vacuo it would vaporize at a much lower temperature. It is therefore very probable that the temperature measurements calculated from the extrapolated part of the curve are fairly accurate, and not overestimated, as had been feared.

In this connection it is of interest to note that Sir Wm. Crookes[1] has calculated from certain assumptions that carbon has zero vapor pressure at 3000° Abs., or approximately 2700°, which is about the temperature (estimated from the calibration curve) at which a more rapid wasting of the heater becomes noticeable.

X. *Conclusion.*—I believe that this furnace opens up a wide field for investigation of high temperature phenomena under exact and easily controlled conditions, and hope that eventually it will enable us to become familiar with the properties of substances up to extremely high temperatures.

I expect soon to be able to give the results of a number of interesting investigations which are now in progress.

RESEARCH LABORATORY,
GENERAL ELECTRIC CO.,
SCHENECTADY, N. Y.

ELECTRIC SMELTING AT SAULT STE. MARIE, ONTARIO.[2]

BY E. HAANEL.

Received June 30, 1906.

INTRODUCTION.

THE disability under which the middle provinces of Canada are placed as regards the upbuilding of an iron and steel industry on account of the necessity of importing the required metallurgical coke either from the United States or the extreme east or west of Canada engaged my attention shortly after assuming the duties of my present position. Considering the fact that the provinces of Ontario and Quebec are supplied with extensive deposits of iron ore and water-powers, the utilization of these water-powers in the production of electric energy in substitution of the energy resulting from the combustion of carbon in blast-furnaces suggested itself as a possible solution of the problem of economically producing pig iron without the use of metallurgical fuel.

Fortunately, the necessity of profitably employing the electric

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[1] Pr. Roy. Soc. A 76, 458 (1905).

[2] An address delivered at Ithaca, N. Y., before the American Chemical Society, Saturday, June 30, 1906.

plants erected in different parts on the Continent, especially in France, for the production of carbide, which had to be closed down as unprofitable, furnished the incentive to invent methods for applying electric energy; first, to the production of the different ferros, and subsequently to the production of pig iron and steel.

In the solution of the problem of applying electric energy to the extraction of metals from their ores Captain Stassano, in Italy, and Héroult and Keller, in France, have rendered conspicuous service. The description of the experiments made by them attracted wide attention, for it was at once seen that if by the electric process pig iron could be economically produced, such countries as Brazil, Chile, Sweden, Norway, Finland and Canada, all rich in iron ore deposits and the necessary fluxes and possessing extensive water-powers, but lacking metallurgical fuel, would be able to render themselves independent of outside sources by employing the electrothermic process for the manufacture of their iron and steel.

It was with a view of ascertaining the practicability of introducing electric smelting into Canada that the honorable Mr. Sifton, then Minister of the Interior, appointed a Commission to investigate this subject. My instructions were: To proceed to Europe for the purpose of investigating and reporting upon the different electrothermic processes employed in the smelting of iron ores and the making of the different classes of steel, now in operation or in process of development, in Italy, France and Sweden.

The special object of this investigation was the ascertainment of all facts in connection with these processes, which were necessary for determining the cost of one ton of product, the quality of the product, and cost of machinery employed and such other facts as were required for the formation of a judgment regarding the feasibility of introducing successfully in Canada electrothermic processes for the production of iron and steel.

I was directed to avail myself of all means necessary to obtain, as far as practicable, reliable and detailed information on this subject. To ascertain what patents had been issued to the different inventors of the processes of electric smelting, the countries where they had been issued, and full particulars thereof. Photographs and accurate drawings (where necessary) of the various parts of apparatus and plants employed were to accompany my report.

The following constituted the members of the staff under my direction: Mr. C. E. Brown, E. E.; Mr. F. W. Harbord, metallurgist; Mr. Erik Nystrom, M. E.; draftsman; Mr. Thomas Cote, secretary.

The results of the investigation of the Commission have been laid down in a report entitled "Report of the Commission Appointed to Investigate the Different Electrothermic Processes for the Smelting of Iron Ores and the Making of Steel in Operation in Europe." This report has been widely distributed, copies having been sent on requisition to Russia, Germany, Italy, France, Sweden, England, Brazil, Honolulu, New Zealand, Japan, India, Canada and the United States, showing the interest taken in and desire for information on the subject of electric smelting.

The only experiments which the members of the Commission were able to witness in the electric smelting of iron ores were those made by Dr. Héroult, at La Praz, and Mr. Keller, of Keller, Leleux & Co., at Livet, France. The first was a mere trial, furnishing no reliable quantitative results; the latter, more extended experiments, continued for a number of days, were made with a very porous hematite containing 3.21 per cent. of manganese and only 0.02 per cent. of sulphur, an ore, therefore, easily reduced and easily desulphurized. Two sets of experiments were made at Livet. In the first experiment 0.475 horse-power years were required per ton of 2,000 pounds of pig iron, corresponding to an output of 5.769 tons per 1,000 horse-power days. In the second experiment 0.226 horse-power years were required per ton of product, corresponding to an output of 12.12 tons per 1,000 horse-power days. In this experiment, moreover, most of the iron produced was white, for which cold working is required and consequently less energy consumed.

The difference in output of these two experiments was so great, being more than double that of the first in the second experiment, that no conclusion could be drawn as to the amount of energy required per ton of product and Mr. Harbord, the metallurgist of the Commission, was compelled to adopt 0.350 horse-power years, the mean of the two experiments, as the probable energy required per ton of product. This would correspond to an output of 7.827 tons per 1,000 electric horse-power days.

Before, therefore, a sound judgment could be formed as to the practicability of the electrothermic process for the smelting of Canadian ores it was desirable to establish with some degree of exactitude the amount of electric energy required per ton of product and also the following important points referring to Canadian conditions, which were either not taken up or were left in doubt by the Livet experiments:

First—Can magnetite, which is our chief ore and which is to some extent a conductor of electricity, be successfully and economically smelted by the electric process?

