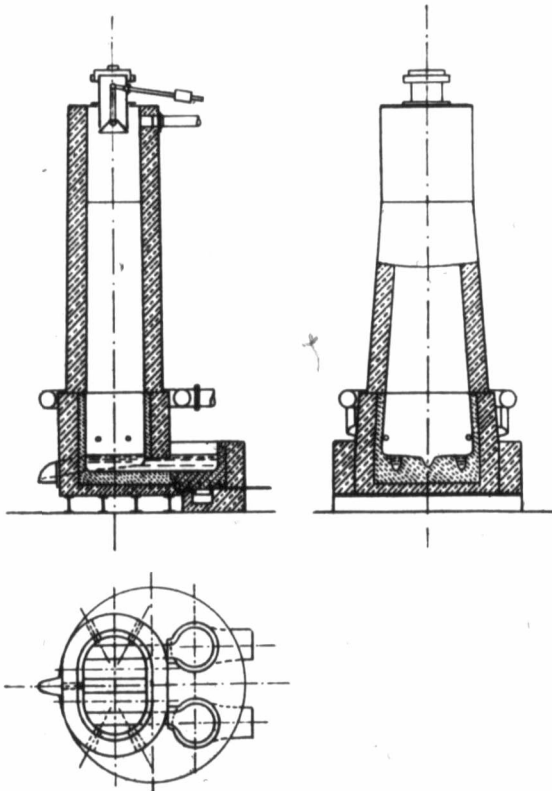

Fig. 9.
Experimental Furnace No. 1.

Ludvika, Sweden, have, together with Trafikaktiebolaget Grängesberg-Oxelösund and Stora Kopparbergs Bergslags Aktiebolag, been interested in the experiments. Fig. 9 shows the construction of the first furnace, which was a shaft furnace

with the hearth lined with quartz. In the bottom of the furnace were three channels, one in the middle, leading to the tapping hole, and two others communicating through openings in the brick work with two wells outside the furnace. These wells were filled with iron, and their bottoms consisted of blocks of graphite, stamped on copper plates, which were connected with the current. The furnace was started with blast, as an ordinary blast furnace. The blast was turned off and the electric current put on as soon as a sufficient amount of molten iron had gathered in the hearth.
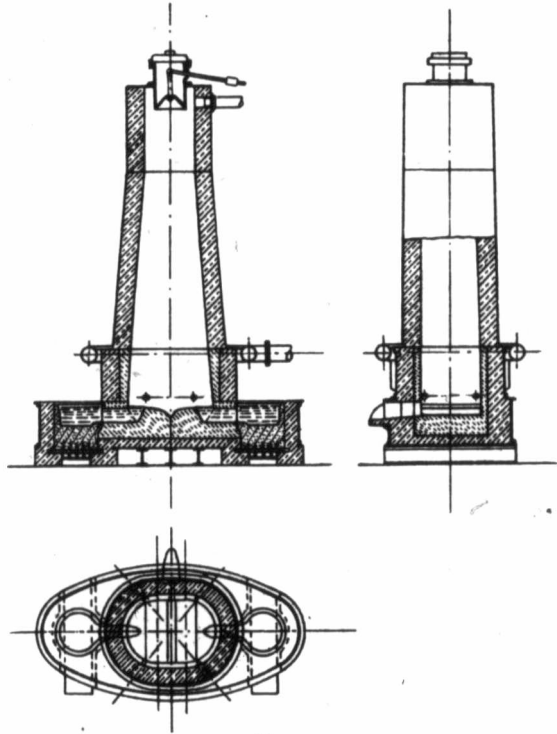
Fig. 10.
Experimental Furnace No. 2.

The electric current entered the furnace through the iron of one of the side channels, passed through the charge, and out to the other terminal through the material in the other side channel. The intention was that the charge, by its resistance to the current, would be heated and melted. Short runs could be made with this furnace, but it proved impossible to get a durable bottom. This was partly due to the quartz, which at the high prevailing temperature became a conductor of the electric current.

On account of this the furnace was rebuilt, and given the form shown in Fig. 10. The same principle was retained here as in the first furnace. The main difference was that the bottom of the furnace was made of magnesia brick, which

made it somewhat more long lived, but the same trouble was experienced, the magnesia- brick becoming at the high prevailing temperature a comparatively good conductor of the electric current.
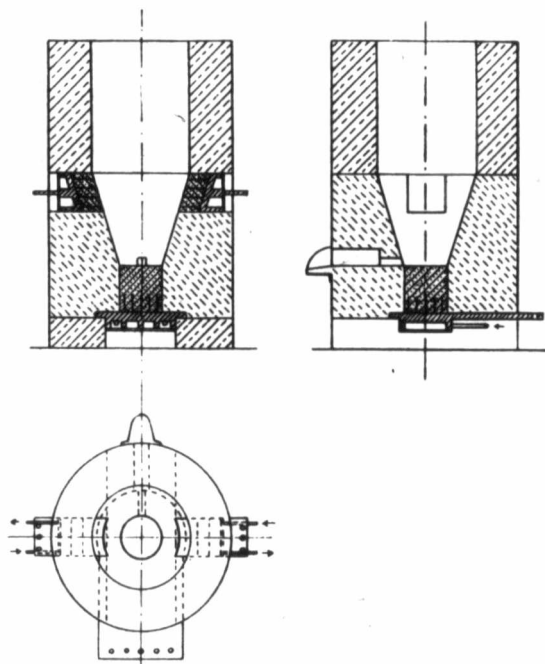
Fig. 11.

Experimental Furnace No. 3.

It was, therefore, evident that a solution of the problem could not be expected by introducing the electric current through the pig iron on the bottom of the hearth. The experiments were continued with another furnace, which is shown in Fig. 11. It was a small shaft furnace, provided with three graphite electrodes, one in the bottom of the furnace, and two opposite each other in the shaft.

The upper electrodes, having been consumed comparatively soon, were replaced with ordinary carbon electrodes, which could be regulated and surrounded with water-cooled stuffing boxes. It was so arranged that the current could be led, either across the furnace between the two upper electrodes, or from them to the electrode in the bottom. This furnace proved to be more durable than the previous one, but, unfortunately, the brickwork in the proximity of the electrodes was badly eaten away.

The knowledge gained from the previous experiments led to the construction of the furnace, the first form of which is shown in Fig. 12. The preliminary experiments with this furnace were promising, and led to the erection of the electric furnace shown in Fig. 13. It is with this electric furnace that the following results have been attained.
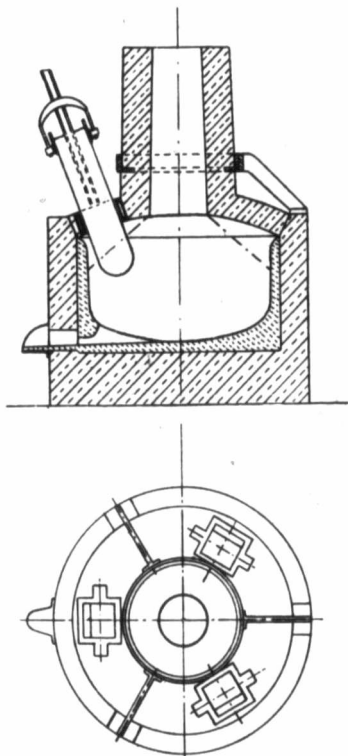
Fig. 12.
Experimental Furnace No. 4.

The Final Furnace.

The furnace (see Fig. 13) consists of one lower part—the melting chamber—and one upper—the shaft. The melting chamber is made in the form of a crucible, 150 cm. high, with a diameter of 225 cm., covered with an arched roof and lined with magnesite brick. When the charge falls from the shaft through the opening of the arched roof into the melting chamber there remains an open space between the charge and the brick work. Experiments made have demonstrated that the sloping angle of the charge is 35° to 40°, when the material is crushed to normal size. In Fig. 13 the slope is indicated by dotted lines. The three electrodes enter the furnace through places in the arched roof, which are not in contact with the
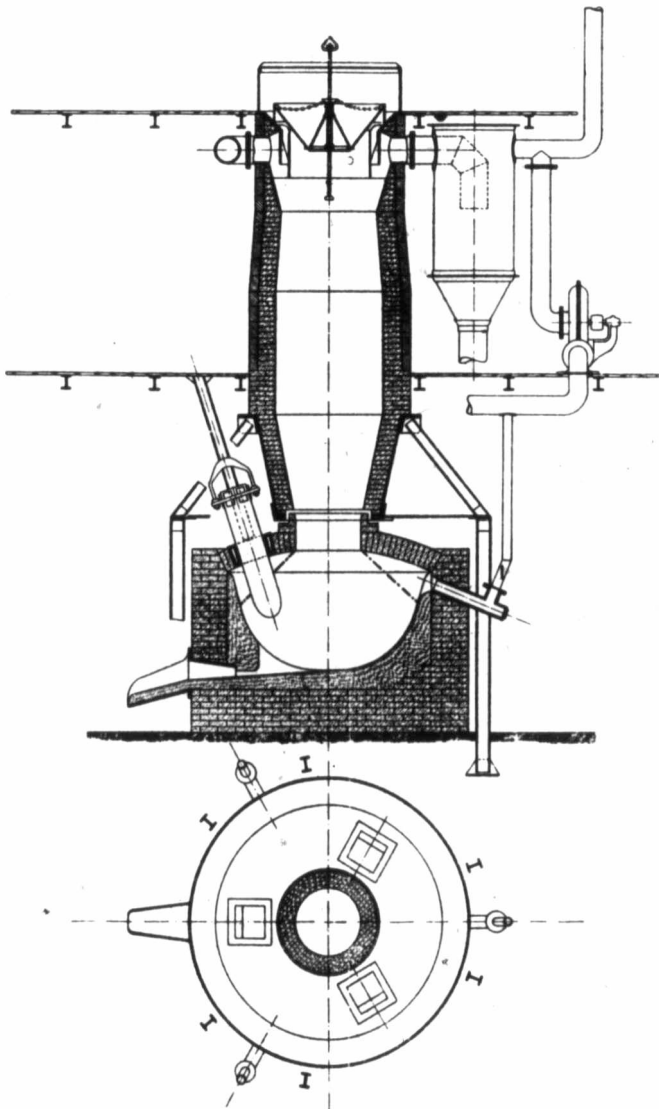
Fig. 13.
Final design of Electric Shaft Furnace.

charge. The experience gained from the experiments with the previous furnaces shows that this arrangement is a very important part of the construction. Between the ends of the electrodes a melting zone is formed, through which the charge must pass. In order to protect the brickwork of the melting chamber and increase its life, three twyers are introduced immediately under the arched roof.

Through these twyers a comparatively cool gas from the upper part of the shaft is blown into the free space between the arched roof and the charge by an exhaust fan.

The gas absorbs heat from the free surface of the charge and from the roof, thus lowering the temperature of the roof and the exposed walls.

This lowering of temperature causes, however, no loss of heat, as the heat absorbed by the gas is imparted, in passing upward through the shaft, to the cooler portions of the charge. The twyers are provided with sight holes, through which the temperature of the arched roof can be observed. By this device it is possible to regulate the necessary quantity of gas. The holders of the electrodes consist of strong steel frames, supporting the wedges, by which the copper plates conducting the current are pressed against the electrodes. Each electrode consists of two carbons, 33 cm. square, placed close to each other.[1] Copper cables of sufficient length to allow the regulation of the electrodes are connected with the copper plates and with copper bars in the roof.

The electrodes are suspended by two steel cables, which are insulated from the holders and connected with a winch arrangement, serving to regulate the electrodes. In order to protect the parts of the electrodes outside the furnace from the oxidizing action of the air, a covering of asbestos and sheet iron is provided. The openings of the arched roof, through which the electrodes enter the melting chamber, are provided with water-cooled stuffing boxes, and there are special devices, not shown in Fig. 13, for preventing the gas from leaking out around the electrodes from the melting chamber.

The shaft, which is 5·2 metres high above the melting chamber, with a maximum inner diameter of 1·525 m., is supported by an iron construction resting on six cast iron pillars, arranged around the melting chamber. By this mode of construction, it is possible to repair or replace, without removing the shaft, those parts of the furnace suffering the greater strain, i.e., the arched roof and the melting chamber. The shaft, as shown in Fig. 13, is similar to that of a blast furnace, and is, at the top, provided with a hopper and charging bell.

Starting and Operation of the Furnace.

The electric furnace was started May 7, 1909, and the smelting operations continued, with a few short interruptions, until July 30, when it was shut down, owing to certain reasons, although still in good working order.

The furnace was started as an ordinary blast furnace. The smelting chamber was heated with wood, the charging bell having been lifted up and the electrodes removed. A few charges of charcoal and coke were then added, the electrodes put in place, the electric current turned on, and the shaft filled with ore, lime, and charcoal, the material of the charge having been well mixed in order to get the charge column more porous. The amount of charcoal added was gradually decreased, and at the end of the first week, the composition of the charge was 100 kgs. of ore, 3 kgs. of calcined lime, and 24 kgs. of coke, and after that 100 kgs. of ore, 4 kgs. of calcined lime, and 22-24 kgs. of coke. Using coke as the reduc-

---

[1] In Fig. 13 the electrodes are shown to consist only of one carbon, but in the last experiment made, two carbons, which were lying close to each other, were used.

ing agent, the greatest number of charges handled per 24 hours was 62, the capacity of the shaft being 72 charges. Using charcoal, the greatest number of charges was 80 per 24 hours, and the capacity of the shaft 41 charges. The amount of charcoal required was from 21 to 28 kgs. per 100 kgs. of ore. The charcoal was measured by volume, and on account of its fairly high percentage of moisture, one hectolitre was considered equal to 16 kgs.

At the beginning of the run, when the bottom of the furnace was still cool, the electric current kept chiefly to the arched roof, heating this strongly and melting away part of it. The gas circulation, however, was soon started, and the cooling by means of the gas, exhausted from the upper part of the shaft, proved to be very effective, the temperature of the roof becoming lower, and the heat going towards the bottom. The tendency of the electric current naturally was to pass where the least resistance existed, i.e., through the layers of the charge not subjected to cooling.

Having been well started, the furnace could be run for several days without gas circulation, the heat showing no tendency to rise towards the roof.

The charcoal in the charge appeared to assist in keeping the heat near the bottom.

It has happened on a few occasions that the quantity of iron obtained has not been in reasonable proportion to the percentage of iron charged into the furnace. During one week, for instance, 48 tons of ore were charged into the furnace, but only 17 tons of pig iron obtained, corresponding to 27 tons of ore. The week after, 22·6 tons of ore were charged, when 23 tons of pig iron were obtained.

The only explanation of this seems to be that more or less reduced iron was deposited on the bottom and on the walls of the furnace. It has also occurred during the run that carbon has accumulated in the melting chamber because too much charcoal or coke had been added. This caused some trouble, but was soon remedied by increasing the quantity of ore in the charge. A disturbance of this kind is, however, easy to prevent, as the slag shows the excess of carbon, in which case calcium carbide is formed and a strong smell of acetylene noticed.

The materials in the shaft showed on certain occasions a tendency to hanging, but when the furnace was charged in such a way that 80 per cent of the ore in the charge was placed near the wall, this trouble disappeared. It was proved possible to charge the electric furnace entirely with fines, if all the ore were placed near the wall and the height of the charge column was kept so that its upper surface was somewhat below the gas cylinder, thus preventing the fines from being sucked into the gas pipes.

To briquette the fines is, therefore, not necessary, and, consequently, by using the electric furnace, the cost of briquetting is saved.

Some small mishaps during the run have had some effect upon the results. At the end of the first week, for instance, one of the water-cooled stuffing boxes commenced leaking, so that the furnace had to be run with two electrodes for some time. Owing to fault of the electrical machinery, the transformers of the furnace had to be coupled on two occasions to the high tension circuit, and had to run with a cycle of 60 instead of 25, etc.

3146—3

No greater fluctuations of the current occurred during the run. Even when the casts were made the hands of the instruments remained still. The highest allowed load of the electrodes was about 9,000 amperes per phase. The phase displacement with the 25 cycle current corresponded to cos. $\phi = 0.8 - 0.9$; with the 60 cycle current cos. $\phi = 0.7$.

The amount of electric energy which can be supplied to the furnace depends evidently on the interior resistance of the furnace, i.e., the greater the resistance the more energy can be supplied without the strength of the current becoming too high. With a 25 cycle current, it has been possible to run the furnace with a tension of 80 volts; with a 60 cycle current, 65 volts at the utmost, were found available. The tension in the furnace mainly depends on what kind of fuel is used, and on the proportion of fuel and ore charged.

This is shown in Table I, the figures of which have been taken from the diary of the smelting operations.

TABLE I.

Charge.	Voltage.	Current per phase.
	Volts.	Amperes.
Coke alone (in excess)	34	9,600
" (not in excess)	36	8,800
Charcoal alone (less than sufficient)	60	6,300
" (sufficient)	54	7,600
" (more than sufficient)	48	7,600
Coke and charcoal (more than sufficient)	35	9,200
" (sufficient)	48	7,600

Any variation of the resistance of the furnace could only be noticed when a large amount of iron was kept in the hearth, and even then it was comparatively small. The furnace was easy to handle, the run regular, and a cast made about every 6 hours.

Seven different charges have been tested, and an account of the results obtained will be given in the following pages. The furnace was first charged with an easily reducible specular hematite, of high iron content, but of comparatively low commercial value, owing to its high percentage of phosphorus, the main object being to find a practical type of furnace. As a consequence of this, it became impossible later on to produce a first-class pig iron even from the best qualities of ore, the iron always being contaminated by the high phosphorus ore still remaining in the furnace.

