ELECTRICAL SECTION

(Stated meeting held Thursday, November 18, 1909.

THE ELECTRICAL REDUCTION OF IRON ORE.

BY

JOSEPH W. RICHARDS,

Professor of Metallurgy in Lehigh University; Secretary of the American Electrochemical Society.

[The application of the electric current as a source of heat energy in the reduction of iron ores would but a short time ago have scarcely been seriously considered. Its possibility has however been more than demonstrated. In this paper, Dr. Richards describes the work of several investigators in the development and operation of this method of manufacturing pig-iron on a practical commercial scale.]

THIS topic is one which a few years ago could only have been discussed in a speculative manner, and by one with the prophetic gift highly developed. The reduction of iron ore by means of the energy of fuel, in blast-furnaces, is carried on on such a stupendous scale and with such great economy that the blast-furnace has been frequently called our most perfect furnace, and the possibility of electrical energy taking any part in this industry appeared highly visionary. When electric furnaces commenced to be developed on a commercial scale, it was generally admitted that if they entered the iron industry at all their best chance was in the production of highly expensive special quality steels, costing $500 to $1000 per ton, and that their poorest chance would be to compete in the manufacture of pig-iron costing $10 to $15 per ton. Yet inside of five short years, those who have watched the development of the electrical iron and steel industry have seen small furnaces turning out fine steels succeeded by larger ones manufacturing successfully common steels, such as steel castings and rail steel, and finally the operation of a larger electric shaft furnace manufacturing pig-iron on a practical commercial scale.

Confining ourselves this evening to the electrical production of pig-iron, most of the credit for the recent advances should be given to the far-sighted interest of the Canadian Government in this subject, principally, under the influence of its active Director of the Department of Mines, Dr. Eugene Haanel, of Ottawa, and to the enterprising Swedes, principally Assar Grönwall, Axel Lindblad and Otto Stalhane, who have founded the company "Aktiebolaget Electrometall" of Ludvika, Sweden. If to these we add the names of H. H. Noble, of the Northern California Power Company, and his able assistant, Prof. D. A. Lyon, who have constructed and operated an electric pig-iron furnace in California, the list of *active* workers in this field is nearly complete.

EXPERIMENTS OF THE CANADIAN COMMISSION IN EUROPE.

When, in January, 1904, the Canadian Government sent a commission, under Dr. Haanel, "to investigate the different electro-thermic processes for the smelting of iron ores and the making of steel in operation in Europe," the commission found and reported upon a number of different electric-steel furnaces in commercial operation, but found not a single electric pig-iron furnace at work. From the voluminous and most valuable report of this Commission (published by the Canadian Government, August, 1904) we learn that, being interested in seeing what might be accomplished in this direction, several of the European works were persuaded to make some experiments on the production of pig-iron. Some of these tests are described briefly in the following extracts from the report:

At La Praz, France.—"Mr. Héroult was good enough to make some experiments for us in smelting iron ores. The furnace employed was exceedingly simple." . . . "These experiments were made for us by Mr. Héroult for the purpose of demonstrating the simplicity of the process of reducing iron ores by the electric process and it was not intended to demonstrate a figure of cost per ton of pig-iron produced by this process." It appears from the data given that this test was very crude and poorly arranged. Too little carbon for reduction was used in the charge, the furnace was run too cold, and the power consumption ran up to 0.525 h. p. year per ton of pig-iron obtained.

At Livet, France.—The works of Keller-Leleux et Cie. possessed furnaces constructed for the reduction of ore, and used for manufacturing ferro-silicon and ferro-chromium. These were placed at the disposal of the commission, and two long runs made of 55 and 48 hours each, with all the data carefully controlled and checked. The complete details of these runs can be found in the report of the commission. Illustrations of the furnace used may be seen in the report. It is of the resistance type, with two shafts, each with its vertical electrode embedded in the charge, and connected by a well in which metal and slag collect. The current passes from the electrodes to carbon blocks embedded in the base of the furnace. The lining was a rammed-in mixture of dolomite and tar, similar to that of a basic-lined Bessemer converter. The electrodes were square, 280 mm. (11 inches) on the side and 1400 mm. (56 inches) long. The 55-hour run was interrupted to put in a wattmeter, and the metal set in the furnace, so that the power consumption for this run 0.52 h. p. year per metric ton of pig-iron, was abnormal. In the second run of 48 hours no interruption occurred, the furnace "working quietly, and without the slightest accident; the gases discharging on top in flickering flames, showing that the gas resulting from the reduction of the ore escaped at low pressure. The workmen were ordinary Italian laborers, without any special training."

