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ELECTRICAL SECTION.

(Stated meeting held Thursday, October 10, 1907.)

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The Electro-Thermic Production of Iron and Steel.

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Why is the metallurgist becoming so largely an electrometal-
lurgist? Because as scientists and industrial men are learning
better how to handle electric currents, how best and most
efficiently to utilize their decomposing and heating power, they
find at their command agencies which can perform what were
formerly technical impossibilities, apparatus which can produce at
commercially possible costs products hitherto mere chemical curi-
osities or even ranking among the "chemical unknowns." The
mechanical engineer has aided this art by his skill in utilizing
water powers, in perfecting gas engines, and in inventing high-
efficiency boilers and steam engines. The electrical engineer has
contributed still more, by his design and construction of gigantic
dynamos, the transmission of large powers to great distances, the
conceiving and perfecting of large electrical furnaces. The met-
allurgist and chemist have utilized these labors of their colleagues
to devise new schemes for the extraction of the metals from their
ores, new ways of melting metals, new methods of refining metals,
new processes for converting cheap raw materials into valuable
products of different composition, and finally altogether new
products made by novel reactions and adaptable to entirely new
and original purposes. There is no need here to specify, in order
to prove the proposition; the latest books and the most recent

journals are full of the surprising achievements of the electro-metallurgist and the electrochemist.

In the scientific development of every art, there are always three stages: First, the experimenter, who thinks, imagines, devises, speculates, wonders if this thing will work, wonders if that reaction is possible, and then finally, on a small scale, determines that some reaction or transformation or decomposition of some kind is a possibility which was never proved so to anyone's satisfaction before. This much being gained, the second stage is entered: is the thing capable of being worked on a large scale? This requires the devising of large and often entirely novel apparatus, the overcoming of unforeseen difficulties, the consideration of many new factors. Frequently the apparatus or process finally evolved on a large scale bear little or no resemblance to the original laboratory experiment. Here the metallurgist must plan, calculate, design, and often invent as many novel features as he has difficulties to overcome. The process once working on an industrial scale, the final test of whether it will survive or not will be its ability to command a market for its product, its strength to stand fierce competition from the older processes now fighting for their existence, the capability of the manager to notch down expenses, notch up efficiency, and ever to improve on the quality of the product and its regularity of production.

We may now look at the avenues by which electricity has approached the commercial metallurgy of iron.

Burgess,* of the University of Wisconsin, has shown in his laboratory how iron may be electrolytically refined by a process similar in most of its details to the electro-refining of copper,— until it is turned out practically chemically pure iron, except for a trace of hydrogen, which later is driven off by heating to redness. Here is an electrochemical method of refining worked out to this point: Pure iron, purer than ever before commercially made, can undoubtedly be furnished in any quantity desired at a cost of probably $10 per ton above that of the mild steel used. The Carnegie Institution very generously and very wisely defrayed the cost of these experiments, by a grant of $2500, and it is altogether probable that the exacting demands for pure material by makers of high-class steels of special and very exact composition,

will lead in the near future to the establishment of a commercial refinery operating Burgess's process, for the production of the highest class of pure commercial iron ever at the command of steel makers. If a rapid tool steel sells at 50 to 75 cents per pound, what is one-half cent per pound on the cost of the raw material if it gives a material to start with which is absolutely pure and therefore of invariable composition?

But the above is not the "electro-thermic" production of iron or steel, and we must back to our subject.

Iron and steel are made, universally, by thermal methods, and the electro-thermic production of these products means simply their production by thermal processes in which the energy of the electric current *as a heating agent* is more or less, or altogether, depended upon to work the process. Pig-iron is made by reducing iron ore by carbon in blast-furnaces; it can also be made by reducing iron ore by carbon in electric furnaces. Steel is made by melting together wrought-iron and cast-iron in a crucible or on the hearth of a Siemens-Martin furnace; the same constituents can be melted together to equally good steel in an induction, arc or resistance electric furnace. Steel is also made by causing iron ore to react on pig-iron, in the open-hearth furnace; the same reaction can be carried out in several types of electric furnaces. Again, iron or steel can be refined in the melted state by oxidizing in the presence of a proper liquid slag; ordinary refining furnaces are limited in the nature of the slag they can use by the limited temperature at their command; electric furnaces can push the refining to much greater limits because of the higher temperature at their command permitting working with highly effective slags ordinarily considered infusible and unuseable. Finally, iron and steel are melted in cupolas, reverberatory furnaces, open-hearth furnaces and crucibles, in order to make castings; they can be melted to liquid material usually of better quality by the use of electric melting furnaces.