TABLE II.

Analyses of the various ores used in the charges.

Ore from	Fe_3O_4	Fe_2O_3	FeO	MnO	MgO	CaO	Al_2O_3	TiO_2	SiO_2	P_2O_4	H_2O+CO_2	Fe	P	S	Charge No.
Grängesberg—															
Skärmingemalm	13·75	71·65	......	0·12	0·74	6·80	0·35	......	3·02	4·19	......	60·11	1·83	Trace.	1 and 3
Längrufvan—															
Briquettes	5·89	76·36	......	0·24	2·66	3·28	2·14	......	11·52	0·009	......	57·70	0·004	"	2
Magnetic Concentrate	80·89	......	6·78	0·13	2·80	2·96	0·91	......	11·30	0·009	......	58·57	0·004	"	6
Johannesburg	58·58	......	2·16	5·58	5·61	4·98	2·46	......	5·56	0·007	11·72	47·69	0·003	0·13	6
Sköttgrufvan	66·37	......	......	0·33	3·19	12·18	Trace.	0·90	4·50	0·007	8·44	49·73	0·016	0·00	4 and 5
Tuollavaara	92·46	1·99	......	Trace.	0·03	1·28	......	......	1·80	0·007	......	68·31	0·003	0·09	5
Taberg	74·48	......	......	0·42	4·96	4·90	4·31	......	15·30	0·014	......	53·93	0·006	0·00	5
Finnmossen	79·64	......	......	0·29	3·78	3·30	1·95	......	8·55	0·023	......	57·66	0·010	0·00	5
Nordmark	68·58	......	......	0·60	5·50	6·27	......	......	16·90	0·023	......	49·61	0·010	0·00	
Brazil—															
Specular ore	......	91·72	5·78	Trace.	0·25	0·20	Trace.	......	0·80	0·126	1·0	68·8	0·055	0·03	7

Composition of:—

Calcined Lime.		Coke.		Charcoal.	
Fe_2O_3	0·5 %	C	85 %	C.	65–80 %
MgO	2 %	H_2O	4 %	H_2O....	12–20 %
CaO	96·5 %	O + N....	1 %	Ash....	3 %
Al_2O_3	0·2 %	Ash	10 %		
SiO_2	0·2 %	S . . . .0·5–0·7 %			

Composition of the Seven Different Charges.

No. 1.—826 Charges.

Ore from Grängesberg.... .. ..kgs.			100
Calcined lime.. .. .. "			4–5
Coke.. .. .. "			10–26
Charcoal .. .., "			10–0

No. 2.—574 Charges.

Ore from Långgrufvan. . .. .kgs.	100
Calcined lime.. .. .. "	11–18
Coke.. .. .. "	0–21
Charcoal.. .. .. : .. "	20–0

No. 3.—959 Charges.

Ore from Grängesberg.. .. ..kgs.	·100
Calcined lime.. .. .. ".	2–4
Coke.. . .. . "	8–13
Charcoal.. .. .. "	13–7

No. 4.—599 Charges.

Ore from Tuollavaara.. .. ..kgs.	100
Calcined lime.. .. .. :: .. .. "	4
Coke.. .. .. "	7–11
Charcoal.. .. .. "	17–11

No. 5.—623 Charges.

Ore from Tuollavaara. . .. .kgs.	20
Ores from Finnmossen, Talberg and Nordmarken, in	
equal parts.. .. .. "	80
Lime (not properly calcined).. .. .. "	5
Coke.. .. .. "	4–0
Charcoal.. .. .. "	18–26

No. 6—Charges.

Number of Charges.				Ore from Láng-grufvan.	Ore from Skött-grufvan.	Ore from Johannis-bergs-grufvan.	Lime.	Charcoal.
				Kgs.	Kgs.	Kgs.	Kgs.	Kgs.
97 Charges with a composition of.				50	20	30	6	21
13	"	"	. . . .	50	20	30	. . . .	21
168	"	"	. . . .	35	15	20	. . . .	16
160	"	"	. . . .	45	10	15	2	16
202	,	"	. . . .	55	10	10	2	16
81	"	"	. . . .	60	10	5	3	16
96	"	"	. . . .	75	. . . .	. . . .	4	16

No. 7.—362 Charges.

Ore from Brazil. . . . . .kgs.   64–50

Calcined lime. . . . . "   2–0

Charcoal. . . . . "   16

The results of the smelting operations with the seven different charges are seen in Table III. The actual amount of iron obtained, when compared with the iron content of the ores of the charges, is rather high, and might be due to lack of care in weighing.

Consumption of Carbon.

It not being possible for any air to enter the furnace, provided it is properly constructed and managed, the consumption of charcoal or coke for the various ores depends partly on the carbon content of the fuel and partly on the quantity of this carbon combining with O to CO_2. Therefore, the actual consumption of carbon is, under normal conditions, equal to the theoretical. This is plainly shown by the results obtained (see Table IV).

TABLE IV.

Charge No.	Consumption of carbon, chemically pure carbon, per ton of pig iron.	According to Tables I and II this consumption of carbon corresponds to a CO_2 content in the flue-gas of	Content of CO_2 in the flue-gas determined by analysis.	Character of ore in the charge.	Iron content of ore and lime.
	Kgs.	Per cent.	Per cent.		Per cent.
3	252	43	39—44·7	Fe_2O_3	58·8
4	254	25	24—28	Fe_3O_4	65·6
5	284	11·5	8—23·8	Fe_3O_4	54·5

In Nos. 3 and 4 the actual consumption of carbon agrees very well with the theoretical. In No. 5 the figures in question agree satisfactorily, taking into consideration that the furnace was run partly with and partly without gas circulation. The consumption of carbon is in a definite proportion to the content of CO_2 in the flue-gas.

If m is the volumetric percentage of CO_2 in the flue gas, and k the percentage of carbon in the iron, then the carbon consumption c per ton of pig iron is in kgs. :—

$$\text{If Fe occurs as } Fe_2O_3, \quad c = \frac{321 \cdot 43 \ (100 - k) \ + 10k.}{100 + m.}$$

$$\text{If Fe occurs as } Fe_3O_4, \quad c = \frac{285 \cdot 7 \ (100 - k) \ + 10k.}{100 + m.}$$

The formulæ are applicable when the carbon is chemically pure and the gas contains only CO_2 and CO. It is evident that a circulation of the furnace gas will have a great influence on its content of CO_2. This is plainly shown in Table V, which gives analyses of gases taken during the run. The figures have reference to the flue-gas, unless otherwise stated.

TABLE III.

Comparison of the results obtained with the various charges.

No. of charge.	Average consumption of power.		Material charged.						Electric energy kilowatt hours.	Pig iron produced.	Consumption of electrodes.		Per ton pig iron.								Time consumed.			Pig iron produced.		Iron content of ore.	Iron content of ore and lime.
	Horse-power.	Kilowatts.	Ore.	Lime.	Ore and lime.	Coke.	Charcoal.	Coke and charcoal.			By combustion.	Total consumption	Coke.	Charcoal.	Coke and charcoal.	*Calculated amount of chemically pure carbon.	Electric energy consumed. Horse-power year.	Kilowatt hours.	Consumption of electrodes by combustion.	Total consumption of electrodes.	Total hours.	Furnace in operation.	Furnace idle.	Per horse-power year (365 days).	Per kilowatt year.		
			Kgs.	Kgs.	Kgs.	Kgs.	Kgs.	Kgs.	Kgs.	Kgs.	Kgs.		Kgs.	Kgs.	Kgs.	Kgs.			Kgs.	Kgs.				Tons.	Tons.	%	%
1	582	428	82600	4034	86634	18672	1468	20140	187467	51425	560	3780	363·9	28·5	392·4	331	0·565	3645	10·9	73·5	475	92·1	7·9	1·77	2·40	62·25	59·35
2	585	431	57400	9934	67334	5446	6925	12371	116591	35380	915	2160	153·9	192·9	346·8	274	0·511	3295	25·9	60·9	309·5	87·4	12·6	1·96	2·66	61·60	52·50
3	653	481	95900	2202	98102	9746	9618	19364	198935	63874	90	710	152·3	150·4	302·7	252	0·483	3114	1·4	11·1	426·5	97·0	3·0	2·07	2·81	66·65	65·20
4	745	548	59900	2396	62296	5906	7891	13797	105485	42660	300	540	136·1	185·0	321·1	254	0·383	2473	7·0	12·7	204	94·2	5·8	2·61	3·55	71·20	68·45
5	800	589	62300	3115	65415	1564	12578	14142	123130	37940	305	540	41·2	331·5	372·7	284	0·505	3245	8·1	14·3	216	96·8	3·2	1·98	2·69	60·90	58·00
6	812	598	62385	1933	64318	....	13662	13662	115770	34728	246	674	....	392·2	392·2	294	0·517	3334	6·9	19·4	198	98·2	1·8	1·93	2·62	55·70	54·00
7	808	595	21400	322	21722	....	5792	5792	44245	15300			....	377·9	377·9	283	0·448	3892	....	....	74·5	100·0	0·0	2·23	3·03	71·40	70·43
1-7	674	496	441885	23936	465821	41334	57894	99228	891623	280307	2410	8404	147·6	206·5	354·1	280	0·492	3181	8·0	30·0	1,903·5	94·1	5·9	2·03	2·76	63·50	60·02

*Calculating the consumption of chemically pure carbon the coke is assumed to contain 85 per cent. and the charcoal 75 per cent C.

Charge.

No.
3

5

conte
gas r

V
the fi
centa
but i
starte

F
in ea
result
CO_2 c

F
most
volum
ing gi
the ar

1'
lower

TABLE V.

Charge.	Date.	Hour.	The composition of gas. Volumetric per cent.				Temperature of the gas,[1] degrees Centigrade.	
			CO_2	CO	CH_4	H.		
No.								
3	June 8	7 a.m.	14·5	......	......	......	75	The gas circulation having been suspended for some days is started and kept invariable.
	" 8	11 a.m.	23·8	......	....	......	......	
	" 8	3 p.m.	27·6	52·0	......	....	......	
	" 8	5 p.m.	23·5	......	......	....	75	
	" 9	10 a.m.	23·6	......	....	....		
	" 10	12 noon	39·0	40·6	......	....	300	Decreasing the gas circulation.
	" 11	11 a.m.	39·2	......	....	......	320	Further decreasing gas circulation.
	" 12	11 a.m.	44·7	39·4	0·6	15·3	250	Still further decreasing gas circulation.
	" 15	9 a.m.	32·2	......	....	....	150	Increasing the gas circulation, which after this is kept invariable.
	" 15	11 a.m.	38·3	......	......	......		
	" 15	4 p.m.	41·0	46·0	.....	12·0	220	
	" 16	10 a.m.	39·0	46·0	....	......	220	
	" 16	10 a.m.	33·6	56·3	......	......	500	Sample taken in the lower part of the shaft.
5	July 6	10 a.m.	22·0	......	......	......	350	The gas circulation suspended.
	" 7	9 a.m.	11·0	....	......	....	90	" " "
	" 8	9 a.m.	8·0	......	......	....	135	" " "
	" 8	10 a.m.	8·0	.	......	....	260	Sample taken from the lower part of the shaft,
	" 9	9 a.m.	17·2	......	......	......	220	The gas circulation is started and kept invariable.
	" 9	3 p.m.	17·6	......	......	......	210	
	" 10	8 a.m.	19·5	......	......	......	275	
	" 10	11.30 a.m.	21·0	......	......	......	215	

The given figures are illustrating. They show that in charge No. 3 the CO_2 content of the gas increases from 14·5 to 39 per cent, while the temperature of the gas rises from 75° to 220°. The ore charged was Fe_2O_3.

With reference to charge No. 5, which was a comparatively lean magnetite, the figures show that the CO_2 content decreased to 8 per cent (the same percentage as in the lower part of the shaft) when the gas circulation was suspended, but increased gradually to 21 per cent as soon as the gas circulation had been started, the temperature of the flue gas rising to 215°.

From the results, it was also evident that a certain speed of circulation was in each case the most suitable, and that a further increase of this speed only resulted in increasing the temperature of the flue gases, when a decrease of the CO_2 content of the gas was soon noticed.

Practical experience will have to determine which speed of circulation is the most suitable, but it is apparent that this depends to a certain degree on the volume of the shaft. Any reliable determinations of the quantity of the circulating gas have not been made, but it may be estimated to be about four to five times the amount of gas produced in the furnace per time unit.

[1] The temperature in the gas outlet was determined by a mercury thermometer, and in the lower part of the shaft by a Le Chatelier pyrometer.

The high percentage of hydrogen in the gas is remarkable. Part of it comes undoubtedly from the charcoal itself, but the greater part is probably derived from the moisture of the fuel. On account of the high temperature, hydrogen is formed, when the moist flue-gas is blown into the furnace.

Consumption of Electrodes.

The consumption of electrodes is a question which is of great importance in the estimate of the economical results of the electric furnace. Due to various reasons, this was not normal with charges Nos. 1, 2, and 3, and should not be taken into consideration. The results with the other charges are given in Table VI.

TABLE VI.

Charge No.	Combustion of Electrodes.	Consumption of Electrodes.
	KGS. PER TON OF PIG IRON.	
3	1·4	11·1
4	7·0	12·7
5	8·1	14·3
6	6·9	19·4
3-6	5·2	13·8

The electrodes used were made in Sweden, of retort carbon, the permitted load being 4 amperes per square centimetre. With reference to the combustion of electrodes, certain conditions seem to indicate that the average figure, given above, could be reduced by 40 per cent. Using electrodes of higher quality, no doubt still better results could be obtained. It is also certain that by using more suitable arrangements the consumption of electrodes could be considerably reduced. By a suitable joining of the electrodes it ought to be possible to make the consumption of electrodes equal to their combustion. During the experiments made only about one-half the length of the electrodes could be used.

The Efficiency of the Furnace.

Of special importance is the efficiency of the furnace, which is the ratio of the useful work produced by the furnace to the electric energy expended.

The power consumed in useful work in the furnace is as follows:—

(1) To produce necessary heat for the reduction.
(2) To melt and superheat the pig iron and slag.
(3) To drive off the H_2O and CO_2 from the charge.
(4) To heat the gases.

The total of this electric energy, less the heat generated by the combustion of the carbon with the oxygen of the ore, is exactly what is theoretically required to be expended in the furnace, and has been called useful electric energy.

Besides this, the electric current has to cover:—

(1) Loss of heat by the cooling water of the stuffing boxes around the electrodes.

(2) Loss of heat in electric conductors and contacts.

(3) Loss of heat by radiation from the brickwork.

Comparing the efficiencies obtained with the different charges, the results with charges Nos. 1, 2, and 7, should not be taken into consideration. With the two former the run of the furnace was not normal, and with the latter the run was too short.

TABLE VII.

Charge No.	Consumption of carbon; chemically pure carbon.	Amount of power required: calculated from the table by aid of consumption of carbon.	Actual amount of power required.	Electric efficiency.	KILOWATTS.			Percentage of iron.
					Total average load.	Useful electric energy.	Loss of electric energy.	
	Kgs.	Kw. hours per ton.	Kw. hours per ton.					
3	252	1470	3114	0·47	481	230	251	58·8
4	254	1438	2473	0·58	548	230	230	65·6
5	284	1741	3245	0·54	589	318	271	54·5
6	294	1870	3334	0·56	598	335	263	51·5

The highest efficiency reached during the experiments was 58 per cent. Table VII shows that the losses vary from 230 to 271 kilowatts, being higher towards the end than at the beginning of the run. According to observations made, the losses of Table VII are divided as follows:—

Losses by the cooling water.. .. ..   118–125 kw.

Losses in the electric conductor and contacts.. ..   40   "

Losses by radiation..   81–110   "

239–275   "

The actual and the calculated losses seem to agree astonishingly well. By building a larger furnace, say of 2,500 horse-power, and by giving special attention to the factors which have influence upon the loss of heat, it seems feasible to construct a furnace of an efficiency of 80 per cent. With such a furnace it would without doubt be possible to reach a production of over 3 tons per horse-power year, providing richer ores are used.

Life of the Furnace.

From the experiments made, it is evidently difficult to estimate the cost of repair to the furnace. The present furnace, however, has been running continuously for 85 days, and should thereby have fulfilled the demands which could reasonably be made as to the life of the furnace. When torn down, the furnace

was in such condition that the operations could still have been continued for some time, had not various circumstances made it necessary to tear it down.

The weakest part of the furnace is the arched roof above the melting chamber, but this can be cooled by gas circulation, which would in a satisfactory way prevent the fusion of the brickwork. The bottom of the hearth and the walls of the shaft should not suffer more than in an ordinary blast furnace. Occasionally, the brickwork adjacent to the electrodes has become red hot, but it ought to be easy to arrange cooling by gas circulation in these places, and besides that, there is no difficulty in repairing these places during the run. The life of the furnace should, therefore, be quite satisfactory, provided that proper arrangements are introduced and suitable brickwork used.

Character of Iron and Slag.

The possibility of making different qualities of pig iron seems to be greater in the electric furnace than in any other process, as by varying the tension of the electric current it is very easy to raise or lower the temperature of the furnace. It was found possible to produce an iron with less than one per cent of carbon; the slag, however, contained a considerable amount of iron. As a rule, the carbon content varied from 2 to 3 per cent.