This second run was successful in producing, at will, different classes of pig-iron, gray, white, and mottled, and in setting a definite figure for the amount of electric energy required per ton of pig-iron produced. The furnace was nominally of 300 h. p. capacity, but running with 350 h. p.; it consumed 0.25 h. p. year per metric ton of pig-iron produced, using 41 per cent. of fuel. This is a satisfactory figure, and is partly attributable to running the furnace hard, *i.e.*, over its normal capacity.

EXPERIMENTS OF THE CANADIAN GOVERNMENT AT SAULT S. MARIE.

On the return of the Canadian Commission from Europe, and the publication of its report, the Canadian Government placed at the disposal of Dr. Haanel and his staff $15,000 for investigating the suitability of the electric process for reducing Canadian iron ores. The experiments were carried out early in 1906, and may be found recorded in detail in the report published by Dr. Haanel in February, 1907 (Ottawa, Mines Branch, Department of the Interior). An analytical discussion of these experiments and the results obtained was presented by the speaker to the American Electrochemical Society, at its meeting in New York City, October 18, 1907, and published in the *Transactions* of that Society, vol. xii, p. 81. The furnace used is shown in Fig. 1. The following conclusions from the author's analysis may here suffice:

1. Too much carbon was used in every case, not allowing a good utilization of the heat of oxidation of carbon in the furnace. A *smaller* proportion of carbon, more perfectly consumed to CO_2 would have generated *more* heat and thus have helped the furnace more.

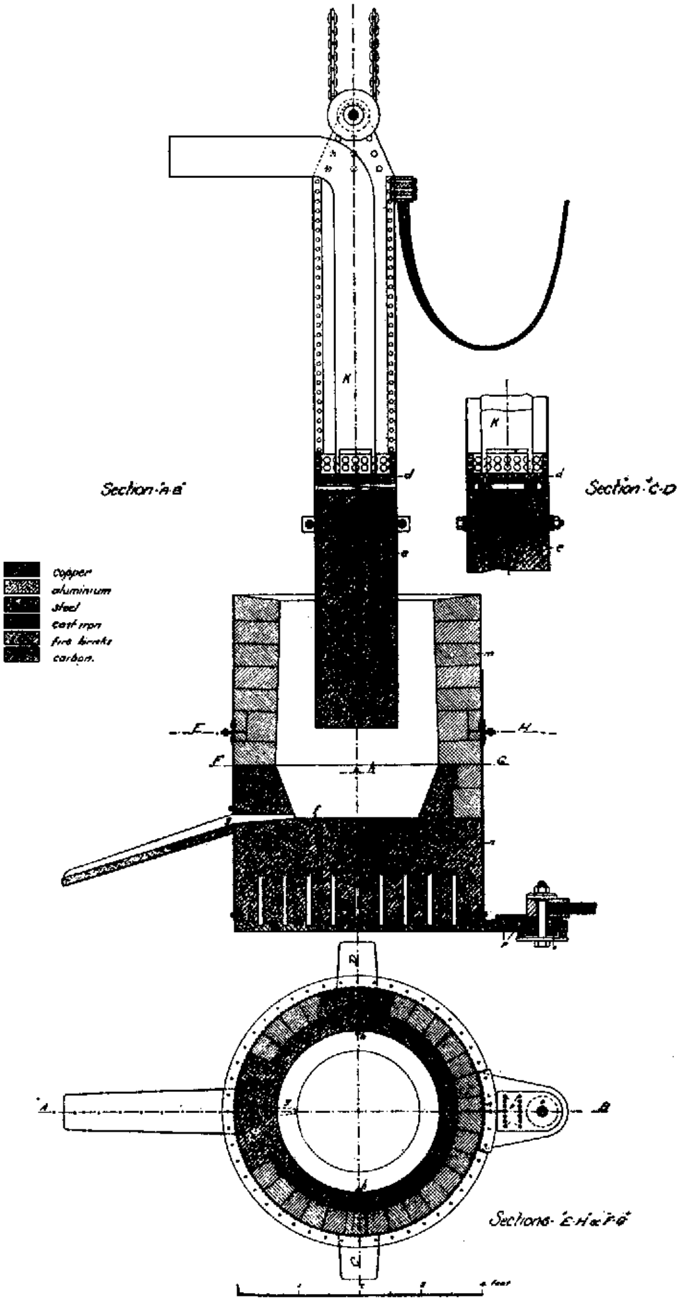
2. The electric current furnished about two thirds of the energy required for all purposes, the carbon one third.