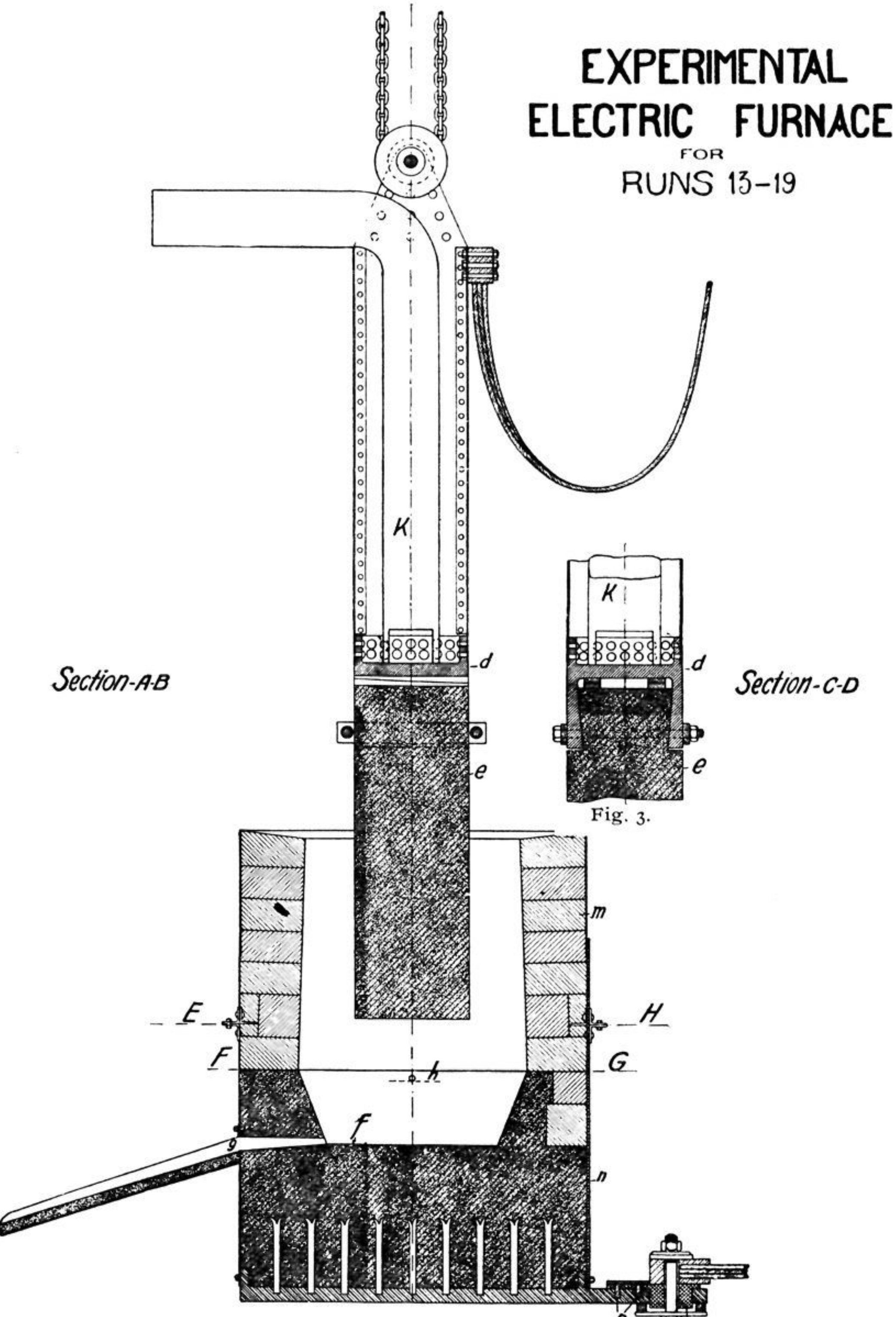
Second—Can iron ores with comparatively high sulphur content but not containing manganese be made into pig iron of marketable composition?

Third—The experiments made at Livet with charcoal as a reducing agent in substitution for coke having failed, could the process be so modified that charcoal, which can be cheaply made from mill refuse and other sources of wood supply useless for other purposes, could be substituted for coke? This is especially important since charcoal and peat-coke constitute home products, while coal-coke for metallurgical processes requires to be imported into the provinces of Ontario and Quebec.

The settlement of these questions was of such paramount importance for the formation of a judgment as to the feasibility of introducing electric smelting of iron ores as an economic process in those provinces of Canada which lack coal for metallurgical coke, but are abundantly supplied with water-powers and iron ore deposits, that the experimental investigation of the subject by the erection of an electric smelting plant at Sault Ste. Marie, Ont., was authorized.

Description of Experimental Furnace and Electrode Holder.—The furnace, as first designed by Dr. Héroult, consisted of an iron casing ¼ inch thick, bolted to a cast-iron plate 48 inches in diameter. This casing was vertically slit to break the magnetic circuit and render the inductance as small as possible. The gap formed by this slit was bridged over by a plate of copper 10 inches wide, which was securely riveted to the iron casing (Figs. 1 and 2).

The bottom plate, which formed one of the terminals for the current, had iron rods cast in, for the purpose of insuring a good contact with the carbon paste rammed into the lower part of the casing which formed the crucible.


EXPERIMENTAL
ELECTRIC FURNACE
FOR
RUNS 13–19
K
d
Section-A-B
e
K
d
Section-C-D
e
m
E
H
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p
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Fig. 3.

Fig. 1.

The casing was made in two parts, the lower part being 3 feet and the upper 4 feet high.

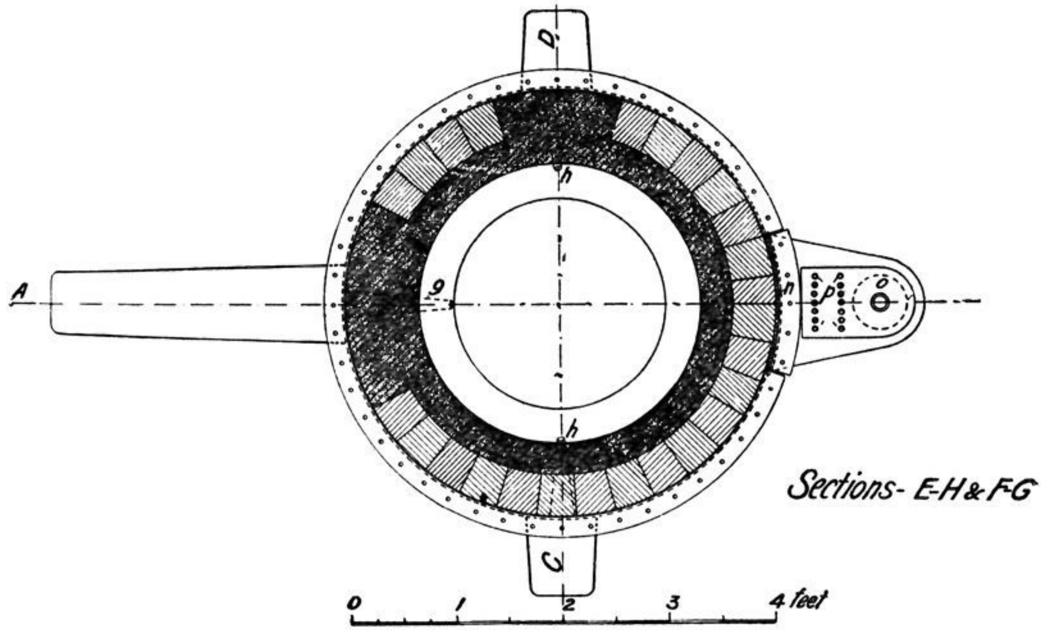

Fig. 2.