It is easy to raise the silicon content of the pig iron in the electric furnace. One analysis showed 3·61 per cent silicon, but it is also possible to keep it as low as 0·3 to 0·5 per cent. It might be assumed that all the phosphorus of the charge goes into the iron. It must, however, be remembered that an electric furnace only requires about one-third of the fuel of a blast furnace, and that, in making high-grade charcoal iron, it is the charcoal which gives the largest part of the phosphorus to the iron. Consequently, the electric furnace should produce an iron with lower phosphorus content than what is obtained with the same materials in the blast furnace.

A special advantage of the electric furnace is the great possibility it offers of removing the sulphur. From a charge containing 0·5 per cent sulphur, a pig iron was made containing less than 0·005 per cent. In order to remove the sulphur, here as in other furnaces, a basic slag and high temperature are required. The calcium carbide formed by the electric current is, probably, an important factor in the removal of the sulphur.

Some analyses of the pig iron from different charges are shown in Table VIII.

TABLE VIII.

Cast No.	C	Si	Mn	S	P
32	2·10	0·22	0·40	0·030	1·42
43	3·65	1·67	0·30	trace	0·89
44	3·44	1·06	0·29		1·31
45	3·50	1·58	0·26		0·89
118	3·10	1·03	0·18	0·065	
175	2·84	0·03		0·040	0·117
179	2·34	0·05		0·035	0·143
183	2·38	0·03		0·065	0·076
187	2·38	0·06		0·045	0·080
191	3·09	0·21		0·010	0·156
195	3·09	0·14		0·020	0·194
199	2·41	0·20		0·020	0·150
202	2·02	0·07		0·045	0·091
206	2·88	0·08		0·080	0·104
210	2·56	0·13		0·050	0·075
214	2·82	0·47		0·020	0·070
222	2·62	0·40		0·025	0·058
226	2·13	0·18		0·030	0·042
231	2·33	0·06	1·07	0·020	0·036
234	2·05	0·19	1·07	0·015	0·044
237	2·81	0·19	1·30	0·020	0·054
245	1·70	3·61	2·09	0·005	0·052
249	2·11	0·20	1·40	0·005	0·057
253	2·86	1·67	1·08	0·005	0·046
257	3·150	0·62	0·72	0·025	0·049
261	2·69	0·17	0·26	0·025	0·020
265	2·90	0·09	0·37	0·015	0·041
273	3·14	0·35	0·29	0·005	0·056
277	3·33		0·66	0·005	0·062
287	2·80	0·03	0·09	0·015	0·020

Table IX gives some analyses showing the variation of the iron content in the slag.

TABLE IX.

—	Fe	S	SiO₂
	%	%	%
Raw slag	6·44	0·55	31·46
Normal slag	1·33	0·38	33·30
Washing slag	0·61	0·70	30·11

Table X shows analyses of slag from taps Nos. 245 and 257.

TABLE X.

Tap No.	FeO	MnO	MgO	CaO	Al₂O₃	SiO₂	P₂O₅	S	Fe
	%	%	%	%	%	%	%	%	%
245	0·23	0·48	17·48	38·10	7·77	35·90	0·016	0·06	0·18
257	3·19	2·68	15·43	31·66	6·51	41·10	0·04	0·05	2·48

for some

chamber,
tory way
walls of
asionally,
ght to be
at, there
furnace
ents are

reater in
n of the
furnace.
carbon;
e carbon

furnace.
it as low
e charge
furnace
making
t of the
an iron
erials in

offers of
pig iron
sulphur,
ed. The
factor in

n Table

Conclusions.

Judging from the results achieved by the experiments at Domnarfvet, the problem of making pig iron from iron ore in the electric furnace seems to be technically as well as commercially solved, but in order to fully ascertain this matter, further experiments ought to be conducted on a larger scale. The necessary condition for a profitable smelting of iron ore in the electric furnace is that sufficient and cheap electric power is available. The following are some points in favour of the electric furnace:—

(1) Cheaper cost of erection of the furnace, as blowing engines and hot blast stoves are not required.

(2) Saving about two-thirds of the fuel required in the blast furnace.

(3) Fine ore can be handled in the electric furnace without previous briquetting.

(4) The gas evolved has a high thermal efficiency, being free from nitrogen.

(5) The possibility of producing directly in the furnace iron with low carbon content.

(6) Some reduction in labour, as only about one-third of the fuel required in the blast furnace is to be handled.

It will probably prove advisable later on to combine the electric shaft furnace with an electric steel furnace, in which the liquid iron from the shaft furnace could be refined.

It seems, therefore, as though the electricity in the future would be of greater importance to the iron industry than what has so far been the case.

For much valuable information during the preparation of this report the writer is indebted to Mr. Axel Lindblad, who is entitled to the greatest credit for the construction of the electric furnace; and to Sven Danieli, who has superintended the expériments.

FRICKS ELECTRIC REDUCTION-FURNACE

PRODUCTION IN 24 HOURS — 23·27 TONS
POWER CONSUMPTION — 2000. K.W.
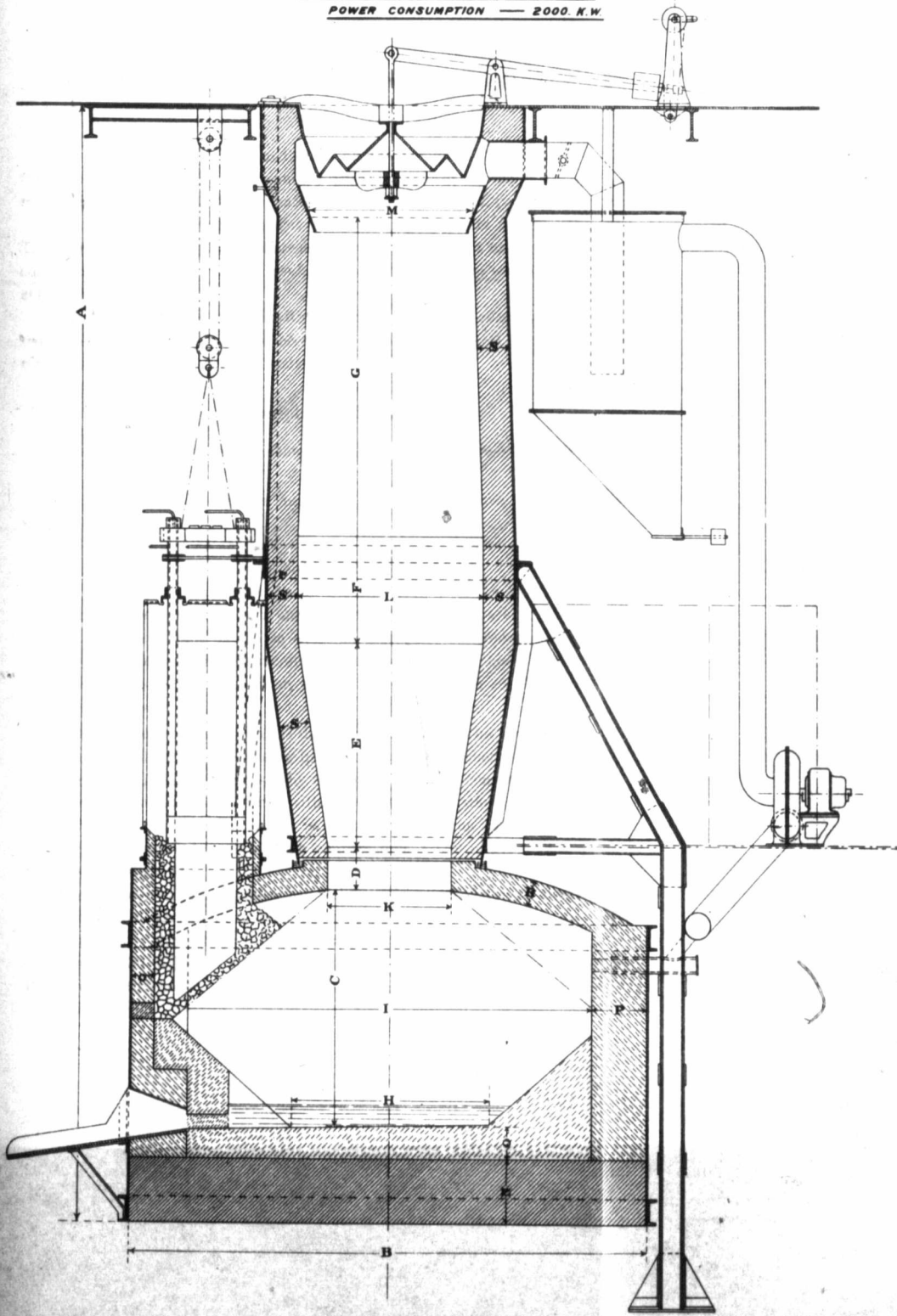

Fig. 14

J

proble

techni

matter

sary o

suffici

favour

(1

stoves

(2

(3

ting.

(4

(5

conter

(6

the bl

I

with

could

I

impor

F

writer

the c

tende

APPENDIX II.

THE 'FRICK' ELECTRIC REDUCTION FURNACE.

System.

The Frick furnace for the reduction of ores belongs to the type of electric furnaces generally called 'resistance furnaces,' because of the material to be treated being used as a resister, heated by an electric current, passing through it.

The characteristic arrangement of this furnace refers to the electrodes. These are surrounded by loose charcoal or coke, and thus not only protected from combustion by the ore, but also insulated against heat losses, which are considerably reduced.

The furnace may be worked with a single or polyphase current. Generally a two-phase current is preferable, because it allows the use of two independent circuits of the greatest possible resistance.

Description of Furnace.

The accompanying drawing shows a furnace of 2,000 kilowatts. The furnace consists of :—

(1) *A wide circular reaction and melting chamber,* covered with a vault-like roof.

(2) *One central feeding shaft,* in which the ore and part of the reducing coal are fed in a similar way as in an ordinary blast furnace.

(3) *Two or more smaller shafts* for the introduction of the electrodes. These latter shafts are provided with openings, through which part of the reducing agent, coke or charcoal, is fed so as to surround the electrodes and to protect them from oxidation. For convenience, these openings are connected by means of small funnels with the top floor, so that the coal may be supplied from there to the electrodes.

The furnace represented on the drawing is designed to be worked with a two-phase current, the two phases being independent of each other.

The whole furnace is encased by a strong steel plate construction.

The reaction chamber is lined with magnesite to withstand the high temperature, which may arise. The lining is of such composition as to be a very poor conductor for electricity even at high temperatures, a fact of great importance in furnaces of this kind.

The diameter of this chamber has to be comparatively large to obtain a sufficiently high resistance and to avoid a too excessive current. This is the opposite of the ordinary blast furnace practice, according to which the furnace is made narrower in the melting zone, mainly with a view to enabling the blast to reach the centre of this zone.

The lower part of the melting chamber, in which the produced pig is collected, is made narrower so as to get a sufficient depth of the iron bath.

The arrangements for tapping pig and slag are the same as in the ordinary blast furnace.

Besides the openings in the wall for tapping of pig and slag, openings are provided, one in front of each electrode and one or more between the electrodes. Through the former the charcoal or coke round the electrode may be raked out when an exchange of electrodes has to be made. The latter may serve for the introduction of gas taken from the furnace top by a ventilator, with the purpose of using the gas as a heat transmitter so as to increase the extension of the hot zone, within which a reduction of the ore by carbonic oxide can take place. This circulation of the gas was first proposed by Harmet, and the idea was recommended by the author in his lecture before 'Jern-Kontoret' in Stockholm, May, 1905.

The main shaft is carried by a special steel beam construction, in a similar way to that used in ordinary blast furnaces, so as not to rest on the roof of the lower chamber.

A sand closing between main shaft and roof prevents gases from escaping this way. On account of the small amount of gas produced in the electric furnace (six to seven times less than in the ordinary blast furnace), the height of the main shaft does not need to be so great. For a 2,000 kilowatt furnace, 6 metres, or 20 feet, will prove quite sufficient in most cases.

The top of the shaft may be closed by any suitable blast furnace top. The drawing shows a 'Charleville' top, as used in Sweden.

The electrodes are carried by a block arrangement, the handles of which are placed side by side near the measuring instruments.

The electrodes are firmly clamped by a water-cooled holder, to which the current is led by means of two heavy copper tubes, simultaneously serving three different purposes:—

(1) As electric conductors.

(2) To convey the cooling water to the holder.

(3) To carry the electrodes.

The current is delivered from one or more transformers, placed in the near neighbourhood of the furnace, and is transmitted to the tubes by heavy copper leads and flexible cables.

The Working of the Furnace.

The starting of the furnace may be done in a similar way as in the case of an ordinary blast furnace. First, a small fire of wood is made to dry the furnace. Then the melting chamber is filled with coke or charcoal, the electrodes are lowered, and the current is turned on. By regulation of the excitation of the dynamo the current is kept low in the beginning, so as not to increase the temperature too quickly.

When the temperature in the chamber has reached 1500° C, the lining has become hard and the furnace is ready to work.

To burn off part of the coal, air may be admitted through the tapholes, precaution being taken all the time that the electrodes are protected.

Now, the furnace is filled with alternate layers of coal and ore with lime. The current is turned on, and raised until full power is reached.

The dimensions of the electrodes and the surrounding layer of coal, which acts as a heat-insulator, are so diminished that the highest temperature will be produced only at the bottom of the electrode, from where the current will find the easiest way and least resistance across to the opposite electrode.

The current, in passing through the coarse mixture of coal and ore, brings this to a high temperature, in which the ore is reduced.

The reduction in the electric furnace differs very much from the reduction in the blast furnace on account of the different sources of heat. The gas in a blast furnace weighs about eight times as much as that produced in an electric furnace during the same time. It, therefore, carries eight times more heat upwards. In fact, the total heat of the gas in the electric furnace when leaving the hot zone is sufficient to heat the stock to about 600° C, whereas in a blast furnace the temperature theoretically could be raised to about 3800° C; providing a great part of the heat is not used for the reduction of the ore. Further, a certain amount of air is consumed by the carbon in rising through the lower part of the shaft.

These two factors extend in a blast furnace the hot zone within which a reduction of the ore can be effected by the carbonic oxide. In an electric reduction furnace the same effect can be obtained by the use of an artificial gas circulation, taking the gas from the top and pressing it into the melting chamber, where it is passed through the hot stock, and acquires a high heat, which is transmitted to the stock in the shaft. In this way a greater part of the carbon may be burnt to dioxide, causing an economy in coal as well as in electric energy.

The gases evaporate the water contained in the stock in the upper part of the shaft. The water vapours in the circulating gas, when passed through the heat zone, are dissociated and form another source of heat in the shaft, thus increasing the effect of the circulation.

In cases where pulverized ore has to be treated, it might be preferable not to use any gas circulation, or only a moderate one, so as not to run the risk of the ore dust being carried off with the gas.

If the prices of power and coal are high, however, it may be economical to use the gas circulation and to have the ore dust briquetted.

The gas, produced in an electric reduction furnace, possesses a much higher calorific value than the gas from a blast furnace, being 1,600 to 2,000 calories per cbm. at 15° C, against 700 to 900 calories in a blast furnace.

The gas is thus as good as best producer gas, and can be used for all purposes, equally well for re-heating furnaces as for open-hearth furnaces.

Sufficient gas is produced for converting the produced pig into steel, if brought in molten condition into an open-hearth furnace. Such a combination will, in many cases, prove most useful, and may be further improved by finishing the steel in an electric furnace.

During the first time of a run the electrodes are allowed to touch or enter into the stock, so as to gradually get the inner edge burnt away. When, however, their under surfaces have assumed a shape of the same slope as the stock, they

should not be allowed to touch the stock, but should be kept a few inches above it, so that the coal from the shafts, surrounding the electrodes, gets an opportunity of rolling down between the stock and the ends of the electrodes. These will thus be perfectly protected from being oxidized. Their life will become considerably longer than in furnaces, where the electrodes enter into or touch the ore.

The wear of the electrodes is due partly to the oxidizing effect of the ore and partly to the mechanical friction of the descending stock. Both these causes are avoided. Only a slight friction will take place between the electrodes and the coal in fine condition, surrounding them.

The heat insulation round the electrodes has, further, the good effect of protecting the walls and the roof against any excessive heat.

On account of the comparatively low temperature prevailing in the main shaft, it is of little value to use thick walls. The thickness of the wall ought only to provide sufficient safety against the wear of the descending stock. This wear is considerably less than in an ordinary blast furnace through the slow downward speed of the stock, the volume of which per ton of pig is slightly more than one-third of that in a blast furnace. On account of the low height of the furnace, the pressure of the stock on the walls is also less than in a blast furnace.

The electrodes, although they are protected against oxidation and excessive wear, will in time wear away. They have to be lowered at long intervals. When finally so worn that the holders become exposed to a too high heat, a fresh electrode may be clamped on the top of the old one, which thus is completely consumed. The clamping together of the electrodes is very much facilitated by the free space round the electrodes when passing through the roof of the furnace. Cheap iron or steel clamps, which are allowed to melt down, are used. To ensure a good contact between the two electrodes, the joint is filled with a good conducting paste of iron, steel, or graphite in powder.

The sheet-casing around each electrode can quickly be removed, if a new electrode is to be inserted.

Coal Consumption.

The consumption of coke or charcoal is determined by the carbon necessary for the reduction of the metalloids and by the carbon in the pig.