I have said that these things *can* be done, meaning by that that they are possible; whether they are commercially possible depends on a dozen of other conditions, which we will duly consider.

The electro-thermic metallurgy of iron has to do with two different problems:

I.   The electro-thermic production of Steel.

II.   The electro-thermic reduction of Iron Ores.

Speaking chronologically, iron ores were reduced first to wrought-iron, and from wrought-iron steel was made by cementation in red-hot carbon. Afterwards iron ore was reduced in blast-furnaces to pig-iron, which was either used itself in the arts, or served as the basis of production of wrought-iron by the puddling processes, or steel in the crucible.

SIEMENS EXPERIMENTS.

The development of the electro-thermic production of steel dates from the experiments of Siemens, in 1880, who attempted to use a combined arc-resistance furnace for melting down steel. In this case the material to be melted, held in a plumbago crucible, formed one pole and a water-cooled copper conductor the other pole. The arc between the two furnished the chief resistance and source of heat energy. The material to be melted, by its broken structure, poor contacts between the pieces and with the crucible, formed the smaller part of the resistance. With 1.6 horse-power, 500 grams of steel was melted in fifteen minutes; with 13 horse-power, 2700 grams of wrought-iron in twenty minutes. Since a kilogram of melted steel contains at least 300 calories, and a melted wrought-iron 350 calories, the heat imparted by the current was—

$$1.6 \text{ H.P., } 15 \text{ minutes} = 300 \times 0.5 = 150 \text{ Calories.}$$
$$13 \text{ H.P., } 20 \text{ minutes} = 350 \times 2.7 = 945 \text{ Calories.}$$

Since one H.P. hour = 642 Calories, the full equivalent of the power used in the two cases was—

$$1.6 \text{ H.P., } 15 \text{ minutes} = 642 \times 0.4 = 257 \text{ Calories}$$
$$\text{Thermal efficiency} = \tfrac{130}{257} = 0.584 = 58.4 \%.$$
$$13 \text{ H.P., } 20 \text{ minutes} = 642 \times 4.3 = 2761 \text{ Calories}$$
$$\text{Thermal efficiency} = \tfrac{945}{2761} = 0.342 = 34.2 \%.$$

While these efficiencies do not appear at first sight high, yet when they are compared with the efficiencies of 3 to 5 per cent. of the heating power of the fuel put into the steel while melting it by coke in a crucible set in a melting-hole, the difference is striking.

The commercial question at once arises: Why was Siemen's method not profitable on a large scale? The answer is to be found in the imperfection of the furnace and not in its inefficiency. The water-cooled copper electrode was dangerous, for it quickly

wore through. The means of regulating the current was not very good, causing great fluctuations in the current passing. The crucible itself became highly heated by the current passing through its walls and lasted but a short time. The steel absorbed both carbon and silicon from the crucible, and copper from the other electrode, and was thus changed in composition. The whole operation and apparatus was conceived on too small a scale. The efficiency, however, so far as the operation went and while it lasted was not bad; power expended at the rate of 585 kilowatt-hours per metric ton of steel melted, while 350 are theoretically necessary.

THE INDUCTION FURNACE.

This was the first to be commercially successful in producing steel. The furnace is a transformer with a secondary of one turn, which latter is a groove filled with the material to be melted. The lining of the furnace—the sides of the groove—were first made of silica, but later of magnesia; the latter was most durable. The induced current generates heat by overcoming the resistance alone of the material to be melted. There is no arc, no electrodes, no movable crucible. The furnace may be placed on trunnions so that it can be poured.