The electrode holder was made of four copper plates riveted together and to a steel shoe (*d*), Figs. 1 and 3, into which fitted the electrode (*e*). In this construction the sides of the electrode and electrode holder were flush, which allowed the holder to penetrate the charge without resistance. This was intended to permit of the consumption of the electrode to nearly its full length and obviate the necessity of throwing away from 2 to 3 feet of unused electrode, which in any other construction would be the case. To keep the contact cool a pipe (*k*) was introduced, by means of which air circulation was effected. It was found, however, that to secure proper contact between the steel shoe and electrode a clamp had to be placed around the shoe, Fig. 3, the bolts of which in descending into the charge would have offered resistance to vertical regulation of the electrode. This change in the contact rendered the long copper attachment useless.

To utilize as much of the electrode as possible, the height of the furnace was diminished to dimensions shown in Fig. 1, which represents the final modification of the furnace as used for the majority of the experiments made.

The contact did not prove entirely satisfactory, as there was a constant loss of from 2 to 3 volts, but as this loss could not be remedied during the experiments a bolt was screwed into the electrode and connected to a voltmeter, which allowed of the determination of loss of volts by taking the difference between the volts indicated in main circuit and on the electrode.[1]

The contact with the bottom plate was at first made by driving a conical copper plug into a conical hole in the projecting part of the bottom plate and making contact by pressing the aluminium block (holding cables), copper plug and bottom plate together by means of a bolt (Figs. 1 and 2). Owing to the oxidation of the surfaces in contact, this method of making contact proved inefficient. A new contact was, therefore, made by turning a copper plug from a block of copper 10 by 12 inches, leaving an oblong flange (Figs. 1 and 2), which was dressed on both sides to make a good bearing. Two rows of holes (*p*), Fig. 2 (14 in all), of $^3/_4$ inch diameter were drilled through the copper flange and into the bottom plate for a depth of about 1 inch, into which was run melted aluminium. This aluminium also filled any crevices which existed between the surfaces of contact.

This contact proved to be fairly satisfactory, although a loss of 1 volt or less was realized.

The lining of the furnace was given the shape of a double cone set base to base. Changes in the dimensions of the interior were made from time to time, as indicated by experience, but during the latter part of the experiments they were as follows:

	Inches.
Diameter of bottom of crucible	24
Height of lower cone	11
Height of upper cone	33
Diameter of joint base of the two cones	32
Diameter at top of furnace	30

The electrodes, manufactured by the Héroult process and imported from Sweden, were prisms of square cross-section, 16 by 16 inches by 6 feet long. The contact with the cables carrying the electric current consisted of a steel shoe riveted to four copper plates which ended in a support for a pulley. The electrode with its contact was supported by a chain passing under the pulley, one end of the chain being fastened to the wall, the other end passing over a winch operated by a worm and worm-

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[1] Later an entirely new contact was made, which proved entirely satisfactory.

wheel. This formed a convenient arrangement for regulating the electrode by hand.

Electrical Machinery.—The electrical energy was furnished by one phase of a 3-phase, 400 kilowatt, 30 cycle, 2,400 volt, alternating current generator coupled by belt to a 300 horse-power, 500 volt, direct current motor. A current of 2,200 volts was delivered to an oil-cooled transformer of 225 kilowatt capacity, designed to furnish current to the furnace at 50 volts. The transformer was placed in a separate room in the furnace building, close to the furnace. From the transformer the current was led to the bottom plate contact of the furnace and to the electrode contact by conductors consisting each of 30 aluminium cables, $\frac{5}{8}$ inch in diameter.

The measuring instruments consisted of a voltmeter, an ammeter, a power-factor meter and a recording wattmeter. The transformer and electric meters were manufactured by the Westinghouse Electric and Manufacturing Company.

An additional voltmeter reading from 10 to 80 volts, supplied by the Keystone Electric Company, which proved very satisfactory, was also placed in circuit to serve as a check.

Experiments.—A number of experiments required to be made to adjust the capacity of the crucible of the furnace to the energy available and to determine the shape to be given to the interior of the furnace to insure easy passage of the charge into the reducing and melting zones. After this, attempts were made to utilize the calorific energy of the carbon monoxide resulting from the reduction of the ore, which in all experiments so far recorded had been wasted. To accomplish this, air under pressure was introduced into the furnace about 12 inches below the upper level of the charge. The carbon of the charge, in the form of coke dust, was mixed with fire-clay and briquetted to prevent it from being consumed by the air blast. It was hoped that by thus utilizing the carbon monoxide in preheating the charge and partially reducing the ore the output would be materially increased.

It was found, however, that the great heat evolved by the combustion of the carbon monoxide caused the charge to become sticky and to hang. Nor could this be remedied by stoking, the space between the walls of the furnace and the electrode being too narrow. Moreover, the electrode, although it had been protected with asbestos and iron sheeting, was found after the experiment to have been badly corroded. The furnace was not at all adapted for these experiments and further attempts in this direction were abandoned. The experiments, however, showed that with a differently constructed furnace, in which the electrode is isolated from the charge, the output might be greatly increased by the introduction of an air blast.

The official experiments were begun about the middle of January, the furnace being in operation night and day, with some few intermissions, until the 5th of March. During that time about 150 casts were made, yielding about 55 tons of pig iron.

The following classes of ore were treated:

(1) Hematite (Negaunee).

(2) Magnetite from the Wilbur mine, Ont. (Wm. Caldwell, Esq.).

(3) Magnetite from the Blairton mine, Ont. (Pierce Co., Marmora).

(4) Magnetite from the Calabogie Mining Co. (J. G. Campbell, Esq., Perth).

(5) Magnetite from the Calabogie Mining Co. (J. G. Campbell, Esq., Perth).

(6) Magnetite from the Calabogie mine (T. B. Caldwell, Esq., Lanark).

(7) Roasted pyrrhotite from Lake Superior Corporation.

(8) Titaniferous iron ore from Quebec (J. G. Scott, Quebec).

The materials for the charge—ore, flux and carbon—were crushed to pass through a $\frac{3}{4}$ inch ring and roughly mixed. The composition of the charge in each run as given in this paper was slightly modified from time to time by varying the percentage of charcoal and flux.

Charging.—In starting the furnace a small quantity of charcoal was placed on the bottom of the crucible and the electrode lowered until an arc was developed between the charcoal and the electrode. The arc was maintained for from sixteen to twenty hours to preheat the furnace. The furnace was then filled up with the charge and by lowering or raising the electrode the current was kept as constant as possible, at 5,000 amperes.