The amount of carbon for reduction varies according to the degree at which the carbonic oxide can be utilized for the reduction, and which is indicated by the proportion between the carbon burnt to carbonic oxide and the carbon burnt to carbonic acid, or, what is the same, the proportion of the volume of CO to the volume of CO_2 in the gas.

If $CO/CO_2 = k$, so may the amount of carbon necessary to reduce

$$1 \text{ kg. Fe from } Fe_2O_3 \text{ be put} = 0.428 \ \frac{(1+k)}{1.33 \ (2+k)}$$

1 kg. Fe from Fe_3O_4 be put $= 0.381$ "

1 kg. Si from SiO_2 be put $= 1.142$ "

1 kg. Mn from MnO be put $= 0.291$ "

1 kg. P from P_2O_5 be put $= 1.29$ "

From the ore to be used it is easy to arrive at an approximate analysis of the pig. The value of 'k' depends on varying conditions as stated above. With a good gas circulation 'k' should attain the value of 2 to 2·5. With no gas circulation 'k' may be above 4.

The accompanying Table I gives the amount of carbon necessary at different 'k' for the above-named metalloids.

The carbon in the pig depends upon the amount of excess carbon in the melting zone, and may be varied between 1, and 4 per cent. There will probably be required a much more accurate weighing and analysis of ore and coal to obtain regular composition of the pig than in an ordinary blast furnace, where an excess of carbon must be present. The total consumption of charcoal or coke is easily calculated from their carbon content.

With the aid of the figures of the table, the *amount of carbon necessary for a few sample pigs* is calculated.

Ex. 1. Ore—Fe_3O_4.

Analysis.	k 0·67	1	1·5	2	2·5	3	4
Fe = 96·4%	17·22	18·35	19·64	20·6	21·4	22	21·9
C = 3·0%	3	3	3	3	3	3	3
Si = 0·15%	0·080	0·086	0·092	0·097	0·1	0·103	0·107
Mn = 0·4%	0·055	0·058	0·062	0·066	0·068	0·070	0·013
P = 0·05%	0·030	0·032	0 035	0·036	0·038	0·039	0·040

kg. C. per 100 kg. pig.

	20·385	21·526	21·829	23·799	24·606	25·212	26·120

kg. charcoal at 84% per 100 kg. pig.

	27·3	25·6	27·2	28·35	29·3	30·0	31·1

Ex. 2. Ore—Fe_2O_3.

	18·85	20·10	21·50	22·60	23·50	24·1	25·1
Fe = 94 %							
C = 2·5%	2·5	2·5	2·5	2·5	2·5	2·5	2·5
Si = 1·5%	0·81	0·86	0·92	0·96	1·0	1·03	1·07
Mn = 1·0%	0·14	0·15	0·16	0·17	0·175	0·18	0·19
P = 1·0%	0·61	0·65	0·69	0·72	0·75	0·78	0·81

kg. C. per 100 kg. pig.

	22·91	24·26	25·77	26·95	27·92	28·59	29·67

kg. coke at 87%

	26·4	27·9	29·6	31	32·1	32·8	34·1

Ex. 3. Ore—Fe_3O_4.

Analysis.	0·67	1	1·5	k 2	2·5	3	4
Fe =96 %........	17·16	18·25	19·55	20·5	21·3	21·95	22·8
C = 3 %........	3	3	3	5	3	3	3
Si = 0·5%.... ...	0·27	0·286	0·306	0·32	0·33	0·34	0·36
Mn = 0·5%........	0·07	0·074	0·078	0·082	0·085	0·087	0·09
kg. C. per 100 kg. pig.	20·50	21·61	22·934	23·902	24·715	25·377	26·25
kg. charcoal at 87%	27·7	25·8	27·3	28·5	29·45	30·2	31·3

The weight of the coal varies thus between 240 and 340 kg. per 1,000 kg. of pig, to the greatest extent depending on the value of k.

Theoretical Power Consumption.

Under this item are to be considered:—

(1) *The reduction heat,* or the heat energy absorbed in the reduction of the metalloids, after deducting the heat, developed by the oxidation of the carbon that absorbs the oxygen, made free through the reduction.

(2) *The heat to expel the carbonic acid* from carbonates and the water from hydrates.

(3) *The melting heat of the pig.*

(4) *The melting heat of the slag.*

(5) *The sensible heat* carried away by the gases.

The reduction heat has to be based on the figures, relating to the heat of formation, that have been measured by various experimenters. These figures differ to a certain extent. The subsequent calculations are based on the following mean values:—

1 kg. C	+ 1·33	kg. O= 2·33	kg. Co	= 2470 kg. cal.	= 2·88 K.W.H.
1 „ C	+ 2·67	„ O= 2·67	„ Co_2	= 8080 „	= 9·42 „
1 „ Fe	+ 0·286	„ O= 1·286	„ FeO	= 1350 „	= 1·575 „
1 „ Fe	+ 0·381	„ O= 1·381	„ Fe_2O_3	= 1650 „	= 1·925 „
1 „ Fe	+ 0·428	„ O= 1·428	„ Fe_3O_4	= 1800 „	= 2·1 „
1 „ Mn	+ 0·291	„ O= 1·291	„ MnO	= 1730 „	= 2·02 „
1 „ Si	+ 1·142	„ O= 2·142	„ SiO_2	= 7830 „	= 9·13 „
1 „ P	+ 1·29	„ O= 1·29	„ P_2O_5	= 5900 „	= 6·88 „

Table No. 2 gives the theoretical power consumption necessary for the reduction of 1 kg. of the various metalloids after deduction of the heat developed by the carbon at different values of k.

Table 2 is calculated from the following formulæ:—

The reduction of:—

1 kg. Fe from Fe_2O_3 – ore requires $2 \cdot 1 \quad -\dfrac{0 \cdot 428\ (2 \cdot 88k + 9 \cdot 42)}{1 \cdot 33\ (k + 2)}$ K.W.

1 " Fe " Fe_3O_4 " " $1 \cdot 925 - \dfrac{0 \cdot 381\ (2 \cdot 88k + 9 \cdot 42)}{1 \cdot 33\ (k + 2)}$ "

1 " Si " SiO_2 " " $9 \cdot 13 - \dfrac{1 \cdot 142\ (2 \cdot 88k + 9 \cdot 42)}{1 \cdot 33\ (k + 2)}$ "

1 " Mn " MnO " " $2 \cdot 02 - \dfrac{0 \cdot 29\ (2 \cdot 88k + 9 \cdot 42)}{1 \cdot 33\ (k + 2)}$ "

1 " P " P_2O_5 " " $6 \cdot 88 - \dfrac{1 \cdot 29\ (2 \cdot 88k + 9 \cdot 42)}{1 \cdot 33\ (k + 2)}$ "

The heat to expel carbonic acid from carbonates and water from hydrates. This is, as a rule, made more economically in separate gas-heated furnaces. Only in cases where small quantities of lime are needed which do not justify the erection of extra furnaces, it is economical to use the reduction furnace for this purpose.

The heat absorbed in expelling the carbonic acid from 1 kg. CaO CO_2 may be taken at 0·514 kilowatt hours, and in expelling the water from 1 kg. CaO H_2O at 0·24 kilowatt hours.

The melting point of pig depends mostly on the temperature. From various experiments it has been found that the heat contained in molten pig is very well expressed by the formulæ:—

$218 + 0 \cdot 29 \quad (t° - 1200°)$ calories per kg.

or $255 + 0 \cdot 388 \ (t° - 1200°)$ kilowatt hours per ton.

At 1200° the heat is $= 255$ kilowatt hours per ton

At 1300° " $= 294$ " "

At 1400° " $= 333$ " "

The melting heat of the slag varies very much with varying composition. A slag suitable for a basic furnace should have the composition of a singulosilicate, the melting heat of which may be assumed to be about:—

$440 + 0 \cdot 40 \ (t° - 1200°)$ calories per kg.

or $515 + 0 \cdot 47 \ (t° - 1200°)$ kilowatt hours per ton.

At 1200° the heat is $= 515$ kilowatt hours per ton.

At 1300° " $= 562$ " "

At 1400° " $= 609$ " "

The amount of slag depends on the purity and composition of the ore, and can be easily calculated from the analysis of the ore, the coal, and the lime as shown in the examples given later on.

The sensible heat of the gases depends on the temperature at which the gases leave the furnace and on the amount of water vapour contained in them.

The gases contain—if the furnace is worked without gas circulation—practically only CO and CO_2, together with the water which is evaporated in the upper part of the furnace from the damp stock. Very little hydrogen or hydrate of carbon coming from the charcoal or coke will be present.

If the gas circulation is used, greater amounts of hydrogen and hydrates of carbon will be formed by the passage of the steam through the highly heated coal

in the melting zone, part of which will reburn in the shaft, while one part will be carried away by the head gases.

The sensible heat of the steam in the gases at a temperature of t° C is:—

600 + 0·48 t° calories per 1 kg.

The sensible heat of the gases can be taken to be about 0·25 × t° calories per kg., although for very accurate calculations the increase of the specific heat with the temperature ought to be taken into consideration.

The water in the gases is exclusively derived from the wet stock, and has to be calculated from the analysis.

The weight of the dry gases, which depends on the value of k and on the carbon consumption necessary for the reduction, is:—

$$= \frac{1}{1+k} \quad (2\cdot33\ k + 3\cdot67)\ \text{kg. for 1 kg. C.}$$

The total theoretical power consumption varies generally between 1,200 and 1,350 kilowatt hours per ton, exclusive of the heat absorbed by the slag, which may be anything between 100 and 300 kilowatt hours per ton of pig, and the heat absorbed in expelling the water of the hydrates and the carbonic acid from the limestone, which may add up to 250 more kilowatt hours per ton of pig.

The total theoretical power consumption may thus vary between 1,300 and 1,650 kilowatt hours per ton of pig, if burnt dry lime is used, which latter figure might reach 1,900 kilowatt hours if crude limestone is used.

These figures are based on an ore of not less than about 57 per cent Fe.

In specific cases it is necessary to make exact calculations, based on the analysis of the raw materials and the products.

The radiation losses can only be calculated from case to case. These losses occur partly through the walls and partly through the electrodes. The losses through the walls may be reduced by insulation, but the gain in less heat radiation in a reduction furnace where the hearth is difficult to inspect and to repair is counterbalanced by the greater wear of the hearth.

A greater saving is obtained through the insulation of the electrodes by the surrounding coal in pieces or powder. In the 2,000 kilowatt furnace shown on the accompanying drawing the total losses will be about 320 to 370 kilowatts.

$$\textit{The practical power consumption will be} = \frac{\text{total power}}{\text{total power-radiation loss}}$$

The efficiency of the 2,000 kilowatt furnace will thus be:—

$$\frac{2,000 - 370}{2,000} = \frac{1,630}{2,000} = 0\cdot815 \text{ or } 81\cdot5 \text{ per cent.}$$

$$\textit{The practical power consumption will be} = \frac{\text{the theoretical power consumption}}{\text{efficiency}}$$

and will thus in a 2,000 kilowatt furnace vary between $\dfrac{1,300}{0\cdot815} = 1,600$ kilowatt

hours per ton pig, and $\dfrac{1,650}{0\cdot815} = 2,030$ kilowatt hours per ton pig, if burnt lime is

used, but may increase to $\dfrac{1,900}{0\cdot815} = 2,340$ kilowatts if limestone is charged.

Smaller furnaces give a lower efficiency, and thus require a greater practical power consumption.

Volume and Heat Value of Head-gases.

The volume of gas produced from 1 kg. C is $= 2\cdot03$ cbm. at 15° C.

The total volume of gas per ton of pig depends mainly on the value of ' k ' or the proportion between CO and CO_2

for k = ...	1	1·5	2	2·5	3	4

is the approximate total volume of gas in cbm. per ton pig

if ore = Fe_2O_3	470	497	518	537	550	568
if ore = Fe_3O_4	427	450	470	485	498	515

the heat value of 1 cbm. gas at 15° C in calories

	1,380	1,650	1,840	1,970	2,070	2,210

and the total heat value of the head gases at 15° C in K.W.H. per ton pig,

if ore = Fe_2O_3	755	956	1,115	1,230	1,325	1,465
if ore = Fe_3O_4	683	867	1,006	1,110	1,198	1,328

The heat value per cbm. of the gases is thus generally superior to that of ordinary producer gas. If k is above 2 the gases contain sufficient heat to convert the pig into steel in an open-hearth furnace.

The electrodes have to carry heavy currents of 12,000 to 15,000 amperes, and have to be of big cross-sections, so as to avoid too large losses.

In a 2,000 kw. two-phase furnace, with 4 electrodes, each of these has to be 600×600 mm. if made of retort carbon. If graphitized electrodes are used, a smaller cross-section is preferable.

The heat developed by the current in the electrodes is carried away by the water, used to cool the holders.

The amount of heat lost through the electrodes is in this furnace less than in other furnaces of similar type, on account of the heat-insulation obtained by the surrounding coal.

The transformers are placed on a floor at such a height that they will not interfere with the tapping of slag and pig, and that the copper connexions become as short as possible.

The costs of production depend first of all on the price of the electric energy.

In comparing the electric reduction furnace with the ordinary blast furnace, it is necessary to take into consideration not only the costs of the current compared with those of the corresponding amount of coke or charcoal, but also the facts which put the electric furnace in a better position than the blast furnace. The electric furnace can without any inconvenience treat ore in powder. The coke and coal may also contain great amounts of cheap dust without inconvenience. The purity of the coal is of much less importance on account of the quantity only, being about one-third of that in a blast furnace. The conditions in an electric

reduction furnace are also very favourable for the elimination of sulphur, as in the melting zone a strong reducing atmosphere and high temperature prevail, which are the conditions for an absorption of the sulphur by the lime according to the reaction: $CaO + S + C = CaS + CO$.

The quality of the electric pig will thus in many cases be superior to that produced in an ordinary blast furnace from the same raw materials.

A general rule as to the economical possibility of the electric reduction furnace cannot be produced.

Each case must be considered on its merits. To give an idea, a calculation of two instances may be given. The calculations are based on the following analyses and assumptions:—

Material.		Plant designed for	
		Sweden.	America.
		per cent.	Pulverized. per cent.
Ore	Fe_3O_4	91·5	83
	MnO	0·2	1·5
	MgO	1·5	....
	CaO	2·0	2·0
	Al_2O_3	0·8	....
	SiO_2	2·8	10·5
	P_2O_5	1·2	....
	H_2O	....	3·0
	Fe	66·3	60
Lime	MgO	1·7	1·7
	CaO	96·5	96·5
	Al_2O_3	0·9	0·9
	SiO_2	0·9	0·9
Charcoal	C	84	84
	H_2O	13	13
	Ashes	3	3
Pig	Fe	96	96
	C	3	3
	Si	0·2	0·5
	Mn	0·2	0·5
	P	0·6	....

Slag containing

	0·2 per cent Fe from ore.		1 per cent Fe from ore.	
	kg.	per cent	kg.	per cent
FeO	2·57	2	12·86	2·66
MnO	0·4	0 30	17·20	3·56
MgO	22·8	17·8	4·40	0·91
CaO	63·2	49·3	284·30	58·90
Al_2O_3	12·21	9·6	2·30	0·77
SiO_2	22·81	17·8	161·50	33·50
P_2O_5	4·1	3·2	....	
	128·09	100·00	482 66	100·00

Weight of ore per ton of pig	1450 kg.	1617 kg.
Value of k = CO/CO_2	2·5	4·0
	kg.	kg.
Weight of carbon per ton of pig		
For reducing Fe	213·00	228·00
" Mn	0·34	0·9
" Si	1·33	3·6
" P	4·50	....
" Fe_3O_4 to FeO slag	0·11	0·55
" Carbon in pig	30·0	30·00
	249·28	263·05

	Sweden.	America.
	kg.	kg.
Weight of charcoal per ton pig.....	297	314
Weight of slag per ton pig from ore and lime.................	128·0	482·66
" " ashes..................	9·0	9·34
	137·0	492·00

Theoretical power consumption per ton pig.

	kilowatt hours.	
For the reduction......................................	879·7	929·1
" melting 100 kg. pig and heating to 1400°...........	333·0	333·0
" melting of 137 resp. 492 kg. slag..................	83·4	298·0
" evaporation of water at 100°..............	29·0	66·7
" heating of head gases to 100°.....................	14·9	15·0
	1340·0	1641·8

	Sweden.	America.
Mean power in kilowatt...........	1600	2000
Radiation losses.....	370	370
Efficiency of furnace in per cent....	76·9	81·5
Weight of head gases per ton of pig........................	600 kg.	608 kg.
Volume. " "	448 cbm.	473 cbm.
Heat value " "	1970	2210 calories

	Sweden.	America.
Practical power consumption per ton of pig in kilowatt hours..	1743	2020
Costs of ore, lime, charcoal, and electric energy for 1 ton of pig..		

(a) for Swedish Furnace.

1480 kg. ore @ 12 kr. (Swedish).............................	=	17·80 kr.	=	19·60 sh.
347 kg. lime @ 16 kr. "	=	0·57 "	=	0·60 "
297 kg. charcoal @ 20 kr. "	=	11·90 "	=	13·10 "
1743 kilowatt hours @ 0·006 kr	=	10·46 "	=	11·50 "
		40·70 "	=	44·80 "

(b) for American Furnace.