3. The consumption of fixed carbon was 24 to 38 per cent. of the weight of pig-iron, giving ratios of CO to CO_2 in the gases of 4.5 up to 9 (by volume); whereas a ratio of 1 is possible, would require far less carbon, and would produce more heat in the furnace. For the details of this analysis, the reader is referred to the original paper. Some of these figures will be used in the comparative tabulations at the end of this paper. One thing is particularly worth noting: the Sault Ste. Marie furnace was small and was worked hard, a condition favorable for small conduction and radiation loss, and economy of power.

RUNNING OF THE SWEDISH SHAFT FURNACE.

The experiments at Sault Ste. Marie bore fruit first in Sweden, by inciting experimenters there to construct a large electric shaft furnace for the regular commercial production of pig-iron. Messrs. Grönwall, Lindblad and Stalhane conducted preliminary experiments at Ludvika, Sweden, in the summer of 1907, with a small furnace of 300 h. p. capacity; in the summer of 1908 a larger furnace of different type was constructed, and in the autumn of 1908 a still larger furnace, embodying the results of all their experience, was completed. This furnace was designed for 1500 kilowatts, and may be truly termed the pioneer electric pig-iron furnace. The best description of this furnace and its working are to be found in a paper by Dr. E. Haanel in the *Transactions of the American Electro-*

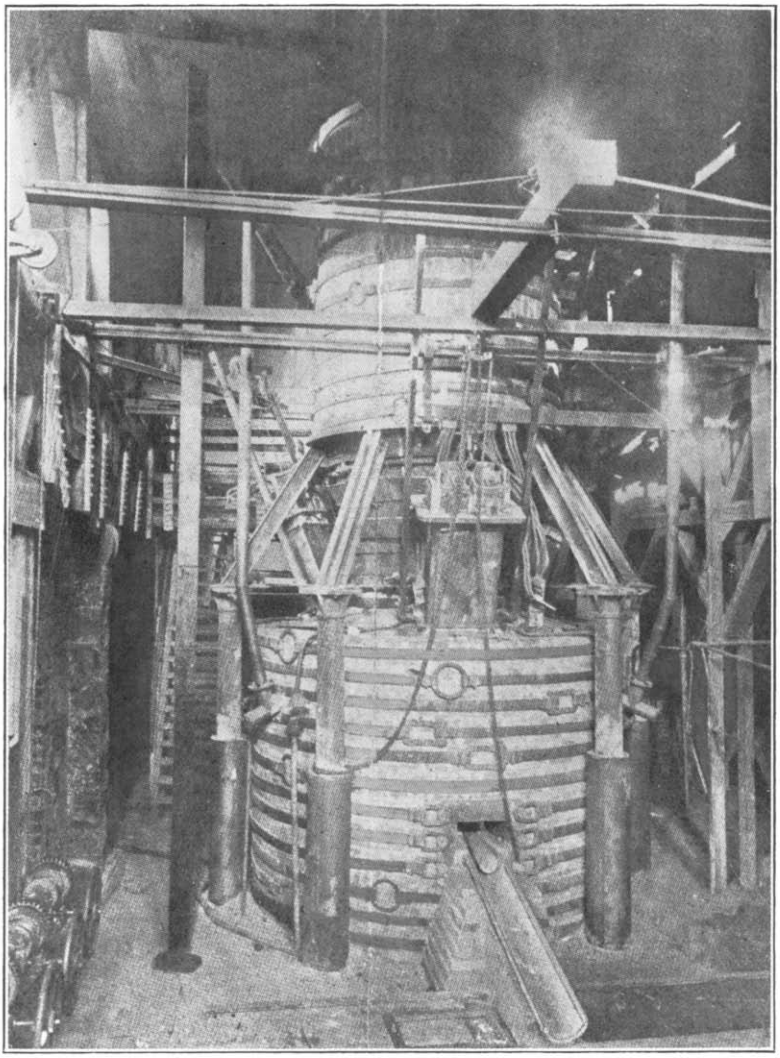
FIG. 1.



Experimental furnace used at Sault S. Marie.

chemical Society, vol. xv, p. 25, and in the subsequent report of Dr. Haanel published by the Canadian Department of Mines.

FIG. 2.