In most experiments when charcoal was used as the reducing agent the electrode occupied a position of about 16 inches from the bottom of the crucible and required very little attention.

Run No. 8.[1]

Ore treated	Hematite
Reducing agent	Briquettes
Flux	Limestone

Analysis of Raw Material.

Hematite.

SiO_2	5.42
Fe_2O_3	88.90
Al_2O_3	2.51
CaO	0.61
MgO	0.30
Mn	0.16
P	0.044
S	0.002
Loss on ignition	2.48
	100.426

Limestone.

SiO_2	1.71
$Fe_2O_3+Al_2O_3$	0.81
$CaCO_3$	92.85
$MgCO_3$	4.40
P	0.004
S	0.052
	99.826

	Per cent.
Metallic iron	62.23

The briquettes were made of 80 per cent. coke dust and 20 per cent. fire-clay.

Briquettes:

	Per cent.
Volatile matter	4.05
Fixed carbon	69.73
SiO_2	15.26
$Fe_2O_3+Al_2O_3$	8.92
CaO	0.90
MgO	0.30
S	0.84
	100.00

The charge, which was slightly modified for subsequent charges by increasing the amount of briquettes and decreasing the limestone, had the following composition:

	Pounds.
Ore	200
Briquettes	60
Limestone	50

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[1] Only those runs are given which are of special interest.

ANALYSIS OF IRON PRODUCED.[1]

	Cast No. 28, Grey iron.	*Cast No. 30, Grey iron.*
Total carbon	4.85	4.35
Si	0.87	1.03
S	0.018	0.019

ANALYSIS OF SLAG PRODUCED.

SiO_2	34.40
Al_2O_3	15.73
CaO	43.53
MgO	2.00
Fe	1.35
S	0.55

$$\frac{\text{Slag (obtained)}}{\text{Iron (obtained)}} = \frac{1162}{2665} = 0.44$$

Length of run	12 hours
Mean volts on furnace	38.5
Mean amperes	4856
Power factor	0.919
Pig iron produced	2665 pounds
Watts $= 38.5 \times 4856 \times 0.919$	171812
Electrical horse-power $= \frac{171812}{746} =$	230.3
Output of pig iron per 1,000 El. horse-power days $= \frac{2665 \times 24 \times 1000}{12 \times 230.3 \times 2000}$	11.57 tons
Electric horse-power years of 365 days per ton of pig	0.236

Subsequent experiments indicate that had charcoal or coke been used as a reducing agent instead of briquettes, thereby greatly reducing the amount of slag produced, the output would have been considerably increased.

RUN No. 13.

Ore treated	Magnetite from Wilbur mine
Reducing agent	Charcoal
Flux	Sand

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[1] A redetermination for the final report of the composition of slags and iron produced renders the analyses here given subject to amendment.

Wilbur Ore.

	Per cent.	
SiO_2	6.20	
Fe_2O_3	55.42	Fe=56.69
FeO	23.04	
Al_2O_3	2.56	
CaO	2.00	
MgO	6.84	
P_2O_5	0.023	P=0.01
S	0.01	
CO_2 and undet	3.907	
	100.000	

Charcoal.

	Per cent.
Moisture	14.06
Volatile matter	28.08
Fixed carbon	55.90
Ash	2.54
	100.58
Sulphur	0.058

The sand used was common furnace sand, of which no analysis was made.

COMPOSITION OF CHARGE.

	Pounds.
Ore	400
Charcoal	125
Sand	27

ANALYSIS OF IRON PRODUCED.

	Cast No. 49, Grey Iron.	*Cast No. 53, Grey Iron.*
Total carbon	5.18	4.65
Si	1.30	1.41
S	0.020	0.012
P	0.029	0.024

ANALYSIS OF SLAG PRODUCED.

SiO_2	35.84
Al_2O_3	31.80
CaO	14.39
MgO	16.22
S	0.26
Fe	0.35

$$\frac{\text{Slag}}{\text{Iron}} = \frac{4195}{12858} = 0.326$$

Length of run	61 hours, 25 min.
Mean volts on furnace	35.75
Mean amperes	5000
Power factor	0.919
Pig iron produced	12858 pounds
Watts=35.75 × 5000 × 0.919	164271
Electrical horse-power = $\frac{164271}{746}$	220.2

Output of pig iron per 1,000 El. horse-power

days $= \dfrac{12858 \times 24 \times 1000}{61.4 \times 220.2 \times 2000}$ .... 11.41 tons

El. horse-power years[1] per ton of pig........ 0.2399

RUN NO. 14.

Ore treated	Magnetite from Blairton mine.
Reducing agent	Charcoal
Flux	Limestone Sand

ANALYSIS OF RAW MATERIAL.

Blairton Ore.

SiO_2	6.60	
Fe_2O_3	60.74	Fe = 55.85
FeO	17.18	
Al_2O_3	1.48	
CaO	2.84	
MgO	5.50	
P_2O_5	0.037	P = 0.016
S	0.57	
CO_2 and undet	5.053	
	100.000	

Charcoal and limestone same as in previous run.

COMPOSITION OF CHARGE.

	Pounds.
Ore	400
Charcoal	125
Limestone	25
Sand	6

ANALYSIS OF IRON PRODUCED.

Cast No. 80, Grey Iron.

Total carbon	3.73
Si	3.53
S	0.042
P	0.034

ANALYSIS OF SLAG PRODUCED.

SiO_2	33.80
Al_2O_3	10.20
CaO	21.78
MgO	30.50
S	2.05
Fe	0.25

$$\frac{\text{Slag}}{\text{Iron}} = \frac{4892}{11989} = 0.41$$

Length of run	65 hours, 30 min.
Mean volts on furnace	36.03
Mean amperes	4987
Power factor	0.919

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[1] 365 days.

Pig iron produced	11989 pounds
Watts $= 36.03 \times 4987 \times 0.919$	165125
Electrical horse-power $= \frac{165125}{746}$	221.34
Output of pig iron per 1000 El. horse-power days $= \frac{11989 \times 24 \times 1000}{65.5 \times 221.34 \times 2000}$	9.92 tons
El. horse-power year per ton of pig	0.276

RUN No. 15.

Ore treated	Magnetite from Calabogie[1]
Reducing agent	Charcoal and charcoal braise
Flux	Limestone

ANALYSIS OF RAW MATERIAL.

Calabogie Ore.

SiO_2	3.80	
Fe_2O_3	56.24	Fe=59.38
FeO	25.76	
Al_2O_3	3.73	
CaO	2.00	
MgO	3.42	
P_2O_5	0.85	P=0.371
S	0.20	
CO_2 and undet	4.00	
	100.00	

Limestone and charcoal the same as in previous runs. The charcoal braise used was of poor quality, being wet, high in ash and mostly fines.