1617 kg. ore sand @ $1·85 ....$	3·		=	12·90 sh.
261 kg. lime @ $0·4...$	0·105		=	0·45 "
314 kg. charcoal @ $0·8.... ....$	2·51		=	10·80 "
2020 kilowatt hours @ 0·075 cts...............................$	1·515		=	6·50 "
	$	7·130	=	30·65 "

The costs for electrodes will be exceedingly small and may probably be kept below $0·18 = 0·6 sh. = 0·54 kr. per ton of pig.

TABLE I.

CO: CO₂ = k.

$$\frac{1+k}{1\cdot33} \quad (2+k=K)$$

Kg C required for reduction of:—

	100	50	9	6·5	5	4	3	2·5	2·0	1·5	1·0	0·67	0
1 kg. Fe from Fe₂O₃ = 0·428K	0·319	0·312	0·293	0·284	0·2765	0·267	0·257	0·25	0·241	0·229	0·214	0·201	0·161
1 kg. Fe " Fe₃O₄ = 0·381K	0·284	0·278	0·261	0·253	0·2465	0·238	0·229	0·222	0·214	0·204	0·1905	0·179	0·143
1 kg. Si " SiO₂ = 1·142K	0·832	0·834	0·783	0·758	0·739	0·715	0·686	0·667	0·643	0·613	0·572	0·538	0·430
1 kg. Mn " MnO = 0·291K	0·217	0·212	0·199	0·193	0·188	0·182	0·175	0·170	0·164	0·156	0·146	0·137	0·1096
1 kg. P " P₂O₃ = 1·29 K	0·962	0·941	0·883	0·855	0·835	0·807	0·775	0·753	0·725	0·692	0·645	0·606	0·485

TABLE II.

CO : CO₂ = k.

K.W.H. required for reduction of:—

	100	50	9	6·5	5	4	3	2·5	2·0	1·5	1·0	0·67	0
1 kg. Fe from Fe₂O₃	1·163	1·162	1·068	1·038	1·004	0·985	0·940	0·914	0·880	0·842	0·786	0·734	0·585
1 kg. Fe " Fe₃O₄	1·091	1·089	1·005	0·977	0·948	0·930	0·891	0·873	0·843	0·805	0·757	0·709	0·580
1 kg. Si " SiO₂	6·63	6·63	6·37	6·29	6·195	6·14	6·03	5·965	5·875	5·76	5·61	5·405	5·08
1 kg. Mn " MnO	1·383	1·382	1·319	1·296	1·275	1·258	1·229	1·212	1·188	1·162	1·123	1·086	0·99
1 kg. P " P₂O₃	4·06	4·06	3·77	3·68	3·57	3·50	3·38	3·305	3·21	3·08	2·92	2·76	2·32

PLATE I.

3146—p 57   The " Frick " Electric Steel Furnace.
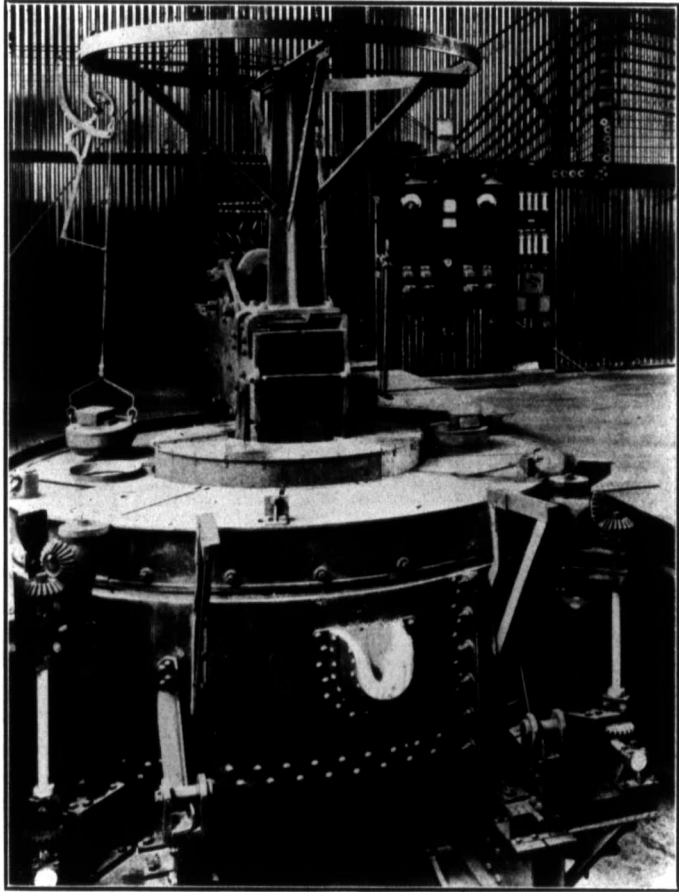
APPENDIX III.

THE ' FRICK ' ELECTRIC STEEL FURNACE.

System.

The Frick furnace for melting and heating steel is an induction, or transformer-furnace.

The heat is produced by a strong electric current of some 20,000 to 200,000 amperes, which by wireless transmission is generated directly in the steel. The hearth is thus in no visible way connected with the dynamo.

Description of Furnace.

The electrical parts of the furnace are:—

(1) *Two primary coils* of insulated copper strips, which receive a single-phase alternating current of 5 to 15 periods, and surround

(2) *A magnetic iron core*, built up of thin iron plates, and forming a closed magnetic circuit around the coils; and

(3) *The ring-shaped steel bath* of uniform cross-section, forming the secondary winding of the transformer.

In big furnaces a third high coil may be placed between the two flat coils to improve the magneto-electric conditions.

The single-phase alternating primary current through the coils sets up an alternating magnetic-flux in the core, which generates a secondary electric current in the ring-shaped metallic circuit formed by the bath in the crucible.

This secondary current is transformed into heat in the same way as the current passing through the filament of an incandescent lamp. Its intensity is equal to primary-current × number of windings in the coils.

In choosing a suitable number of windings it is possible to adapt the furnace to any voltage between 100 and 5,000 volts. This latter voltage is used in the 1,000 horse-power furnace in the Krupp works in Essen, and has never caused the slightest inconvenience.

(4) *Copper connexions* between the furnace and the switchboard. All furnaces, since November, 1904, have been made tilting; therefore, the leads on the furnace are connected with the leads to the switchboard, either by flexible cables, or if low voltage and big amperage is used, demanding too heavy cables, by a switch arrangement, which disconnects the furnace when tilted.

(5) *A switchboard*, with usual instruments, as voltmeter, amperemeter, kilowattmeter, electricitymeter, double-pole switches and shunt-regulator to increase or decrease the power, absorbed by the furnace.

If the distance to dynamo is excessive, it might be less expensive to place the shunt-regulator near the dynamo and to use a relais-arrangement to operate it.

The regulating of the current ought always to be managed from the furnace.

The mechanical parts of the furnace are:—

(1) *A tilting arrangement.* Smaller furnaces are tilted on rockers. For larger furnaces (over 8 tons) live rollers running on circular paths are more suitable.

The tilting can be carried out by hand with the aid of crab and block, by electricity or by hydraulic means. The latter method is the most convenient.

Generally, the centre of rotation is slightly above and in front of the centre of gravity, so that a comparatively small power is needed for tilting.

The only inconvenience of this arrangement is the downward movement of the spout.

When it is purposed to cast directly in the moulds, a certain advantage is gained by bringing the centre of tilting forward to the spout, which thus does not alter its position during casting. This arrangement, which is used in the 1,000 horse-power furnace at the Krupp works, requires a rather expensive beam-construction and hydraulic cylinder.

(2) *A steel construction* to support the furnace-body, the transformer, and other appliances. One part of the platform next to the furnace is also fixed to this construction, so as not to interfere with the tilting.

(3) *A furnace body,* consisting of a sheet-iron casing on two strong beams, resting loose on the steel construction. In case of repair, the whole furnace body can thus be carried away, and in less than two hours can be replaced by a spare one, thus enabling the plant to work nearly continuously.

To prevent any current passing outside the metallic parts of the furnace-body, the casing is made in at least two parts, electrically insulated from each other.

The casing is lined with insulating bricks, within which the ring-shaped crucible is contained.

As material for the crucible is best magnesite used, this is rammed around an iron mould of the shape of the melting channel.

(4) *A cover in one place,* the different constructions of which are discussed below in connexion with the different types of furnaces. The use of one outer and one inner cast-iron or cast-steel ring, between which an arched circular roof of refractory bricks is held, is common.

These rings are also divided into several electrically insulated parts.

(5) *A ventilating fan* for cooling the primary coils and the centre part of the core. The fan has in some cases been placed on the beam-construction, so as not to cut off the air during tilting.

It has, however, been found of no inconvenience to shut off the air even for a couple of hours, if the main current is broken, and as it is advisable to have a spare fan, they are now placed in some distance from the furnace.

The power-consumption of the fan amounts to 0.25 to 0.5 per cent of the total energy consumed by the furnace. In case the air has to be filtered, these figures may be more than doubled. A filtration has, however, been found super-fluous even in the centre of Sheffield steel works.

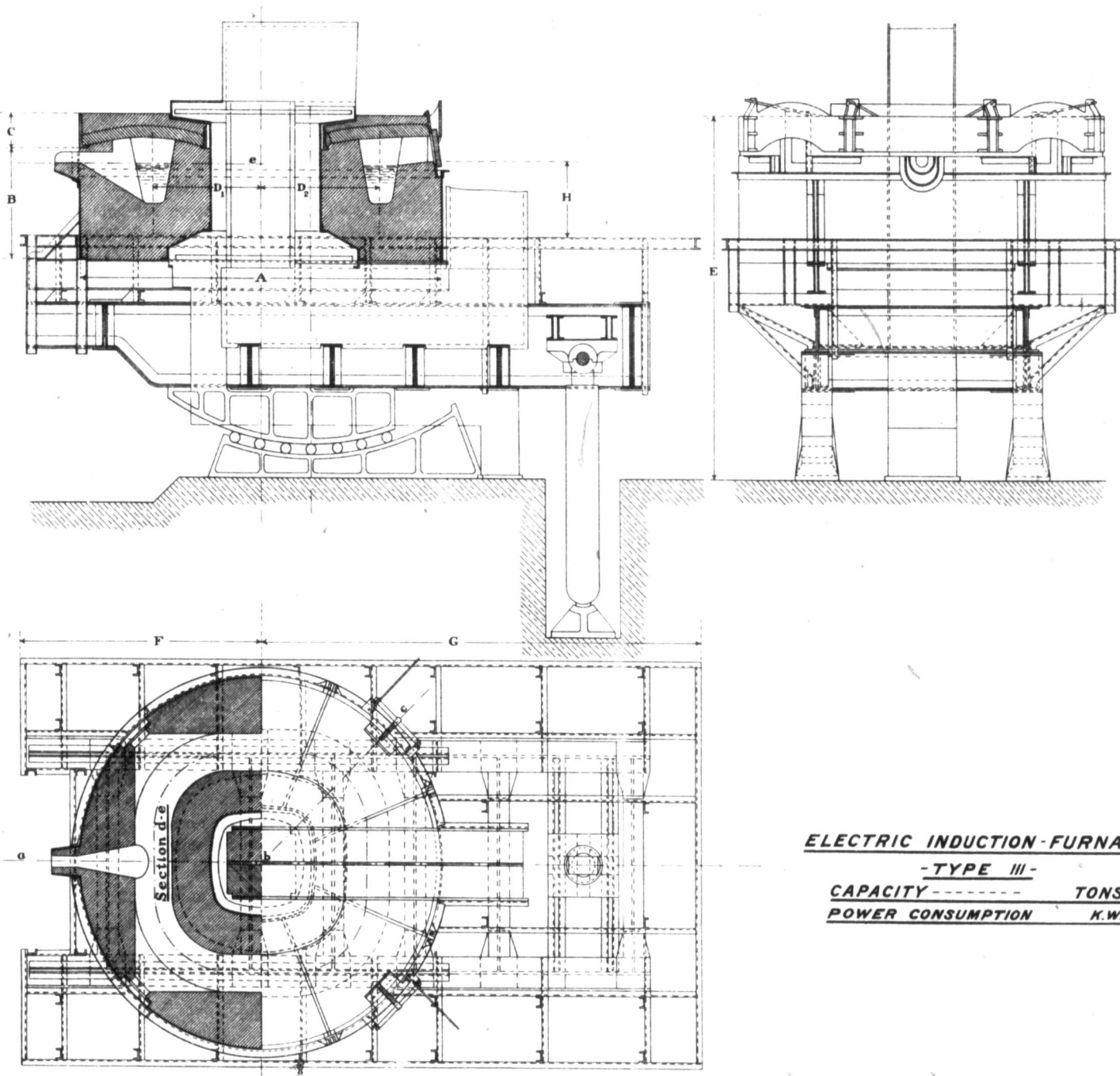*Three different types of furnace* have been devised to suit different purposes:—

Section a·b·c

ELECTRIC INDUCTION-FURNACE
-TYPE I-
CAPACITY --------- 3 TONS
POWER CONSUMPTION 250 K.W.
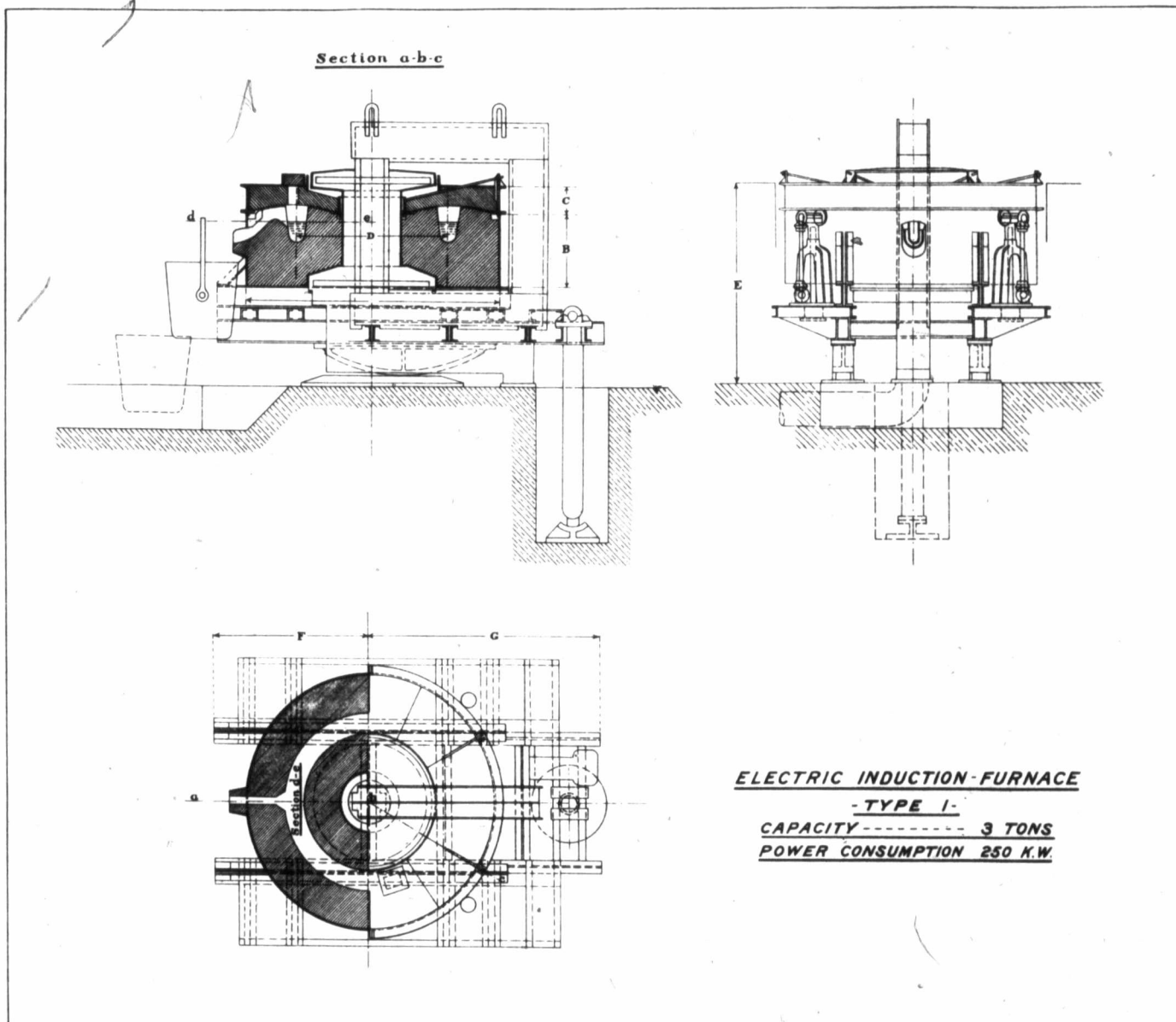
Fig. 15

The furnace i...
small furnaces a rin...
rings are more con...