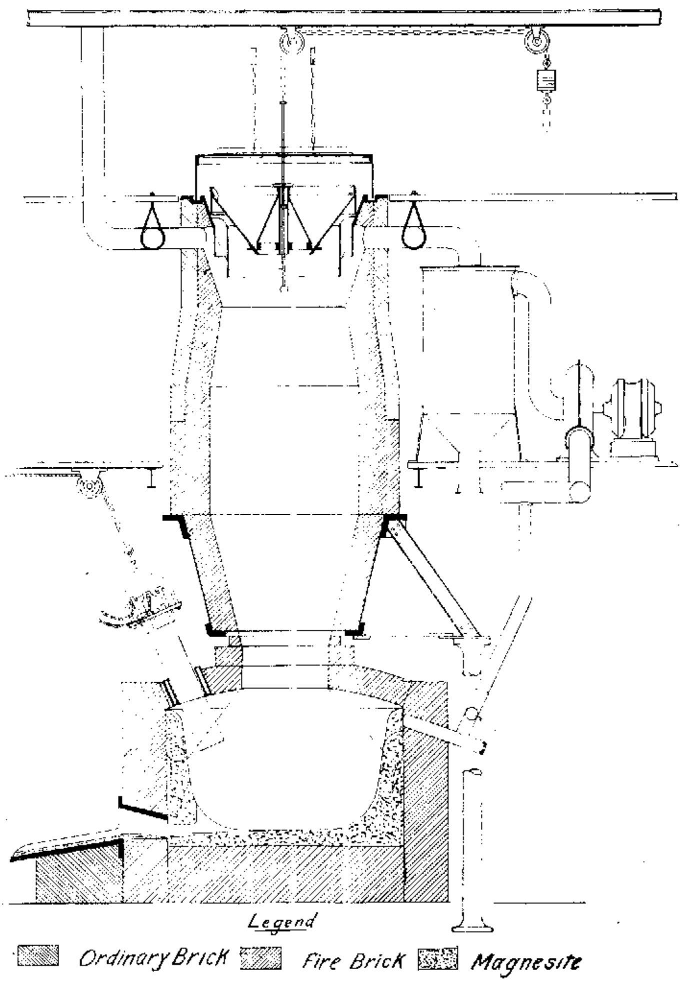


Electric shaft furnace at Ludvika, Sweden.

in October, 1909, entitled "Investigation of an Electric Shaft Furnace at Domnarfvet, Sweden. The following details and illustrations (Figs. 2 and 3) are taken from Dr. Haanel's publications:

The total height above the ground-level is 25 feet; the

FIG. 3.



Section of Luovika furnace.

crucible is 7 feet high, the shaft 18 feet. The entire weight of the upper shaft is carried on six cast-iron columns none of it rests on the arch covering the crucible. This arched roof has openings for the three electrodes, each composed of two carbons 11 in. square by 63 in. long, making each electrode 11 in. by 22 in. by 63 in. The electrode holder is a steel frame into which the electrodes are fastened by copper wedges. The electrodes pass through water-cooled stuffing boxes. The crucible is lined with magnesite-brick—a material never usable in blast-furnaces. Some of the escaping furnace gas is pumped back by means of a fan into the free space under the crucible arch, for the purpose of cooling off that arch and so preserving it from the intense radiated heat.

The electric current is supplied as three-phase current to the three electrodes by three transformers of 500 kilo-volt-amperes each, transforming the current down to 1/14 its primary voltage, and capable of regulation between 20 and 85 volts.

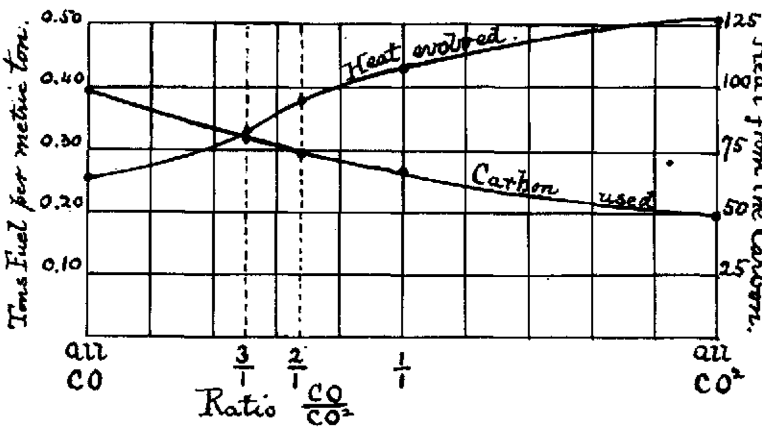
The especially novel features are the arch over the crucible, the projecting downwards of the electrodes through this arch into contact with the charge as it spreads out from the central shaft into the crucible, the magnesia lining, and the return of part of the throat gases into the crucible under the arched roof. It can readily be seen that a large amount of thought and experience are embodied in the details of this furnace.