The composition of the charge, when using charcoal, was:

	Pounds.
Ore	400
Charcoal	125
Limestone	30

When using charcoal braise, the composition of the charge was:

	Pounds.
Ore	400
Charcoal braise	145
Limestone	40

During this run the alternator had to be stopped on account of repair of motor. The furnace was then considerably cooled and some time was consumed before it was again in working condition.

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[1] Calabogie Mining Company.

First Part of Run—Analysis of Iron Produced.

	Cast No. 89, Grey iron.	*Cast No. 90, Grey iron.*
Total carbon	3.53	3.43
Si	0.95	1.17
S	0.024	0.016
P	0.554	0.457

Analysis of Slag Produced.

SiO_2	24.30
Al_2O_3	27.16
CaO	36.06
MgO	10.74
S	1.67
Fe	0.25

$$\frac{\text{Slag}}{\text{Iron}} = \frac{1335}{4520} = 0\ 29$$

Length of run	23 hours, 50 min.
Mean volts on furnace	36.16
Mean amperes	5.000
Power factor	0.919
Pig iron produced	4520 pounds
Watts $= 36.16 \times 5000 \times 0.919$	166155
Electrical horse-power $= \frac{166155}{746}$	222.72
Output of pig iron per 1000 El. horse-power days $= \frac{4520 \times 24 \times 1000}{23.83 \times 222.72 \times 2000}$	10.21 tons
El. horse-power year per ton of pig	0.268

Second Part of Run—Analysis of Iron Produced.

	Cast No. 92, Grey iron.	*Cast No. 95, Grey Iron.*
Si	0.73	0.95
S	0.011	0.012

$$\frac{\text{Slag}}{\text{Iron}} = \frac{892}{2722} = 0.33$$

Length of run	16 hours, 15 min.
Mean volts on furnace	35.85
Mean amperes	5000
Power factor	0.919
Pig iron produced	2722 pounds.
Watts $= 35.85 \times 5000 \times 0.919$	164730
Electrical horse-power $= \frac{164730}{746}$	220.81
Output of pig iron per 1000 El. horse-power days $= \frac{2722 \times 24 \times 1000}{16.25 \times 220.81 \times 2000}$	9.10 tons
El. horse-power year per ton of pig	0.301

RUN No. 16.

Ore treated	Magnetite from Calabogie[1]
Reducing agent	Charcoal
Flux	Limestone Quartz

ANALYSIS OF RAW MATERIAL.

Calabogie Ore.

SiO_2	6.06	
Fe_2O_3	58.00	Fe=59.85
FeO	24.78	
Al_2O_3	1.00	
CaO	0.40	
MgO	6.00	
P_2O_5	0.046	P=0.020
S	0.17	
CO_2 and undet	3.544	
	100.000	

Charcoal.

Moisture	2.20
Volatile matter	20.60
Fixed carbon	74.40
Ash	2.80

Limestone same as in previous runs.

COMPOSITION OF CHARGE.

	Pounds.
Ore	400
Charcoal	125
Limestone	45
Quartz	5

ANALYSIS OF IRON PRODUCED.

Cast No. 102, Grey Iron.

Total carbon	4.20
Si	1.75
S	0.005
P	0.047

ANALYSIS OF SLAG PRODUCED.

SiO_2	30.90
Al_2O_3	12.30
CaO	40.09
MgO	12.91
S	1.48
Fe	0.56

$$\frac{\text{Slag}}{\text{Iron}} = \frac{2556}{7150} = 0.36$$

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[1] Calabogie Mining Co., Shaft No. 4.

Length of run	38 hours, 20 min.
Mean volts on furnace	36.5
Mean amperes	4993
Power factor	0.919
Pig iron produced	7150 pounds.
Watts $=36.5 \times 4993 \times 0.919$	167483
Electrical horse-power $=\frac{167483}{746}$	224.50
Output of pig iron per 1000 El. horse-power days $=\frac{7150 \times 24 \times 1000}{38.33 \times 224.50 \times 2000}$	9.97 tons

Run No. 17.

Ore treated	Magnetite from Calabogie mine[1]
Reducing agent	Charcoal
Flux	Limestone Quartz

Analysis of Raw Material.

Calabogie Ore.

SiO_2	4.00	
Fe_2O_3	55.31	Fe=58.29
FeO	25.20	
Al_2O_3	2.24	
CaO	2.40	
MgO	4.00	
P_2O_5	0.95	P=0.415
S	0.45	
CO_2 and undet	5.45	
	100.00	

Charcoal same as in run No. 15. Limestone same as in previous runs.

Composition of Charge.

	Pounds.
Ore	400
Charcoal	125
Limestone	20

Occasionally small quantities of quartz were added.

Analysis of Iron Produced.

	Cast No. 111, Grey Iron.	*Cast No. 113, Grey Iron.*
Si	1.49	1.55
S	0.016	0.015
P	0.500	0.520

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[1] T. B. Caldwell, Esq.

ANALYSIS OF SLAG PRODUCED.

SiO_2	26.96
Al_2O_3	20.64
CaO	27.40
MgO	15.50
S	1.41
Fe	0.21

$$\frac{\text{Slag}}{\text{Iron}} = \frac{3263}{8303} = 0.39$$

Length of run	43 hours, 5 min.
Mean volts on furnace	36.79
Mean amperes	5000
Power factor	0.919
Pig iron produced	8303 pounds.
Watts $= 36.79 \times 5000 \times 0.919$	169050
Electrical horse-power $= \frac{169050}{746}$	226.6
Output of pig iron per 1,000 El. horse-power days $= \frac{8303 \times 24 \times 1000}{43.08 \times 226.6 \times 2000}$	10.20 tons
El. horse-power year per ton of pig	0.268

RUN No. 18.

Ore treated	Roasted pyrrhotite
Reducing agent	Charcoal
Flux	Limestone

ANALYSIS OF RAW MATERIAL.

Roasted Pyrrhotite.

SiO_2	10.96
Al_2O_3	3.31
Fe_2O_3	65.43
CaO	3.92
MgO	3.53
S	1.56
P	0.016
Cu	0.41
Ni	2.23
Metallic iron	45.80

Charcoal and limestone same as in previous run. The limestone in the charge was decreased from 120 pounds when starting to 50 pounds. The composition then being:

	Pounds.
Ore	400
Charcoal	110
Limestone	50

ANALYSIS OF IRON PRODUCED.