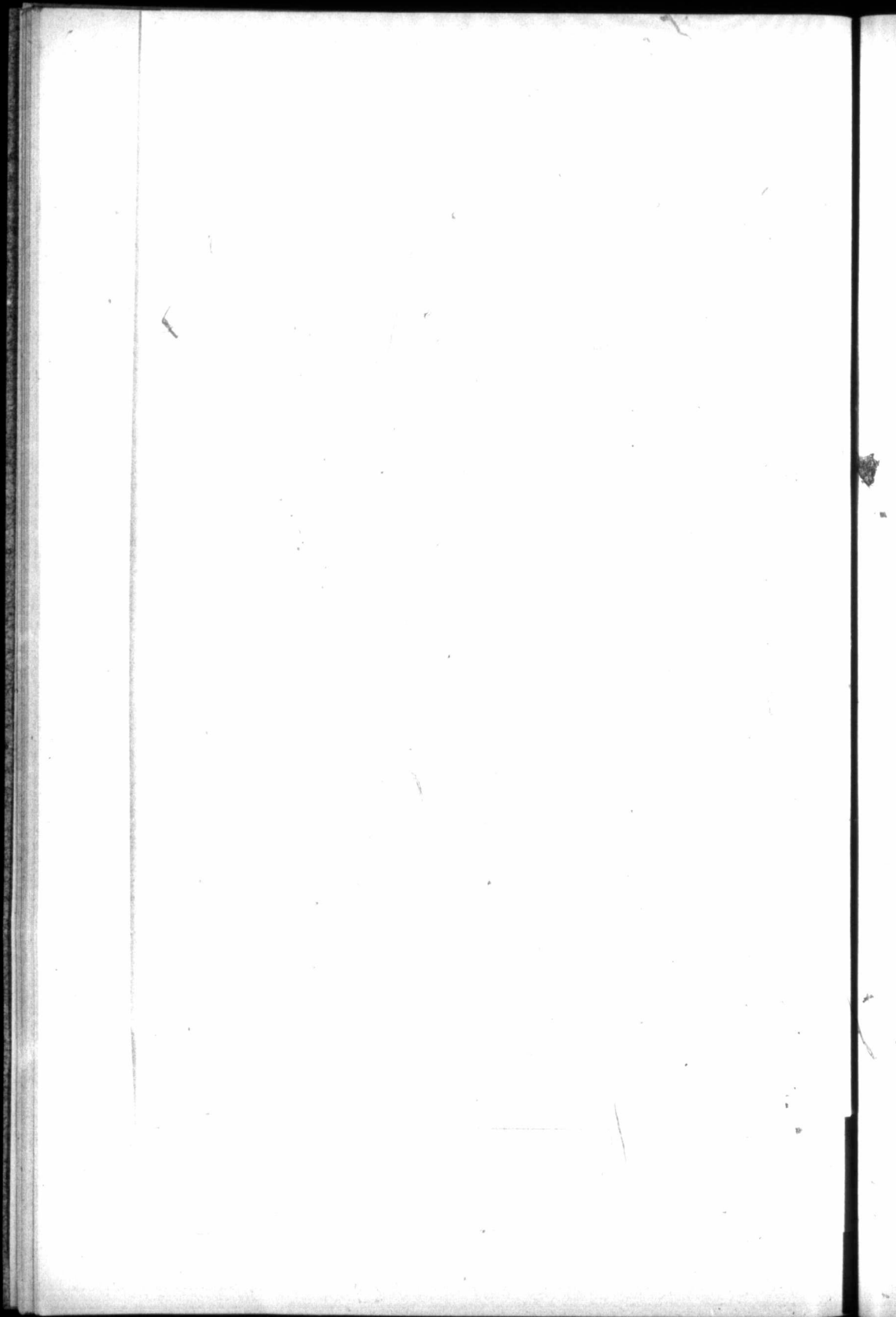Section a·b·c

Section d·e

ELECTRIC INDUCTION·FURNACE
- TYPE III -
CAPACITY -------- TONS
POWER CONSUMPTION K.W.

Fig. 16

Type I: with a rotating cover, for melting of cold material. Plan 1.

The cover rests in four points on wheels, which may be turned round by the aid of shaftings, driven by an electric motor. Two or three openings are provided, through which the materials are charged. Cast-iron plates on the top of the cover, resting on the outside and inside ring, protect the brickwork and add to the convenience of the working.

The air is prevented from entering the furnace between cover and crucible by sand-grooves underneath both the outer and inner supporting ring.

This construction offers the following advantages:—

(1) Every part of the crucible is perfectly free to inspection.

(2) By the use of only a few openings the heat-radiation-losses and power-consumption are considerably reduced.

(3) By turning the cover, additions of lime, charcoal, deoxidizers may be evenly and quickly distributed over the bath. In the same way the slag can easily be skimmed off the bath and removed through the taphole.

Type II: with a fixed cover, provided with a sufficient number of openings, to get access to nearly all parts of the crucible. This type may be preferable in cases where the cost of erection counts more than a saving in power-consumption on account of low power-cost, or for very big furnaces, above 15 tons, in which a turning cover would prove too heavy and cumbersome.

Type III: for heating and refining liquid steel, previously melted in another furnace, Bessemer or open-hearth.

This type has a fixed cover with two or four *lateral* openings, through which the whole furnace can be inspected, slags added and removed and physics added.

Although this type is specially designed for refining steel, it can also be used for melting and refining of cold material, in which case a charging machine should be used to bring in the charge quickly and to prevent too great heat-losses through the furnace-doors.

This type resembles as much as possible an open-hearth furnace. It has not yet been tested in practical work, but judging from the very satisfactory results obtained in the Roechling-Rhodenhauser furnace, and published in the Journal of the Iron and Steel Institute, 1909, Vol. I, there is little doubt that it will become of most valuable assistance in the electrical refining of steel.

The main advantages are:—

(1) A greater surface of the bath, facilitating the reaction between slag and steel.

(2) The heat generated uniformly in the whole bath.

(3) No heavy circulation of the steel for heat-transmission, but only a gentle rotation, sufficient to ensure regularity of product, but not cutting the lining, which with a little attention can be made to stand for several weeks.

Description of the Working of the Furnace.

The furnace has always to be started with the aid of a cold steel-ring. In small furnaces a ring of steel wires has been used. For larger furnaces cast-steel-rings are more convenient.

On turning on the current the ring is heated, and the temperature of the crucible is slowly and steadily raised.

The regulation of the current is effected either by varying the number of turns in the primary coils, by influencing the exciting field of the dynamo, or by affecting the speed of the engine. The second method is the most common.

When the ring reaches a temperature of about 1,400° C and starts to melt, the furnace lining has become hard. If liquid steel from another furnace is available, it may now be poured into the furnace, dissolving the ring. But the starting ring may also be heated until it melts. Sometimes the ring will break in one place, before a sufficient quantity of liquid steel has been formed on the bottom of the crucible to ensure a closed electric circuit. The crack is then filled with turnings, which in fusing weld the ring together again.

By covering the ring with charcoal, when near the melting point, the scale formed on the ring is reduced, and the melting down of the ring is quickened.

As soon as a liquid bath has been formed, the furnace is ready to start regular work.

Melting of cold material.—The metal to be charged, of suitable size and weight, should be distributed as regularly as possible. As the heat is generated directly in the melted steel, and at the same rate in every part of the furnace, very little heat-transmission is necessary, the cold pieces being, as it were, dissolved in the already liquid metal.

For the sake of power-economy, the charging is done as quickly as possible, to keep the furnace at its lowest possible temperature during the melting down of the metal. The radiation losses increase as the square of the temperature in the furnace.

After the whole charge has been brought in, the further treatment depends on the quality of raw materials used and of product wanted.

If raw materials are sufficiently pure, only a deoxidation may be necessary, otherwise a refining from phosphorus and sulphur may also take place. These processes are about the same in treating cold as in treating liquid material, and will, therefore, be discussed together.

Heating of liquid steel.—The electric furnace in countries without cheap water-power will only in exceptional cases be used to melt cold material for the production of high quality steel. This melting down can be effected cheaper in an open-hearth furnace.

This may clearly be proved by considering the total efficiency, obtainable out of coal, if on one side used to provide gas for a Siemens-furnace, and on the other side to generate electric power.

It will be sufficient to compare the most efficient cases.

The most economical results from coal are obtained, if it is gasified in big recovery plants.

Such gas can be used either directly in an open-hearth furnace or to drive a gas-engine, connected to a dynamo, furnishing current to an electric furnace.

In a well-designed plant of a 15 ton, 2,500 horse-power furnace, the efficiency of the different parts ought to be:—

Gas-engine..	30 per cent.
Dynamo..	91 "
Electric furnace, for cold scrap.	82 "
Total efficiency of the electric steel melting.. ..	22·4 "

The efficiency of a 15 ton open-hearth furnace of very best construction is 25 per cent, but reaches in general only 20 per cent.

The electric melting gives thus about the same output per ton of coal as an open-hearth furnace.

The price of the electric steel is, however, higher on account of the more expensive plant, including gas-engine and dynamo.

Considering that the efficiency of the open-hearth furnace drops considerably at high temperature, partly because of the slower transmission of heat, partly because of the greater radiation-losses, whereas the efficiency of the electric furnace does not drop more than perhaps 3 or 4 per cent if the temperature is raised from 1,500° to 1,650°, so must a combination of the two furnaces give very satisfactory results. On account of the three to four times greater production which is obtained from the electric furnace if the melting is effected in another furnace, the primary costs of the plant do not influence the price of the steel so very much.

The electric furnace will thus find its widest application for treating melted steel, delivered either from a Bessemer, or a Siemens-Martin furnace.

It will probably in most cases be convenient to erect the electric furnace distant from the auxiliary furnace, and to have the steel brought in a ladle, although it may also be delivered through a runner directly from one furnace to the other.

If a ladle is used, its content is tilted into a short channel, provided with arrangements to retain the slag and with a short vertical runner at the end, directing the steel towards the bottom of the crucible.

Immediately after a complete ring has been formed, the switches are closed and the excitation of the dynamo increased as quickly as possible, and so full power may be reached, before the ladle is empty, which means a certain advantage over arc furnaces.

The treatment of the steel depends on the degree of refining that is desired.

Slagging.—Before entering on the topic of refining, the different ways of slagging may have to be mentioned.

In the treatment of pure raw-materials very little slag is necessary—only sufficient lime having been added to neutralize the silicon from the metal. This slag is poured out in tapping the steel.

In a furnace of type I, having a rotating cover, the slag, shortly before, and during the operation of tapping, is brought forward to the spout in a most convenient way by means of a skimmer. The man places himself on the cover, and starting on the one side at the back of the furnace forces the slag in front of the skimmer towards the spout whilst the cover is turned. Then the other side is skimmed off in the same way. The whole operation is performed in less than one minute.

If the slag happens to be rather stiff, it might be necessary to assist in getting round the corner at the spout. With proper adjustment of the lime added,

the slag is easily made sufficiently fluid to run out by itself, only needing a slight assistance at the back part of the furnace.

In a furnace of the type II, with a fixed cover having numerous openings in the top of it, the slagging is generally done in the same way; but, as the skimmer has to be taken from one opening to another, the work is much less convenient.

In a furnace of the type III, with two or four lateral doors, the slag can either be drawn out through these or tapped through the spout.

The refining of the steel requires much greater quantities of slag, making its withdrawal more difficult. On this account only the types I and III are to be recommended.

For the refining, at least two slags are required.

The easiest and most effective way to get out the first slag is by pouring the whole content of the furnace into a ladle, the slag being brought to the spout in the same manner as described above.

The metal is returned to the furnace through the bottom of the ladle.

The slagging in the Frick furnace is thus as convenient as in any other electric furnace. In arc furnaces the electrodes interfere with the work. It has repeatedly been stated, that slagging in an ordinary transformer furnace is impossible. Such statements are evidently based on experience with the original Kjellin furnace, in which a deep and narrow channel is used, a number of sectional covers have to be lifted off to get access to the bath, and the slag is cooled through the considerable radiation loss taking place on account of the construction of the covers.

In the Frick furnace the slag is hot by the good heat insulation obtained with the cover in one piece.

Slags, which are sufficiently basic to prevent a cutting of the lining, run out in tapping with very little assistance. Not the slightest difficulty has been experienced in this direction.

It is also evident that this furnace cannot offer any greater difficulty than the Roechling-Rodenhauser furnace, as to the convenience of withdrawing the slag, as the crucible is quite sufficiently wide for the raking tools, or 300, 350, 420, and 500 millimetres at the surface of the bath in a furnace of 3, 5, 8 and 15 tons capacity, respectively.

Refining.—The refining can be carried on in the Frick furnace in the same way and to the same degree as in other electric furnaces.

The surface of the bath is, as a rule, 10 to 20 per cent larger than in other furnaces, thus furnishing plenty of contact for the reactions between the steel and the slag.

Through the gentle and steady rotation of the steel, described later on, these reactions are essentially furthered.

The temperature of the slag is also of great importance. For a given temperature of the steel, the temperature at the contact between steel and slag must be the same for all furnaces.

In arc furnaces the temperature of the slag increases and has its highest value at the upper surface, the heat being developed above the bath.

In an induction furnace the slag is less hot at the upper surface, all heat being generated in the steel.

The mean temperature of the slag in an arc furnace is thus higher than in an induction furnace.

The fall of the temperature is, however, not great, if proper care is taken to get good heat insulation above the bath, which is one of the main advantages of the cover in the Frick furnace.

In melting pure materials only a thin layer of slag covers the steel, and it has been found that the difference between the temperature on the top of the slag and that of the steel is scarcely perceptible with a Wanner or Féry pyrometer.

In refining, rather large quantities of slag are required, resulting in a greater difference of temperature.

Should the slag on the top not become fluid, and thus not participate in the reaction, this can easily be remedied by stirring the slag, which in the Frick furnace can be much more easily done than in an arc furnace, where the electrodes interfere, and may easily be damaged, and where the melter is exposed to electric shocks.

The refining results in induction furnaces are quite equal to those in arc furnaces.

Dephosphorization.—According to the degree to which the phosphorus has to be reduced, one or two slags have to be used. The dephosphorization is accomplished in the same way as in the open-hearth furnace, by the combined action of lime and oxide of iron.

The high temperature of the electric furnace facilitates the elimination of phosphorus.

As all furnaces until now have exclusively been used for the melting of pure stock, very little actual results can be given. In one instance, however, the phosphorus was reduced to 0·004 per cent.

The experience with other electric furnaces of similar type shows that similar results may be obtained in quite a secure and regular way.

When the dephosphorization is completed, all the slag has to be removed. The quickest and most radical way is to empty the whole furnace and to return the steel alone. This method is more suitable for the Frick furnace than for arc furnaces, less time being lost on the ground mentioned above. Care has to be taken to prevent any considerable loss of heat by radiation during this procedure. Runners and ladle ought to be kept well covered.

Desulphurization can be carried much further in an electric furnace than in a Bessemer or open-hearth furnace, on account of the ease with which a non-oxidizing or neutral atmosphere, and thus a slag free from oxides, can be maintained.

Before the sulphur can be eliminated, it is necessary to reduce, as much as possible, the ferrous oxides, absorbed by the steel, during the oxidation process. This is done cheaply with charcoal or retort carbon dust, spread on the bath. To prevent the carbon from igniting in the air, it should be protected with the lime, which is needed for the formation of the finishing slag.

To make this slag fluid a certain amount of sand, fluorspar, chlorcalcium, must be added.

As soon as the oxides have been reduced, the sulphur can be absorbed by the slag, combining according to the formula: $CaO + C + FeS \rightleftharpoons CaS + Fe + CO$.

The resulting calcium-sulphide being insoluble in the steel, this is ensured against any re-absorption of sulphur, as long as the bath is protected by a neutral atmosphere, preventing the formation of FeO.

The carbon-content of steel.—When high-class steel is produced by melting pure raw materials, or the electric furnace is used to take the place of the crucible process, the proper carbon-content is obtained by the suitable mixing of pig and scrap.

A certain oxidation of the carbon takes place mainly through the scale and rust on the raw materials. After the bath is well melted a sample is taken, and if the carbon is too high, scale or pure ore is added. If the carbon is too low, carburizers as spiegel or retort carbon are used.

In some cases liquid steel of about the same carbon-content as the ultimate product is delivered into the electric furnace, as for instance, if in combination with an open-hearth furnace, in which the steel has been melted and dephosphorized to a sufficient degree without eliminating the carbon.

If delivered from a Bessemer plant, or if the phosphorus is wanted as low as 0·01 per cent or less, the liquid steel is preferably delivered low in carbon.

The recarburization is then effected after the dephosphorization and along with the desulphurization.

To make the bath absorb the carbon quickly, the carburizer should be sufficiently heavy to dip into the steel, so as to offer a big surface of attack.

Retort carbon or carbon briquettes, made heavy through an admixture of pure steel turnings, are convenient for the purpose.

A further recarburization may be made in the ladle by adding bags of charcoal if the last sample before tapping shows an insufficient content of carbon.

Deoxidation.—As on account of the construction of the Frick furnace only very little air can enter the crucible, and the atmosphere over the bath is reducing or neutral, the amount of oxygen passing from the air into the steel is very small. However, even in melting high-class steel from pure raw materials, there is a certain oxidation caused by the rust and scale from scrap and pig. A deoxidation has to follow, and is carried out in the usual way by adding in the furnace, a short time before tapping, proper amounts of reducing alloys, such as ferro-silicon or silicon-manganese-aluminium. From the quantities of the deoxidizers used, one can gather that the amount of Fe to be reduced is about 0·2 to 0·6 per cent of the total weight of the steel.

If the steel has been purified from phosphorus, either in the electric furnace itself or by foregoing treatment in a Siemens-Martin or Bessemer furnace, it contains considerable quantities of oxides. These are, as mentioned above, to a great extent removed by retort carbon or charcoal, and, if a desulphurization of the metal is wanted, the deoxidation is a condition for and goes hand in hand with the purification from sulphur. Therefore, if the sulphur is removed to traces, the greatest part of the oxides will have left the steel, and only a small quantity of reducing alloys have to be added for further deoxidation.