There is only one determination published of the resistivity of molten iron; it is stated by Gin to be 0.0002 Ohm per centimeter cube. The resistance of a circular or other shaped closed groove containing melted iron can therefore be calculated roughly. In an induction furnace the amperes in the secondary of one turn will be those in the primary circuit multiplied by the number of turns, less losses due to magnetic leakage. The energy generated in the iron will be as its resistance multiplied by the square of the amperes passing:

$$Q = RA^2 = \frac{r \times 1}{s} A^2.$$

but the weight of iron is:

$$W = \frac{1 \times s}{g}.$$

Therefore heating effects per unit of weight of iron

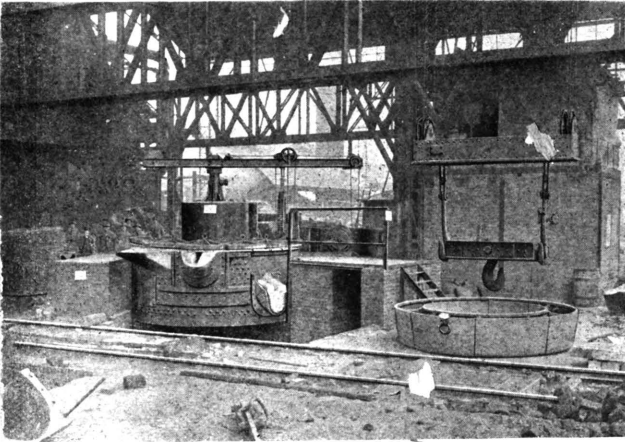$$\frac{Q}{W} = \frac{g \times A^2}{S^2}$$

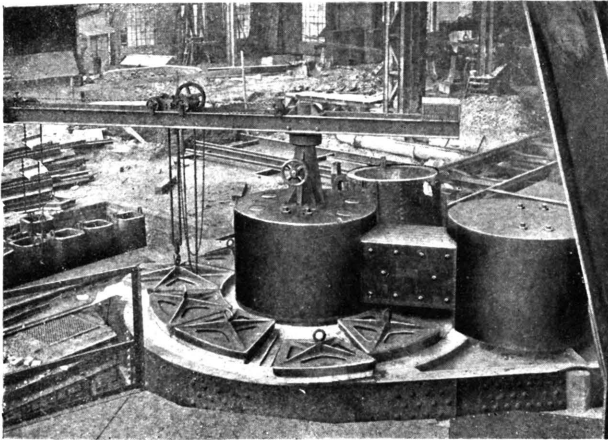Fig. 1   The 1000 H.P. induction furnace at Voelklingen.

Fig. 2.   Top view of same, showing covered groove containing the melted metal.
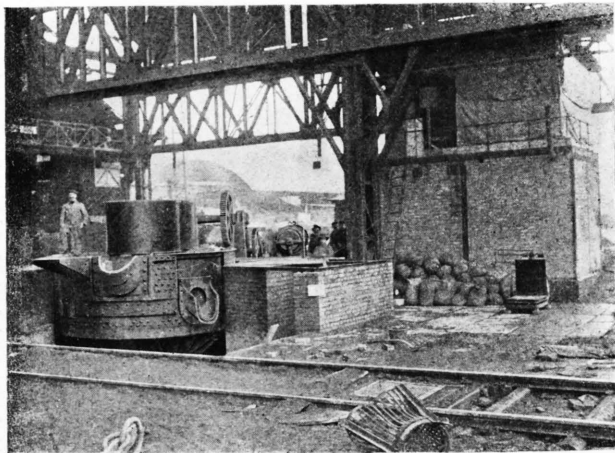
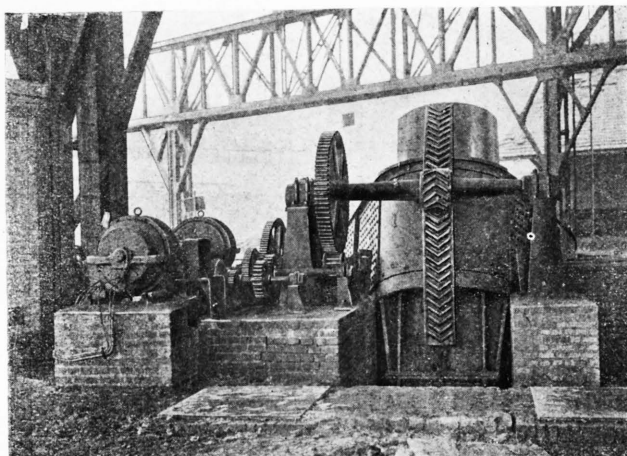Fig. 3. View of same during construction.