	Cast No. 125.	*Cast No. 130.*	*Cast No. 133.*
Total carbon	3.23	3.38	2.50
Si	4.90[1]	4.50[1]	6.32[1]
S	0.007	0.006	0.007
P	0.062	0.037	0.042
Cu	0.86	0.87	0.71
Ni	3.70	4.12	4.00

ANALYSIS OF SLAG PRODUCED.

SiO_2	16.44
Al_2O_3	13.86
CaO	53.25
MgO	8.80
S	5.28
Fe	0.65
Cu	trace
Ni	trace

$$\frac{\text{Slag}}{\text{Iron}} = \frac{5060}{7336} = 0.69$$

Length of run	56 hours, 20 min.
Mean volts on furnace	36.05
Mean amperes	5000
Power factor	0.919
Pig iron produced (ferro-nickel)	7336 pounds.
Watts $= 36.05 \times 5000 \times 0.919$	165649
Electrical horse-power $= \frac{165649}{746}$	222.05
Output of pig iron (ferro-nickel) per 1000 El. horse-power days $= \frac{7336 \times 24 \times 1000}{56.33 \times 222.05 \times 2000}$	7.038 tons
El. horse-power year per ton of pig	0.389

RUN NO. 19.

Ore treated	Titaniferous iron ore
Reducing agent	Charcoal
Flux	Limestone Fluorspar

ANALYSIS OF RAW MATERIAL.

Titaniferous Iron Ore.

SiO_2	7.12	
Fe_2O_3	30.30	Fe = 43.59
FeO	28.78	
Al_2O_3	7.00	

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[1] By increasing the limestone of the charge the silicon content of the ferro-nickel pig recently produced has been depressed to 2 per cent.

CaO	1.00	
MgO	4.14	
P_2O_5	0.064	P=0.028
S	0.04	
TiO_2	17.82	
Cr_2O_3	2.50	Cr=1.42
	99.684	

Charcoal and limestone same as in previous run.

COMPOSITION OF CHARGE.

	Pounds.
Ore	400
Charcoal	100
Limestone	50
Fluorspar	50

ANALYSIS OF PIG IRON PRODUCED.

	Cast No. 136.	*Cast No. 137.*
Total carbon	...	3.50
Si	4.50	2.80
S	0.007	0.091
P	0.143	0.060
Ti (approx.)	1.00	1.30

ANALYSIS OF SLAG PRODUCED.

SiO_2	7.00
Al_2O_3	28.50
CaO	14.23
MgO	2.93
TiO_2	38.92
Fe	1.13
S	0.90

On account of the furnace being in a very bad condition, the lining being eaten away by the limy slag used in the previous run, the run had to be stopped and no figures as to output could be obtained.

The slag was very fluid and likely the fluorspar in the charge could have been reduced considerably or omitted altogether.

The iron obtained in cast No. 136 was probably mixed with some iron from the previous charge, when ore with high phosphorus content was used.

The Smelting of Magnetite.—It was expected that considerable difficulty would be experienced in the smelting of magnetite, on account of its conductivity. It was thought that with the furnace in use, in which the electrode was immersed in the charge, the current would disseminate itself laterally from the sides of the electrode through the charge, preventing the current at the reducing and fusion zone from attaining such density as would be required for the high temperature necessary for reduction and fusion. With charcoal as a reducing agent this difficulty was not experienced, nor was the inductance of the furnace increased by the presence of magnetite.

It should, however, be mentioned that the phenomenon of rapid temporary decrease of ohmic resistance of the charge shortly after the current is put on, when the charge consists of conductors in the form of small pieces, described by J. Bronn, in his article entitled "Zur Anwendung lose geschichteter kleinstückiger Leiter für electrische Heizwiederstände,"[1] was occasionally observed in some of the runs made. This trouble occurred chiefly at the beginning of a new experiment, before the furnace had acquired its normal temperature. By adding a few shovels of iron ore, omitting flux and charcoal, it was sometimes possible to cause the electrode, which to keep the current constant had by hand regulation been elevated, to return to its normal position. In a few instances, however, this method failed, especially when the furnace was choked with fines and the gases evolved escaped under great pressure. Since the electric installation did not permit the compensation of the temporary increase of conductivity of the charge by decrease of voltage with constancy of current, the electrode in such case rose to the top of the furnace and it became necessary to melt down the charge and start anew.

If the explanation offered by Bronn is correct that the decrease of the ohmic resistance during the "Anheizungsphase" is occasioned by the more intimate contact of the conducting pieces of the charge due to pressure of escaping gases from the pores of the carbon and the carbon dioxide evolved from the limestone, it is evident that preheating the charge, which might be effected by utilizing the carbon monoxide resulting from reduction, would entirely overcome this difficulty, if the charge were sufficiently porous to permit the gases evolved to escape at low pressure. Under such conditions the electrode would maintain its normal position throughout the operation, requiring to be lowered only to keep step with its consumption.

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[1] "Electrotechnische Zeitschrift," 1906, Heft 9.

The ores treated, with the exception of the hematite and the roasted pyrrhotite, contained a high percentage of magnesia, producing a very infusible slag. When the furnace had been running for some time this infusible material formed a scale around the crucible, the electric energy available not being sufficient to keep it in a molten condition. The crucible and lower part of the furnace were, therefore, partially filled up, preventing easy access of the charge to the reducing and melting zone. This slower feeding left the charcoal on top of the furnace exposed to the air a longer time, thus increasing the amount of charcoal required and decreasing the output. With a greater current than was available and consequent higher temperature, the formation of the scale would have been prevented and the output correspondingly increased.

The electric installation at our disposal was far from ideal for electric smelting experiments. Aside from the drop of voltage due to the frequent slipping of the belt connecting motor and generator, it was impossible to increase the current beyond 5,000 amperes at from 35 to 40 volts. This inelasticity of the system prevented the determination of the most suitable current and voltage for a given charge in the furnace.

The Use of Charcoal as a Reducing Agent.—It was of great importance to ascertain whether charcoal without being briquetted with the ore could be used instead of coal-coke. No difficulty whatever was experienced, in fact so admirably adapted was charcoal, when crushed to pass a ¾ inch ring, as a reducing agent in the electric furnace that coke and briquettes of coke with clay were abandoned and all the experiments with magnetite and roasted pyrrhotite described were made with charcoal. Some of the charcoal available was of very poor quality, being little better than charred wood containing only about 56 per cent. of fixed carbon. This and the fact that a considerable quantity of the charcoal was consumed on top of the furnace account for the large quantity of charcoal used per ton of product. A modification of the furnace, protecting the upper layer of the charge from the atmosphere, and the use of charcoal properly carbonized would decrease considerably the amount of charcoal which was actually used in the experiments and consequently reduce the cost of production as given.