If, however, the steel is kept in a strong circulation and movement, as is the case in most of the electric furnaces, the finest particles of the slag, which are distributed in the metal like the constituents of an emulsion, cannot be separated from the steel, thus preventing a complete deoxidation. As will be discussed farther down, the circulation in the Frick furnace is much less pronounced than in other electric furnaces, only a gentle rotation of the steel taking place.

Additions for special steel.—The electric furnaces, especially the induction furnaces, are well suited for producing high speed and other alloyed steel. In arc furnaces there is a difficulty and uncertainty in obtaining a product of proper composition, as the difference in temperature, and the heat of the arc in particular, influence the reactions between additions and steel. But for the induction furnace, where the temperature is the same in every part of the steel, the additions can be calculated in exactly the same way as in a crucible, with due regard taken to the basic slag and lining.

Tapping.—When the steel is 'killed' and ready to tap, the slag is brought forward to the spout, the current is switched off, the furnace tilted, and the steel poured into the ladle. Final additions of manganese and silicon should be made to the steel when in the ladle, this way of working giving a better control over the composition of the product.

If the furnace is charged with cold material, about one-third to one-fourth of the steel has to be left to form a sufficient bath, but working with molten metal, the crucible is completely emptied. This done, the furnace is tilted back, the current switched on again, and the furnace is ready for next charge.
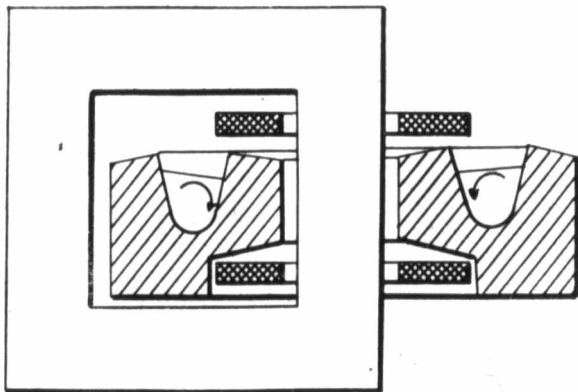

Fig. 17.

Rotation of steel bath.—The magnetic leakage fields around the primary coils cutting the paths of the electric current through the steel, produce a movement in the direction of the arrows, and a force pressing the steel towards the outer wall, causing the surface to take an inclined position.

This rotation has thus a tendency to carry the slag—floating on the steel—towards the inner wall, and can, especially in big furnaces, if it becomes too rapid, cut the lining by mechanical friction.

3146—5

As the rotation is caused by the electro-magnetic forces, it can only be regulated by suitable dispositions of the coils. In this respect the arrangement of two flat coils above and below the crucible offers considerable advantage over the arrangement of one high coil between the inner wall of the crucible and the iron core, as proved in a competition between the two systems at Krupp's works.

Effect of slag on lining.—The slag, being forced from the outer wall, hardly affects this at all; its cutting effect is concentrated on the inner wall.

At first this appeared a rather serious drawback, the life of the lining being very much reduced by the unequal cutting of the two walls. But in fact this rotation of the steel is of great importance in ensuring the inner wall from cutting, if only some little precaution is taken to feed in basic materials, preferably lime and magnesite, before materials containing silicon or phosphorus are introduced. Through the rotation the lime is pressed against the inner wall, and prevents the particles of silica and phosphoric acid, through the rotation brought up to the surface along the outer wall, attacking the inner wall. The acid particles become, so to say, satisfied by the basic materials before reaching the inner wall, which by a little attention may be kept practically unattacked.

This method can be regarded as an automatical repairing of the lining.

In some cases it might be regarded as less desirable to use a very basic and rather stiff slag; the inner wall may then be protected against cutting by an artificial cooling of the slag-line. It is evident that the heat losses, involved in such cooling, are very much less than if the outer wall were subjected to the cutting effect of the slag.

Uniformity of product.—The fear has been expressed that the additions made in the comparatively long and narrow channel of the induction furnace, should not be equally distributed through the steel. Analyses from the Frick furnace prove that the metal is perfectly uniform in every part of the furnace.

But even with the same analyses, the ingots from one charge or the bars from one ingot can differ in quality, and objections have been raised against the electric furnace as not producing a steel of equal and reliable composition. This might sometimes happen in furnaces where there is a difference in temperature, or where the movement of the bath is so strong as to not permit particles of slag, mechanically mixed with the steel, to settle and separate. In the Frick furnace, with equal heat in every part and only a gentle rotation, there is less liability of this occurring.

Cooling of coils and centre core.—The heat, produced through the electrical and magnetical losses in the iron core and the coils, as well as the heat radiation from the outer surface of the inner wall, must in some way or other be carried away, to prevent the insulation in the coils from becoming damaged, and also to keep down the losses in the coils, the electrical resistance in which increases with the temperature.

The coils are constructed to stand a temperature of up to 120° C, but do not reach more than about 60° to 70° C.

The cooling is effected by the means of air delivered from an electrically driven fan. The amount of air required is calculated on the basis of 1 cubic

metre air per 1 second to deal with 1 kilowatt of loss at 1° C increase of tempera-
ture.

The power required by the fan only amounts to 0·25 to 0·5 per cent of the
total energy of the furnace, unless a filtering of the air is required.

In very big furnaces, over 2,000 horse-power, the pressure which the fan will
have to overcome to force a sufficient quantity of air through the narrow space
between furnace body and iron core, may require too much power, so that a
cheaper and more effective cooling would be arrived at by use of circulating oil
in similar manner as in ordinary transformers.

Precautions to protect lower coil.—One of the main critiques against the
Frick furnace suggests the danger to which the lower coil is exposed in case of a
breakdown of the crucible.

This danger is totally avoided by the arrangement of channels in the brick-
work, which deflect any liquid steel from the centre towards openings in the
bottom of the furnace body at such places, so that no harm either to the coils or
to other metallic parts of the furnace can be done.

The precautions have been so satisfactory that, after their introduction, not
the slightest damage has had to be recorded, although breakdowns have been
rather numerous during the experiments with the lining.

Steadiness of power.—One of the advantages of the Frick furnace against
the arc furnaces is the absolute steadiness of the power-demand.

In treating liquid steel, the full power can be maintained throughout the
process without any attention or regulation.

In melting down cold scrap, the excitation has to be increased with the
increase of the bath.

This steadiness of the load is of great value to the power plant, and makes
the costs of upkeep and repair of the engine a great deal lower than in the case
of arc furnaces.

Maximum capacity and power of furnace.—The economy of the electric
furnace is improved by increase in size in similar manner to most technical
apparatus.

It is, therefore, of importance not to be too much limited as to size and
power.

The Frick furnace has already been built up to a capacity of 10 tons and a
power consumption of 1,000 horse-power. The excellent results of this furnace
show that no extra difficulties arise from the larger size.

A 15 ton furnace, to consume 2,500 horse-power, has been designed for the
treatment of liquid steel. The dimensions and price of such a furnace do not
indicate that a limit has been reached.

By combining two furnaces, sizes of up to 50 tons and 4,000 horse-power may
be obtained.

Furnaces erected and in operation.—Three furnaces have been built, all
meant to replace crucible plants, and up to now only cold material has been
charged.

One furnace of 1,800 kg. capacity and 250 horse-power, erected at Messrs.
John Brown and Company, Limited, Sheffield, for experimental purposes, has

given satisfactory results with regard to the melting, and the steel has proved to be equal to crucible steel. At Messrs. William Jessop and Sons, Limited, Sheffield, a furnace of 3,000 kg. and 600 horse-power is built, which has not yet come into regular working.

The most decisive results have been obtained with a furnace of a capacity of 10,000 kg. and 1,000 horse-power, installed at the works of Messrs. Fried. Krupp, A.G., in Essen. The furnace has been in regular operation since January this year, and proved so successful, that the firm has taken over the exclusive patent rights for Germany. Results from one melting-period are given below:—

'Duration of melting period, June 2–July 14. . . . . 42 days.
Number of charges. 134
Average time for charge. . . . . 6½ hours.
Metal charged. . . . . 883 tons.
Good ingots produced. 850   "
Loss and waste. 33 tons = 3·73 %
K.W.H. per ton charge, heating of furnace included. 638
    "   "   "   "   excluded. 623
    "   "   ingot   "   excluded. 647
    "   "   "   "   included. . . . . . 663.'

Purposes for which the Frick Furnace is Suitable.

(1) *High-class steel* (high-speed steel, tool steel).—Steel from the Frick furnace has been used for different kinds of tools with good result. Chisels were tested on castings, and reported to be fully equal, or in some cases better, than those of crucible steel. The same refers to shear-blades: their time of working on bars up to 1 per cent C being 64 hours, against those of crucible steel, 52 hours.

2. *Good quality rolled and hammered steel* (rails, tyres, shafts, wire). Tyres, made of steel (C = 0·65 to 0·70 per cent), produced in a Frick furnace, gave the following figures in the drop-test:—

Original diameter of tyre = 1265 m/m = 49¾".
Weight of 'Tup' = 1000 kg. = 2200 lbs.

No. of blows.	Height of drop.	kgm.	Foot. lbs.	Diam. of tyre.	No. of blows.	Height of drop.	kgm.	Foot. lbs.	Diam. of tyre.
1	3 m.	3000	26000	1244	13	5 m.	5000	43300	1102
2	"	"	"	1229	14	"	"	"	1090
3	"	"	"	1215	15	"	"	"	1079
4	"	"	"	1205	16	"	"	"	1069
5	"	"	"	1190	17	10 m.	10000	86600	1022
6	"	"	"	1188	18	"	"	"	987
7	"	"	"	1181	19	"	"	"	955
8	4 m.	4000	34700	1162	20	"	"	"	923
9	"	"	"	1149	21	"	"	"	898
10	"	"	"	1138	22	"	"	"	877
11	"	"	"	1127					
12	"	"	"	1118		Not broken.			

(3) *Steel castings.*—The electric steel is suitable for all sorts of steel castings, on account of the absence of gases, causing blow-holes in ordinary open-hearth and Bessemer steel. In the electric furnace a dead soft material of practically unlimited temperature can be produced, giving castings of the thinnest sections perfectly sound and clean.

The comparatively low *power factor* of the Frick furnace does not influence the melting costs, and only to a small degree the first cost; in fact, only the price of the dynamo.

According to a formula, developed by the inventor in a paper read before the Swedish Metallurgical Society ' Jern-Kontoret ' in May, 1905, the power factory of an induction furnace being $\cos \phi$ is :—

$$\operatorname{tg} \phi = \frac{\sim}{15,950,000} \times \frac{1}{R} \left(\frac{1}{W_p} + \frac{1}{W_s} \right)$$

$\sim$ = periods per second of the alternating current.

R = electric resistance of the steel bath in ohms.

W_p = the magnetic resistance round the primary coils.

W_s = the magnetic resistance round the secondary circuit, or the steel bath.

The same formula is applicable to arc furnaces, and it brings out the fact that a high electric resistance and weak magnetic leakage fields make tg ϕ small and $\cos \phi$ or the power factor high.

In arc furnaces the electric resistance is concentrated in the arc, and requires a voltage of 50 to 60 volts to be overcome.

In the Frick furnace, the voltage, which is necessary to overcome the resistance of the bath, is only 8 to 12 volts.

The magnetic resistance of the leakage fields is also very low.

The consequence is that tg ϕ is very high.

It is a good rule to use tg ϕ 10 at 10 periods as a measure of the electric and magnetic conditions of a furnace. The value of tg ϕ 10 varies for the Frick furnace between 0·6 and 5 for furnaces of 1 to 15 tons.

From the formula it will be seen that tg ϕ increases proportionately to the periodicity of the current. As a high value of the tg ϕ corresponds with a low $\cos \phi$, one way of obtaining a high power-factor is to use a current of low periodicity.

The power-factor has no influence at all on the power consumption of the furnace, but only on the size and price of the dynamo.

For every size and power of furnace one periodicity is the best, giving the lowest cost of total plant.

The periodicity varies from 5 to 15 periods per second.

The price of the dynamo is in all cases higher than for an arc furnace. By special designs to meet the extraordinary conditions which arise through the low periodicity and power-factor, it has been possible to simplify the construction and to reduce the price of the dynamo to such an extent, that it influences the price of the steel very little.

In the case of a 15 ton, 2,500 horse-power furnace, the extra cost of the dynamo above a standard type will only be about £2,000, affecting the price of the steel with about 0·15 sh. per ton if melted steel is treated.

Why is single-phase preferable to polyphase current?—As will be shown later on, in the economy of an electric furnace mainly depending on the degree to which radiation-losses are reduced, these losses are 80 to 92 per cent of the total.

As now the amount of heat radiated increases with increasing surface, other conditions being equal, it is important not to unnecessarily increase this surface.

The smallest possible surface and radiation loss is obtained with only one ring-shaped crucible.

To utilize a two- or three-phase current, two or three ring-shaped crucibles are necessary, and increase the radiating surface by more than 30 per cent.

The only advantage of a three-phase current is, that the price of the dynamo is lower, but this lower first cost is outbalanced by the higher power consumption, unless the power is very cheap.

It may, exceptionally, be wanted to connect the electric furnace, if of small capacity, to an existing three-phase plant; but as a rule it is preferable to have separate dynamos for the furnaces, so that the power consumption can be regulated by influencing the excitation of the dynamo, without interfering with other consumers.

The simplest combination is one engine for each furnace.

If a separate dynamo has to be used, it is of no use to complicate the furnace, but to stick to the simpler system of mono-phase current.

Efficiency and power consumption.—The electrical energy, delivered to the furnace, is spent on:—

(1) Losses in the primary coils and in the magnetic iron core. These may be called electrical losses, and can be kept down by using ample dimensions. They generally amount to 4 to 5 per cent.

(2) Heat losses, either conveyed from the bath through the walls to the outer surfaces, and radiated to the surroundings, or directly radiated from the steel through openings in the furnace.

These losses depend on the temperature of the steel; on the thickness and insulation of the walls; and on the size of the radiating surface.

The approximate radiation loss from a Frick furnace can be expressed by:—

$$W_r = 60 + 8 \text{ to } 10 \times G.$$

W_r = radiation loss in kilowatts at a steel temperature of 1500°.

G = capacity of furnace in tons.

A furnace producing high-carbon steel from cold material, has a lower mean temperature than a furnace for the production of low-carbon steel, requiring a higher casting-temperature.

Likewise the mean temperature of a furnace in treating previously melted steel is higher than in melting cold material.

The radiation loss increases very nearly as the square of the temperature.

(3) Theoretical heat, required for the melting of the steel and of the slag, and by the various reactions, taking place in the furnace.

To make an approximate estimate of the theoretical heat-energy, necessary for a certain process, the following figures are very useful:—

The total heat-energy in one ton of steel at 1400° C is.. .. 330 K.W.H.
To increase the temperature of 1 ton of melted steel 1° C.. 0·4 "
The mean energy to melt 1 ton of slag at 1400° C.. .. .. .. 600 "
To increase the temperature of 1 ton of melted slag 1° C.. 0·6 "
The energy necessary to expel the carbonic acid from 1 ton of
  limestone.. .. .. 500 "

The heat produced by most of the chemical reactions in a steel bath or between steel and slag is known with fair accuracy. In a paper, read by Mr. Frick (*see* ' Jern-Kontorets Annaler,' 1905), a table of the most usual reactions is given.

Calculations based on those figures show:—

The theoretical energy to melt and finish 1 ton of steel from cold, raw materials, containing an average 0·1 per cent Si, and so rusty, that 0·1 per cent carbon is lost in reducing same, 4 kg. lime being added to form a basic slag, if tapping temperature = 1550° C.. .. .. 390 K.W.H.
Same, if tapped at 1650° C.. .. .. 430 "
The theoretical energy to superheat 1 ton of liquid steel
  100° C, say from 1500° to 1600° C.. .. .. 40 "
  150° C, say from 1500° to 1650° C.. .. .. 60 "
  200° C, say from 1450° to 1650° C.. .. .. 80 "
The theoretical energy to eliminate 0·01 per cent phosphorus from 1 ton of liquid steel, without increasing its temperature, if an oxidizing slag is formed with 1 per cent P_2O_5, 50 per cent CaO, 20 per cent FeO, 20 per cent Fe_2O_3, and 10 per cent SiO_2, 15 per cent hereof having been delivered with the steel.. .. .. 15 "
  Final temperature of the slag = 1650°.

Similar calculations can be made for any case. Those given are only meant to convey an idea of the magnitudes involved.

The actual power consumption may now easily be calculated.

Example 1.—10-ton furnace, working with 8·5 tons, 560 kilowatts power-consumption, melting cold materials as above, tapped at 1650° C.

Mean temperature of bath = 1550°.
Electrical losses, 4·2 per cent.. .. .. = 23·5 K.W.
Radiation losses.. .. .. 160 "

  Total loss.. .. .. 183·5 "

$$\therefore \text{Total loss in per cent} = \frac{183\cdot5 \times 100}{560} \quad \cdots\cdots\cdots = \quad 32\cdot8 \text{ per cent.}$$

Efficiency of furnace.. .. .. = 67·2 "

Theoretical heat energy per ton . . . . = 430   K.W.H.

Calculated total power consumption $= \dfrac{430}{0.672}$ . . . . = 640   "

Actual total power consumption according to long run
results 610   "

Example 2.—15-ton furnace, 1600 kilowatt power-consumption for super-
heating basic Bessemer steel 150° C for eliminating 0.04 per cent phosphorus,
0.06 per cent sulphur.