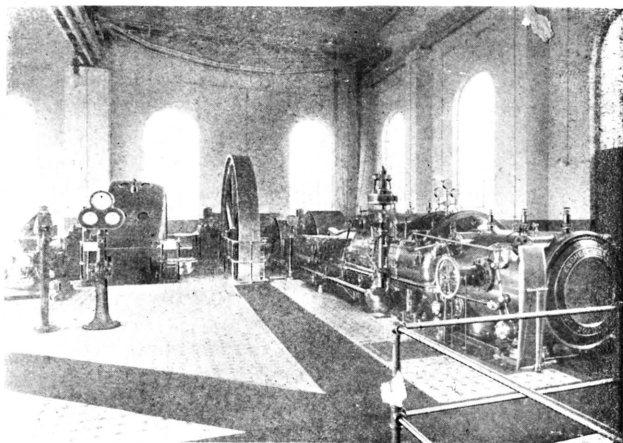Fig. 4. Back view, showing tilting mechanism.
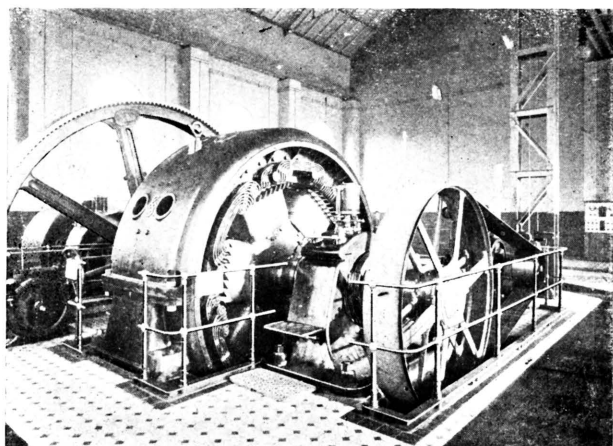
Fig. 5.   Power house, showing gas engine.

Fig. 6.   Alternating current dynamos used.

From this we see that the rate at which energy is delivered to each unit weight of iron varies, for one thing, inversely as the square of the cross-section of the metal in the groove.

The Kjellin furnace first installed at Gysinge, Sweden, in February, 1900, held only 80 kilograms of steel, and with a 78 kw.
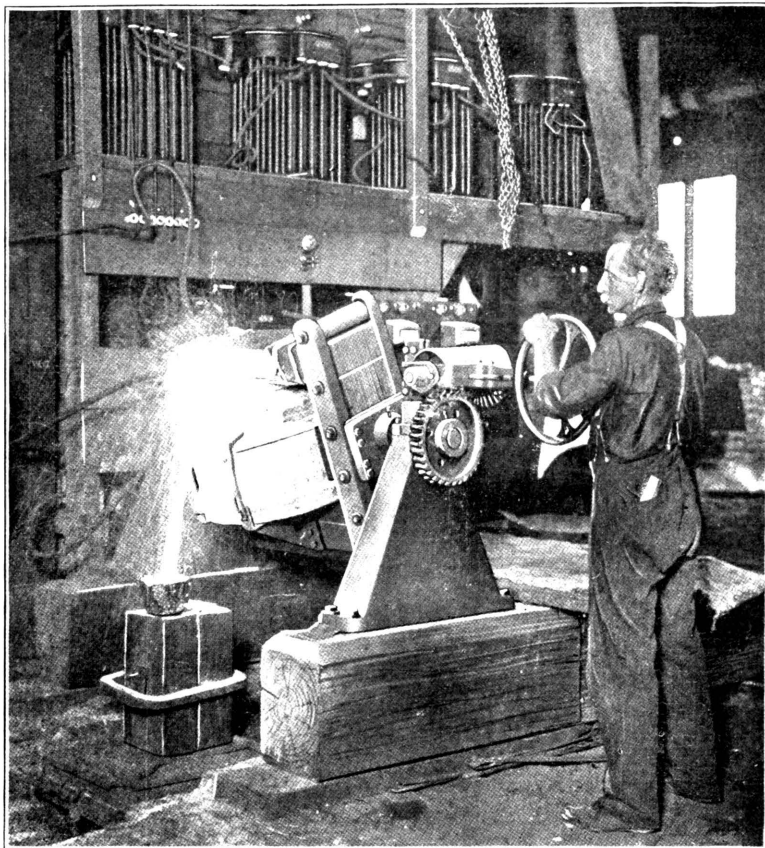

Fig. 7. The Disston furnace.

dynamo produced 270 kg. of steel in twenty-four hours. In November, 1900, a furnace holding 180 kg. was built, and with 58 kw. of electric energy made 600 to 700 kg. of steel per day. Next a furnace holding 1800 kg. of steel was built, run by a 300 H.P. turbine directly driving a dynamo giving 3000 volts on the primary windings of the furnace. This furnace is still in opera-

tion, making 5000 kg. of steel per day. Another furnace has been built and is now running, operated by 165 kw. of current, holding 1350 kg. of steel, and turning out from pig-iron and scrap, charged cold, five tons of steel per day, and when using melted pig-iron six tons.