Consumption of Electrode.—For the production of 42,711 pounds of pig iron, 384 pounds of electrode were consumed, the same electrode having been in commission for thirteen days.

Consumption of electrode per ton of pig iron:

$$\frac{384 \times 2000}{42711} = 17.98 \text{ pounds.}$$

During the time this electrode was in commission the material in the furnace was melted down several times, exposing the red hot electrode to the oxidizing atmosphere. The consumption of electrode was found to be greater for white iron than for grey iron and since the 42,711 pounds of pig iron produced included several casts of white iron, the consumption of electrode was also on that account greater than it would have been had only grey iron been produced.

Power Factor.—The power factor of the furnace was determined by Mr. Chas. Darrall, of the Canadian Westinghouse Company of Hamilton, Ont., and was found to be 0.919. This high power factor is due to the construction of the furnace casing, as described above.

Since the true electric power is the apparent electric power multiplied by the power factor, it is evident that any error made in the determination of the power factor which tends to decrease its value will appear to decrease the consumption of energy per ton of product. The large output of 12.12 tons per 1,000 electric horse-power days, *i. e.*, the small amount of electric horse-power absorbed per ton of product in the second Livet experiments, was obtained in a furnace with the abnormally low power factor 0.564. Whatever doubt may be engendered as to the correctness of the figure obtained for the absorption of electric energy on account of this low power factor of the Keller furnace, such doubt cannot arise regarding the figures obtained with the Héroult furnace for the absorption of electric energy in the Government experiments on account of its remarkably high power factor 0.919.

Moreover, since the cost of alternate current generators increases with increase of capacity, furnaces with high power factors (which can utilize a high percentage of the capacity of the generators) will be more economical as regards the first cost of the electrical installation of an electric smelting plant than furnaces with low power factors.

Modification of Experimental Furnace for Commercial Production of Pig Iron.—Probably the largest unit which can at present be constructed on the model of the experimental furnace will not exceed 1,500 horse-power. The construction of the experimental furnace to fit it for the production of pig iron on a commercial scale will require to be modified in the following important particulars:

(1) The top of the furnace requires to be modified to permit of the application of labor-saving machinery for charging.

(2) Provision requires to be made for the collection and utilization of the carbon monoxide produced by the reduction of the ore: this involves also the protection of the charcoal of the charge from combustion on top of the furnace.

The greater capacity insuring less loss of heat by radiation and the modification of the furnace to permit of the utilization of the carbon monoxide will materially increase the output beyond that ascertained by the experimental furnace. The experiments indicated that under *normal* conditions about 11.5 tons were produced by an expenditure of 1,000 electric horse-power days (see runs Nos. 8 and 13). It is, therefore, not unreasonable to assume that under similar conditions with a properly constructed plant the output per 1,000 horse-power days would certainly reach 12 tons. This figure has been adopted in calculating cost of production per ton of pig.

The protection of the charcoal of the charge from combustion on top of the furnace will materially decrease the amount of charcoal necessary for reduction and consequently lessen the cost of this item. This saving has, however, not been taken into account in the estimate of cost.

On account of the value of the product, the smelting of roasted nickeliferous pyrrhotite by the electrothermic process, as carried out with the Government experimental plant, admits of immediate commercial application without other modification of the furnace than increase of its capacity.

The Lake Superior Corporation has acquired the Government plant by purchase and employs it for the semi-commercial production of ferro-nickel pig. The company has had the furnace in operation night and day since about March 7th. The smelting operations are left entirely in the hands of the workmen, who had been trained during the progress of the Government experiments. I am informed that the furnace works with admirable regularity, the regulation of the electrode requiring hardly any attention, and the output is of excellent and uniform quality.

The Electric Furnace as Compared with the Blast-Furnace.—The tendency among iron manufacturers for some time has been to increase the size and capacity of blast-furnaces until the enormous capacity of 600 to 800 tons per day with a furnace stack 100 feet high has been reached.

But for the economical working of a blast-furnace there is a point beyond which the furnace can be neither increased nor decreased in size. It seems to have been established that furnaces with a height of 90 feet and corresponding output prove the most economical. While fuel is cheap and ore of good quality and high iron content is still abundant, any disadvantages of such large units will not be felt. It may, however, be of value to call attention to some of the disadvantages connected with the employment of large units. These are as follows:

First—Large first cost of furnace.

Second—Excessive cost of charging machinery and upkeep of same.

Third—Large expense and probable idleness through break-down.

Fourth—Cost of and difficulties of making repairs, relining, etc.

Fifth—Serious complications resulting from scaffolding, involving loss of life and money.

Sixth—Financial loss resulting from wrong composition of charge, involving many tons of iron before correction can be made.

Yet, with even these drawbacks the blast-furnace of to-day, representing the result of a hundred years' experience and inventive skill, must be pronounced a perfect machine, hardly permitting further improvement, and if the electric furnace, which is yet in its infancy, is able in its present state of development to compete with a blast-furnace under the special conditions of cheap electric energy and high price of metallurgical fuel, what may we not expect of its performance when all the calories available in an electric furnace will have been utilized by proper design, as the result of years of experience?

It is, therefore, scarcely to the point to speak of faults or disadvantages of a new invention, which, as they are realized, may be corrected, but it is of great importance to point out any advantages a new apparatus may possess over a long-tried machine. The following are some points in favor of the electric furnace:

First—Original small cost of furnace.

Second—Absence of bulky or costly charging machinery.

Third—Small expense involved through breakdown.

Fourth—Small cost and ease with which repairs may be made.

Fifth—No serious complications arising from scaffolding.

Sixth—Loss due to wrong composition of charge reduced to a minimum.

Seventh—Perfect control of the temperature in the reducing and melting zone.

In reviewing the advantages arising from the introduction of the electric furnace, it must be understood that a smelting plant operated by electricity is composed of several small units, the disablement of any one of which will not render the plant idle.

Again, in case of accident, such a furnace will cool down in a comparatively short time, permitting repairs to be made in the least possible time.

General Remarks.—The far-reaching consequence of the gratifying results achieved by these experiments will at once be apparent. Many of our magnetites are too high in sulphur to be handled by the blast-furnace and consequently have so far been of no commercial value. But the very best of pig iron, as has been proven, can be made from ores which contain as high as 1.5 per cent. of sulphur. A blast-furnace will not usually handle an ore which contains more than 0.1 per cent. of sulphur and requires, therefore, an ore which cannot be obtained at a low figure.

Regarding the water-power required for the application of this process it may be stated that many water-powers exist in Ontario and Quebec, surrounded by iron ore fields, in localities ill adapted for the application of electric energy for any other purpose and could be developed to furnish an electric horse-power year for from $4.50 to $6.00.