Materials tapped at 1700°.

Mean temperature, 1625°.

Electrical losses, 4.0 per cent . . . . 64 K.W.

Radiation losses 210   "

Total loss 270   "

Total loss in per cent . . . . 17 per cent.

Efficiency of furnace 83   "

Theoretical energy per ton . . . . 156 K.W.H.

Calculated total power consumption, per ton $\dfrac{156}{0.83}$ 188   "

Actual results from treating liquid steel have not yet been obtained; but the
figures given above may be regarded as rather conservative.

The power consumption in melting cold materials has been:—

In 1.8 tons, 180 kw. furnace, worked
at 150 kilowatts . . . . about 800 K.W.H. per ton.

In 3 tons, 400 kw. furnace, worked
at 300 kilowatts, using very rusty materials . .   "   750   "

In 10 tons, 736 kw. furnace, worked
at 560 kilowatts, and 8.5 tons . . . .   "   610   "

It is very difficult to make a comparison between the Frick furnace and other
electric furnaces as to power consumption and efficiency, because of information
lacking with regard to temperature, weight of slag, etc.

As a basis of comparison between different systems, the total loss at say
1500° C of the steel could be chosen. This loss could be satisfactorily ascer-
tained by regulating the power so as to keep this temperature constant for say
10 hours. By subtracting the electrical losses, which may be fixed by special
measurements and calculations, the radiation losses are obtained.

Cost of production.—The cost of production depends first of all on the price
of the electric current.

If water-power is at disposal, the price for the current is as a rule low, vary-
ing between 30 and 150 shillings per kilowatt year. The full power can be
utilized during 6,000 hours a year, which is a conservative assumption for an
electric furnace plant. The cost is: per kilowatt-hour, or unit = 0.005 sh.
= 0.06 d., up to 0.025 sh. = 0.3 d.

If waste gases from blast furnaces or coke ovens are used, the price per
kilowatt-hour will be about = 0.017 sh. = 0.2 d.

Producer gas with ammonia recovery is equally able to produce electric current at a price per unit of 0·017 sh. = 0·2 d.

In the case of small plants, steam-power may become as cheap; and for several reasons more suitable than gas. On account of the long yearly runs, it pays to make the plant as up-to-date as possible. The engines ought to work on super-heated steam, and be provided with best Corliss, or other precision valves. The speed should be low. The cost of the electric current should not need to exceed 0·034 sh. = 0·4 d. per kilowatt-hours, even for a plant of only 250 horse-power.

The cost for the lining depends mainly on its life. At the Krupp furnace the lining has lasted up to six weeks, and will, after more experience, last longer. In treating liquid steel, when the slag-line is maintained at one and the same level, a repairing of weak places is easier done, than if cold materials are melted.

With proper attention, and by adding lime in front of the inner wall, only little work will be needed for repairing smaller defects.

Instead of spending much time on frequent repairs, it is more essential to use the crucible as long as possible, and to have a spare crucible at hand for exchange, so that only a short interruption is necessary.

The cost of relining, including current for bringing the crucible up to full heat, at 0·4 d. per unit is approximately:—

For a furnace of 1,800 kg. capacity.. .. .. = 900 sh.
" " 3,000 " .. .. = 1,500 "
" " 10,000 " .. .. = 3,000 "
" " 15,000 " .. .. = 6,000 "

The number of men necessary if melting cold materials at a furnace

	1·8	3	10 tons.
of..			
Foreman..	1	1	1
Men for charging... .. ..)	.	.	2
Men to bring in and weigh raw materials...	2	2	1
Men for ladle and casting arrangements.. ..	1	1	2
Men for moulds..	.	1	1
Crane driver..	1	1	1
Total..	5	6	8

The number of extra men necessary for treating liquid steel from a Bessemer, or Siemens-Martin furnace, depends on the kind of work required from the electric furnace.

If the steel is only raised in temperature and deoxidized, one or two men would be sufficient to make the additions, keep the spout clean, and to look after the extra ladle wanted for the transfer of the steel from one furnace to the other.

If the steel is to be subjected to a dephosphorization, one or two more men will become necessary, depending upon the size of the furnace.

To give an idea of the costs of the electric melting, calculations have been made to suit varying conditions.

3146—6

Example 1:—

Capacity of furnace..	3 tons.
Power of furnace..	300 K.W.
Life of lining..	6 weeks.
Stops over Sunday..	42 hours.
Tapping temperature..	1550°
Raw materials pure, cold.	
Yearly production good ingots..	2,350 tons.

Work done in the electric furnace, melting and deoxidizing:—

		Cost per ton.
Lining..	sh.	4·7
Current @ 0·4 d..	"	24
Wages..	"	8·9
Total..	"	37·6

Example 2:—

Capacity of furnace..	10 tons.
Power of furnace..	560 K.W.
Life of lining..	6 weeks.
Stop over Sunday..	24 hours.
Tapping temperature..	1650°
Raw materials pure, cold.	
Yearly production good ingots..	5,880 tons.

Work done in the electric furnace, melting and deoxidizing:—

		Cost per ton.
Lining..	sh.	3·8
Current @ 0·4 d..	"	22
Wages..	"	5·3
Total..	"	31·1

Example 3:—

Capacity of furnace..	10 tons.
Power of furnace..	560 K.W.
Life of lining..	6 weeks.
Stop over Sunday..	24 hours.
Tapping temperature..	1650°
Raw materials: dephosphorized liquid steel from a Siemens-Martin furnace, of 1450° C.	
Yearly production good ingots..	26,000 tons.

Work done in the electric furnace, heating 200° C, deoxidizing:—

		Cost per ton.
Lining..	sh.	0·8
Current @ 0·24 d. = 0·02 sh..	"	2·7
Wages..	"	0·3
Total..	"	3·8

Example 4 :—

Capacity of furnace	15 tons.
Power of furnace	1.600 K.W.
Life of lining	4 weeks.
Stop over Sunday	24 hours.
Tapping temperature	1700°

Raw materials, containing 0·05 per cent P and 0·07 per cent S from acid Bessemer, delivered at 1550° C. *

Yearly production good ingots............... 39,000 tons.

Work done in the electric furnace, heating 150°, eliminating 0·04 per cent P, 0·06 per cent S, deoxidizing:—

	Cost per ton.
Lining..................................sh	1·5
Current @ 0·2 d. = 0·0167 sh..............."	3·5
Wages................................."	0·4
Total................................"	5·4

These calculations do not give the total costs of the steel, but only aim to show how the price varies under different conditions.

To arrive at the total price of the steel, the costs of the raw materials, lime, ore, deoxidizers, tools, heating and repairing ladle, moulds, analyses, interest, depreciation and repair of the furnace plant with cranes, have to be added.

These items are so different, that they can only be taken into consideration in estimates for special cases.

The interest and depreciation of the power plant are included in the price of the current.

The figures in examples 3 and 4, give the *total extra* cost arising from passing the steel through the electric furnace, with exception of interest, depreciation, repair; and, in example 4, about 70 kg. lime and 20 kg. ore are used to form the slag.

From these calculations, it is evident that the electric furnace has a wide field in combination with other furnaces.

Claims of Superiority.

(1) The furnace is equally suitable for melting cold materials, for super-heating liquid steel, delivered from a Bessemer or open-hearth furnace, and for refining from oxides, phosphorus, and sulphur. (The Roechling-Rodenhauser furnace and all arc furnaces, except Stassano's, can hardly be used for melting cold material.)

(2) The power load is absolutely steady. In arc furnaces, occasional short circuits cause heavy variations.

(3) Advantage through the absence of electrodes:—

    (a) No cost for electrodes (amounting to 1 sh.—2 sh. 6d. per ton steel).

    (b) No loss of energy (especially through water-cooled bottom electrodes. Girod.)

    (c) Treating liquid steel, the current can be turned on as soon as charging is started, and full power reached, before all charge is in (in arc furnaces, current cannot be put on until all steel is charged).

    (d) Simpler way of working. No need to cut off power during slagging (in arc furnaces the electrodes have to be removed).

(4) The use of flat coils above and below the crucible is preferable to one high, cylindrical coil between the centre iron core and the inner wall (Kjellin's system), viz.:—

    (a) The power factor is—other circumstances being equal—higher; or, for the same power factor it is possible to use thicker walls and better insulate the furnace, which means a lower power consumption.

    (b) The electrical dispositions cause a moderate movement in the steel bath, sufficient to secure perfect uniformity and to assist the chemical actions, but the circulation is not so strong as to damage the inner wall of the crucible or to cause any other disturbances in the working.

(5) The revolving cover offers several advantages, viz.:—

    (a) Every part of the crucible can be inspected.
    (b) Simpler way of charging.
    (c) Slag easily removed.
    (d) Less radiation losses on account of fewer openings; therefore, slag more liquid.
    (e) Repairing easy.

(6) One single, uniform bath section is preferable to two or three narrow channels and a wide hearth (system Roechling-Rodenhauser), viz.:—

    (a) The heat is developed uniformly in the bath, thus avoiding all heat transmission.
    (b) No heavy circulation.
    (c) For equal wall thickness the surface of the furnace and the radiation-loss is smaller.

(7) By careful insulation the heat losses are reduced to a minimum, making the total efficiency superior to other electric furnaces.

⊕

CANADA

DEPARTMENT OF MINES

MINES BRANCH

Hon. W. Templeman, Minister; A. P. Low, LL.D., Deputy Minister;
Eugene Haanel, Ph.D., Director.

REPORTS, AND MAGNETOMETRIC SURVEY MAPS
OF ECONOMIC INTEREST.

PUBLISHED BY THE

MINES BRANCH

REPORTS.

1. Mining Conditions of the Klondike, Yukon. Report on—by Eugene Haanel, Ph.D., 1902.
2. Great Landslide at Frank, Alta. Report on—by R. G. McConnell and R. W. Brock, M.A., 1903.
3. Investigation of the different electro-thermic processes for the smelting of iron ores, and the making of steel, in operation in Europe. Report of Special Commission—by Eugene Haanel, Ph.D., 1904. (Out of print.)
4. Rapport de la Commission nommée pour étudier les divers procédés électro-thermiques pour la réduction des minerais de fer et la fabrication de l'acier employés en Europe. (French Edition), 1905. (Out of print.)
5. On the location and examination of magnetic ore deposits by magnetometric measurements. Eugene Haanel, Ph.D., 1904.
7. Limestones, and the Lime Industry of Manitoba. Preliminary Report on—by J. W. Wells, 1905.
8. Clays and Shales of Manitoba: their Industrial Value. Preliminary Report on—by J. W. Wells, 1905. (Out of print.)
9. Hydraulic Cements (Raw Materials) in Manitoba: Manufacture and Uses of. Preliminary Report on—by J. W. Wells, 1905.
10. Mica: its Occurrence, Exploitation, and Uses—by Fritz Cirkel, M.E., 1905. (Out of print.)
11. Asbestos: its Occurrence, Exploitation, and Uses—by Fritz Cirkel, M.E., 1905. (Only a few copies available.)
12. Zinc Resources of British Columbia and the Conditions Affecting their Exploitation. Report of the Commission appointed to investigate—by W. R. Ingalls, 1905.

55. Report on the Bituminous, or Oil-shales of New Brunswick and Nova Scotia; also on the Oil-shale Industry of Scotland—by Dr. R. W. Ells.

58. The Mineral Production of Canada, 1907 and 1908. Annual Report on—by John McLeish, B.A.

59. Chemical Analyses of Special Economic Importance made in the Laboratories of the Department of Mines, 1906-7-8. Report on—by F. G. Wait, M.A., F.C.S. (With Appendix on the Commercial Methods and Apparatus for the Analysis of Oil-shales—by H. A. Leverin, Ch.E.)

62. Mineral Production of Canada, 1909. Preliminary Report on—by John McLeish, B.A.

63. Summary Report of Mines Branch, 1909.

67. Iron Ore Deposits of the Bristol Mine, Pontiac county, Quebec. Bulletin No. 2—Einar Lindeman, M.E., and Geo. C. Mackenzie, B.Sc.

Schedule of Charges for Chemical Analyses and Assays.

IN THE PRESS.

68. Recent Progress in Electro-Metallurgy. Bulletin No. 3—Dr. Eugene Haanel.

71. Investigation of the Peat Bogs, and Peat Industry of Canada: with Appendices I, II, and III—the last named being a translation of the Ekenberg Wet Carbonizing Process. Bulletin No. 4—A. Anrep, Peat Expert.

IN PREPARATION.

69. Asbestos: its Occurrence, Exploitation, and Uses—by Fritz Cirkel, M.E. (Second Edition, enlarged.)

Coal and Coal Mining in Nova Scotia—by J. G. S. Hudson.

Coal Tests at McGill University. Report on—by Dr. John Bonsall Porter.

MAPS.

6. Magnetometric Survey of Calabogie mine, Bagot township, Renfrew county, Ontario. Vertical Intensity—by E. Nyström, M.E., 1904.

13. Magnetometric Survey of the Belmont Iron mines, Belmont township, Peterborough county, Ontario—by B. F. Haanel, B.Sc., 1905.

14. Magnetometric Survey of the Wilbur mine, Lavant township, Lanark county, Ontario—by B. F. Haanel, B.Sc., 1905.

15. Magnetometric Survey of Iron Ore Deposits at Austin brook, Bathurst township, Gloucester county, N.B. Vertical Intensity—by E. Lindeman, M.E., 1906.

33. Magnetometric Survey, Vertical Intensity: Lot 1, Concession VI, Mayo township, Hastings county, Ontario—by Howells Fréchette, M.Sc., 1909.

34. Magnetometric Survey, Vertical Intensity: Lots 2 and 3, Concession VI, Mayo township, Hastings county, Ontario—by Howells Fréchette, M.Sc., 1909.

35. Magnetometric Survey, Vertical Intensity: Lots 10, 11, and 12, Concession IX, and Lots 11 and 12, Concession VIII, Mayo township, Hastings county, Ontario—by Howells Fréchette, M.Sc., 1909.

36. Survey of Mer Bleue Peat Bog, Gloucester township, Carleton county, and Cumberland township, Russell county, Ontario—by Erik Nyström, M.E., and A. Anrep, Peat Expert.

37. Survey of Alfred Peat Bog, Alfred and Caledonia townships, Prescott county, Ontario—by Erik Nyström, M.E., and A. Anrep, Peat Expert.

38. Survey of Welland Peat Bog, Wainfleet and Humberstone townships, Welland county, Ontario—by Erik Nyström, M.E., and A. Anrep, Peat Expert.

39. Survey of Newington Peat Bog, Osnabruck, Roxborough, and Cornwall townships, Stormont county, Ontario—by Erik Nyström, M.E., and A. Anrep, Peat Expert.

40. Survey of Perth Peat Bog, Drummond township, Lanark county, Ontario— by Erik Nyström, M.E., and A. Anrep, Peat Expert.

41. Survey of Victoria Road Peat Bog, Bexley and Carden townships, Victoria county, Ontario—by Erik Nyström, M.E., and A. Anrep, Peat Expert.

48. Magnetometric Map of Iron Crown claim at Klaanch river, Vancouver island, B.C.—by Einar Lindeman, M.E.

49. Magnetometric Map of Western Steel Iron claim, at Sechart, Vancouver island, B.C.—by Einar Lindeman, M.E.

50. Vancouver island, B.C.—by Einar Lindeman, M.E.

51. Iron Mines, Texada island, B.C.—by E. H. Shepherd, C.E.

52. Sketch Map of Bog Iron Ore Deposits, West Arm, Quatsino sound, Vancouver island, B.C.—by L. Frank.

53. Iron Ore Occurrences, Ottawa and Pontiac counties, Quebec, 1908—by J. White, and Fritz Cirkel, M.E.

54. Iron Ore Occurrences, Argenteuil county, Quebec, 1908—by Fritz Cirkel, M.E.

57. The Productive Chrome Iron Ore District of Quebec—by Fritz Cirkel, M.E.

60. Magnetometric Survey of the Bristol mine, Pontiac county, Quebec—by Einar Lindeman, M.E.

61. Topographic Map of Bristol mine, Pontiac county, Quebec—by Einar Lindeman, M.E.

70. Magnetometric Survey of Northeast Arm Iron Range, Lake Timagami, Nipissing district, Ontario—by Einar Lindeman, M.E.

IN THE PRESS.

72. Brunner Peat Bog, Ontario—by A. Anrep, Peat Expert.
73. Komoka Peat Bog, Ontario—   "   "
74. Brockville Peat Bog, Ontario—   "   "
75. Rondeau Peat Bog, Ontario—   "   "
76. Alfred Peat Bog, Ontario—   "   "
77. Alfred Peat Bog, Ontario: Main Ditch profile—by A. Anrep.

IN PREPARATION.

64. Index Map of Nova Scotia: Gypsum—by W. F. Jennison, M.E.
65. Index Map of New Brunswick: Gypsum—by W. F. Jennison, M.E.
66. Magdalen islands: Gypsum—by W. F. Jennison, M.E.

Magnetometric Survey of Huron Mountain mine, Timagami Forest Reserve, Ontario—by B. F. Haanel, B.Sc.

Magnetometric Survey of Lot 7 A, Range V, Leeds township, Quebec—by B. F. Haanel, B.Sc.

Note.—All applications for Reports, or Maps issued by the Mines Branch of the Department of Mines, should be addressed to

EUGENE HAANEL, Ph.D.,
Director of Mines,
Ottawa.