A trial run was made under Dr. Haanel's inspection, starting with the cold furnace. Besides the handicap of starting cold, and with all the masonry fresh, the furnace was insufficiently supplied with power. Instead of the 1500 kw. which it was designed for, only about 400 could be gotten. Under these circumstances, the losses of heat by radiation and conduction were probably almost so great intrinsically as they would have been with full power, which means that they were relatively, or proportionately to the energy used, probably three or four times as great. The result of the test is therefore far from indicating the maximum commercial efficiency of this furnace.

In spite of these adverse conditions, pig-iron was made from the ore at the rate of 0.40 electric horse power year consumed per metric ton of pig-iron. The fuel consumed for reduction was 27.5 kg. of coke per 100 of pig-iron, and of electrodes 5 kg. It is altogether reasonable to assume that the power consumption, when in regular running, will not exceed 0.3 e. h. p. year, and on this basis, counting power at $12 per e. h. p. year and charcoal (83 per cent. carbon) at $8.00 per metric ton (2204 lbs.), Professor Odelstjerna, of Stockholm, has estimated that pig-iron can now be made, in Sweden, in this furnace, at $1.50 per ton less than in Swedish blast-furnaces. It is my opinion that this furnace, if run at 3000 kw., could make pig-iron at 0.2 e. h. p. year per ton of output, making a further saving of $1.20 per ton. With a prospective saving of $2.50 per ton, the Swedish blast-furnace industry stands a good chance of being superseded by the electric furnace, as soon as the latter gets into proper working order.

Accompanying diagrams are intended to illustrate the fundamental principles of electric furnace reduction of iron ore.

FIG. 4.



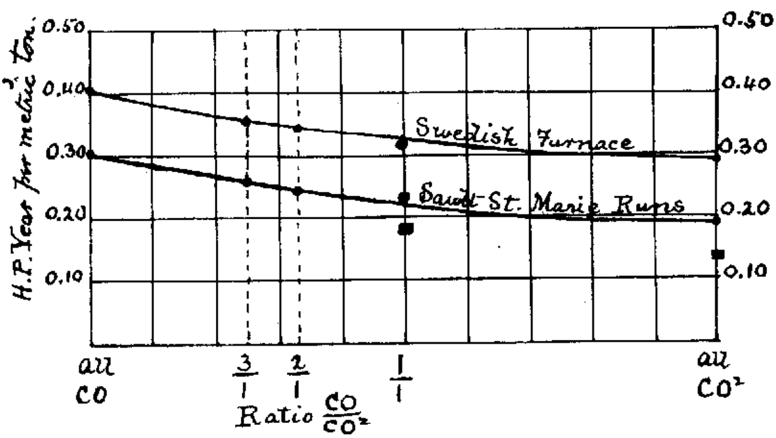
Variation of fuel required and heat evolved, with composition of waste gases produced.

They are entirely dependent upon the rate at which the furnace is run and the proportion of CO to CO_2 in the gases. In the latter respect, a proportion of 1 : 1 by volume is entirely practicable and should be attained in electric smelting, although 2 : 1 is the usual ratio in blast-furnace practice. A kilogramme of oxygen burning carbon to CO gives up 1820 heat units (calories), but if burning (only half as much) carbon to CO_2 it gives up 3075 calories. Since there is a definite amount of oxygen to be removed per ton of pig-iron made, more assistance is obtained from the combination of carbon and oxygen the more CO_2 and the less CO is formed. Fig. 4 shows the heat evolved, in units of 1000 calories, as the ratio of CO : CO_2 varies from all

CO to ratios of CO to CO_2 = 3, 2 and 1, and extended to the supposed case of all CO_2 being formed. It shows graphically the fact that the smaller the amount of carbon used the more heat obtained from its oxidation, because it is being burnt by a fixed quantity of oxygen.

Experiments on the reduction of iron oxides in currents of CO gas render it improbable that a lower ratio of CO : CO_2 than 1 : 1 can be obtained in practice, even under the most favorable electric furnace conditions. This corresponds to 0.26 ton of carbon per ton of pig-iron made, and a thermal assistance from the carbon of 1,111,500 calories (1750 horse-power-hours) per ton of iron.

FIG. 5.