With such a price for the energy required, the small consumption of electrode, the cheapness of the ore employed and the peculiar excellence of the pig iron produced, electric smelting of iron ores in Canada, using charcoal or peat-coke made from our peat bogs of enormous extent, may be pronounced commercially feasible.

Under the prevailing conditions in Canada it now only remains for the engineer to design a plant on a commercial scale, say of 100 to 150 tons daily output, with all the necessary labor-saving appliances. Just as in the case of the blast-furnace so likewise with the electric furnace, experience gained will result in further economy and the day may not be far distant when the carbon monoxide, which is of high calorific value and which at present as a product of the reaction taking place in the electric furnace is allowed to escape without utilization, will be employed for increasing the output by something like one-fourth. When this is accomplished, the blast-furnace could not compete with the electric furnace, even under conditions where coke might be cheaper than at present quoted in Ontario and Quebec.

With the present advance which has been made in the transmission of electric energy, batteries of electric furnaces could be set up at various iron ore deposits, which could be fed with electric energy from some centrally located water-power, thus effecting a saving of the transportation costs of the ore from the mine to the furnace.

The following is a summary of the results of the experiments which have been made under Government auspices at Sault Ste. Marie:

First—Canadian ores chiefly magnetite can be economically smelted by the electrothermic process.

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

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

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

Fifth—A ferro-nickel pig can be produced practically free from sulphur and of fine quality from roasted nickeliferous pyrrhotite.

Sixth—Pyrite cinders, resulting from the roasting of pyrite in the manufacture of sulphuric acid and which at present constitute a waste product, can be smelted into pig iron by the electric process.

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

The results of the introduction of electric smelting into countries possessing iron ore deposits and water-powers but lacking metallurgical fuel may be summarized as follows:

First—The utilization of water-powers which cannot at present be profitably employed for any other purpose.

Second—The utilization of iron ore deposits, which on account of their high sulphur content cannot be treated by blast-furnace methods and have so far been valueless. This is of extreme importance, for already the question has arisen, how long the present supply of blast-furnace iron ore is likely to last and ores are now accepted by furnace men with a metallic content such as would not have been looked at a few years ago, and when these ores are exhausted and none but sulphurous ores or titaniferous ores are available, the stacks of the numerous blast-furnaces, which have rendered such magnificent service to our present civilization, will be silent and smokeless, having been supplanted by the electric furnace which can successfully treat an ore which the blast-furnace cannot handle.

Third—The utilization of peat bogs for the production of peat coke, to be used as reducing material for the operation of electric furnaces, and utilization of mill refuse and sawdust, for which there has so far been no practical use.

Fourth—Rendering such countries independent of fuel import for metallurgical processes.

Fifth—Enabling them to produce their own pig iron for home consumption and consequently retaining in their country the money which otherwise would have to be sent abroad to purchase pig iron in the crude and manufactured state.

Sixth—The development of steel plants and rolling mills using only electric energy.

Estimate for a 10,000 Horse-power Plant[1] Producing 120 Tons of Pig Iron per day of Twenty-four Hours.

Furnaces, contacts, overhead work	$ 24,500
Bins, chutes, elevators	14,000
Crushers	4,000
Hoists and regulators	10,500
Instruments	1,400
Cables for conductors	8,400
Building	10,500
Mixer and casting machine	10,000
Traveling crane and tracks	5,000
Ladles	1,500
Slag trucks	3,000
Ore bins	3,000
Repair shop	5,000
	$100,800
Charcoal plant	50,000
Power plant (assuming cost of developing one electric horse-power = $50.00)	500,000
	$650,800
Electrode plant	6,000
Unforeseen expenditure	43,200
	$700,000
Amortization: 5 per cent. Depreciation: 5 " " Interest: 5 " " } 15 per cent. on $700,000	105,000
On a production of 43,200 tons per year of 360 days per ton of pig iron	$ 2.43

Cost of Production per Ton Pig Iron.

Ore (55 per cent. metallic iron) at $1.50 per ton	$ 2.70
Charcoal, one-half ton at $6.00 per ton	3.00
Electric energy, amortization, etc	2.43
Labor	1.00
Limestone	0.20
Eighteen lbs. of electrode at 2 cents per lb	0.36
General expenses	1.00
Total	$ 10.69

The figures here given on the authority of Dr. Héroult are outside figures and I desire to make the following remarks respecting them:

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[1] This estimate is given on the authority of Dr. P. Héroult.

First—The price of ore will depend upon its quality and on local conditions and is not, therefore, a fixed figure.

Second—As stated previously, many water-powers in Ontario and Quebec can be developed to furnish an electirc horse-power year at from $4.00 to $5.00. This lower cost will reduce the electric energy required per ton of pig, as stated in the estimated cost.

Third—A better class of charcoal than was available for the experiments and proper protection against its consumption on top of the furnace will materially decrease the quantity of charcoal required per ton of pig, as stated in the cost sheet, and consequently lower the cost of production below the figures stated.

DEPARTMENT OF MINES,
OTTAWA, CANADA.

FORMALDEHYDE DISINFECTION. DETERMINATION OF THE YIELD OF FORMALDEHYDE IN VARIOUS METHODS OF LIBERATING THE GAS FOR THE DISINFECTION OF ROOMS.[1]

BY DANIEL BASE.

Received June 9, 1906.

IN the multitude of experiments on disinfection by formaldehyde gas very few of the experimenters have made any attempt to determine the exact amount of formaldehyde gas that entered the room from the charging apparatus. Several writers make reference to the percentage of the gas present in the air of the room, but they either do not state how the determinations were made or they obtain the percentage indirectly;[2] M. von Brunn,[3]

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[1] These experiments were performed in the Division of Pharmacology, Hygienic Laboratory, U. S. Public Health and Marine Hospital Service, and are published by the permission of Surgeon-General Wyman; the results are incorporated in Bulletin 27, of the Hygienic Laboratory, where they are used by Dr. T. B. McClintic to illustrate his bacteriological results.

[2] Kinyoun: "Formaldehyde as a Disinfecting Agent and its Practical Application," Pub. Health Rep., U. S. P. H. & M. H. S., Jan. 29, 1897; Sprague: "Rapid Disinfection with High Percentages of Formaldehyde," Medical News, Dec. 11, 1897 (work done in the Hyg. Lab., U. S. P. H. & M. H. S.); Hill and Rickards: "Notes on Formaldehyde," Proc. 13th Ann. Meeting, Am. Pub. Health Assn., Dec. 9-12, 1902 (work done in Boston Board of Health Bacteriological Laboratory).

[3] v. Brunn: "Formaldehyddesinfection durch Verdampfung verdünnten Formalins" (Breslauer Methode), Z. Hygiene und Infectionskrankheiten, 30, 201 (1899).