Variation of power required, with composition of waste gases produced.

Fig. 5 shows the variation of horse power required per ton of pig-iron with the ratios of CO : CO_2 in the gases. It shows distinctly how wasteful of power it is to run a furnace with too much carbon; with a certain amount of carbon charged it is practically impossible to utilize it except it burns mostly to CO, and then the high power consumption is the result of the lack of proper thermal assistance from the carbon. The power curve of the Swedish furnace is above those of the S. S. Marie runs, for the same fuel consumption or ratio of CO : CO_2, because the former furnace was being run at not over one-fourth, possibly nearer one-sixth, of its proper power supply, while the latter furnace was small and was pushed hard. The difference of 0.1 h. p. year per ton of pig-iron made is probably entirely ascribable to high radiation and conduction losses, due to the relatively slow running.

THERMAL ANALYSIS OF RUN OF SWEDISH SHAFT FURNACE.

Dr. Haanel gives sufficient data for forming a good idea of the heat distribution in the large Swedish furnace. The data are as follows:

Composition of ore	Fe = 62.96 per cent.
Composition of coke	C = 85. per cent. S = 0.55 per cent. Ash = 14.45 per cent.
Composition of slag	SiO_2 = 26.54 per cent. CaO = 54.48 per cent. S = 0.78 per cent. Fe = 0.35 per cent.
Composition of pig-iron	Fe = 94.485 per cent. C = 3.20 per cent. Si = 0.075 per cent. Mn = 0.33 per cent. P = 1.90 per cent. S = 0.01 per cent.
Composition of gases	CO_2 = 25.00 per cent. by volume. CO = 65.00 per cent. by volume. H = 10.00 per cent. by volume.

Charges: Ore, 220; Coke, 37.4; Lime, 4.4.

From the above data it can be calculated, assuming the gases escaping at 250° and the pig-iron and slag at a little above blast-furnace temperature, that the energy received and distributed by the furnace is about as follows, per 100 kg. of pig-iron concerned:

HEAT DEVELOPED.

Carbon oxidized to CO	52,318 calories.	
CO oxidized to CO_2	44,785 calories.	
Formation of slag	2,058 calories.	
Carburization of iron	2,256 calories.	
Total heat of chemical reactions	101,417 calories	= 31 per cent.
Heat energy of 0.041 e. h. p. year	223,171 calories	= 69 per cent.
Total available energy	324,588 calories.	
Average required in blast-furnaces	400,000 calories.	

HEAT DISTRIBUTION.

Reduction of iron oxide..........	155,221 calories =	48 per cent.
Reduction of other oxides.........	10,174 calories =	3.5 per cent.
Evaporation of water.............	1,025 calories =	0.3 per cent.
Sensible heat in waste gases......	4,075 calories =	1.3 per cent.
Sensible heat in pig-iron.........	32,500 calories =	10.0 per cent.
Sensible heat in slag.............	8,600 calories =	2.7 per cent.
Rad'n and cond'n loss (diff.)....	112,850 calories =	33.2 per cent.

The last item of the above schedule is very much larger than it should be. Some modern blast-furnaces run with one-tenth that much. The trouble with this furnace was that it was run only about one-tenth as fast as it should be for heat economy. If we assume that this furnace is run fast and carefully, so as to get a ratio $CO:CO_2$ in the gases of 1 : 1, we can estimate what will be the probable running of a large electric pig-iron furnace, such as will undoubtedly be in steady operation in the near future. The requirement for power will be that necessary to furnish the needed heat, less that furnished by the chemical reactions. These will be, per ton of pig-iron produced:

Needed for reductions.........	1,655,000 calories =	2600 h. p. hours.
Sensible heat of pig-iron	300,000 calories =	470 h. p. hours.
Sensible heat of slag..........	60,000 calories =	100 h. p. hours.
Radiation and conduction......	100,000 calories =	160 h. p. hours.
	2,115,000 calories =	3330 h. p. hours.
Furnished by chemical reactions	1,111,500 calories =	1750 h. p. hours.
Needed from electric current..	1,003,500 calories =	1580 h. p. hours.

The following is therefore the conclusion of this investigation:

If a larger electric shaft furnace is run rapidly, with abundant power, and the gases escaping contain at least as much CO_2 (by volume) as CO, the minimum power requirement which will be approximated is 1580 *h. p. hours, or* 0.18 *h. p. years, per metric ton* (2204 *lbs.*) *of pig-iron produced.*

One ton per 0.226 h. p. year has already been reached in an experimental run.