The American Electric Furnace Co., which builds the Colby and Kjellin electric furnaces in this country, is now supplying steel melters with induction furnaces varying from 25 lbs. of steel capacity, requiring 10 kw., up to 18,500 lbs. capacity, requiring 736 kw. (1000 H.P.). The latter furnace melts 80,000 lbs. of steel in twenty-four hours, with an expenditure of 600 kilowatt-hours per ton of steel if charges are put in cold, and 500 kilowatt-hours per ton with melted pig-iron forming one-third of the charge. A furnace on the same principle to melt charges of 150 tons is now in course of construction at the Roechling Iron Works, Voelklingen, Germany.

Taking the above figures, it will be seen that the induction furnace is attaining a high degree of thermal and metallurgical efficiency. The waste during melting in the induction furnace is only 2.5 per cent., whereas it is some 5 per cent. in open-hearth practice.

PROBLEM I.

Taking the data given above for the output of Kjellin furnaces of increasing sizes, calculate for each the net thermal efficiency.

Solution: One kilogram of melted steel, sufficiently over-heated to allow of casting, will contain at least 275 Calories if high carbon steel and 325 Calories if low carbon steel; say 300 Calories for average steel. One kilowatt-hour furnishes 860 large Calories, as its heat equivalent. We have then the following calculations for the furnaces in the order given:

270 kg. melted in 24 hours by 78 kw.

$$\text{Efficiency} = \frac{270 \times 300}{78 \times 24 \times 860} = 0.051 = 5.1\ \%.$$

700 kg. melted in 24 hours by 58 kw.

$$\text{Efficiency} = \frac{700 \times 300}{58 \times 24 \times 860} = 0.18 = 18\ \%.$$

5000 kg. melted in 24 hours by 300 H.P. at the turbine = 224 kw. = 200 kw. effective electrical power at the furnace.

$$\text{Efficiency} = \frac{5000 \times 300}{200 \times 24 \times 860} = 0.36 = 36\%.$$

5000 kg. melted in 24 hours by 165 kw.

$$\text{Efficiency} = \frac{5000 \times 300}{165 \times 24 \times 860} = 0.43 = 43\%.$$

80,000 lbs. (36,400 kg.) melted per day by 736 kw.

$$\text{Efficiency} = \frac{36,400 \times 300}{736 \times 24 \times 860} = 0.72 = 72\%.$$

96,000 lbs. (43,600 kg.) melted per day by 736 kw., if one-third is put in as melted pig-iron, carrying 250 Cal. per kilogram.

$$\text{Efficiency} = \frac{(43,600 \times 300)-(14,500 \times 250)}{136 \times 24 \times 860} = 0.62 = 62\%.$$

Charging part of the charge melted is seen to lower the net thermal efficiency, but to increase the output of the furnace. With cheap power, the latter item is of the greatest importance.

LITERATURE ON THE INDUCTION FURNACE.

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Stahl und Eisen, XXV, Feb. 1, 15; March 1, 1905; XXIX, Jan. 9, 16, 1907.

Engineering and Mining Journal, *74*, 78 (1902); *75*, 524. (1903).

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　　　　Great Britain: 18,921 (1900).

　　　　Germany: 126,606 (1900).

HÉROULT'S FURNACE.

The Héroult tilting electric furnace resembles a tilting open-hearth furnace, with two large electrodes passing through the center of the roof. The electrodes are built up of carbon slabs,

170 centimeters long and 36 centimeters square, at a cost of about twenty cents per kilogram.   The hearth is stamped in burnt dolomite, the roof silica brick; the electrodes are protected inside the furnace by water jackets, to prevent their combustion by the air. The furnace can hold 4000 kg. of steel, costs $10,000, and such a one has been in constant operation in La Praz, France, since 1903. The electrodes dip only into the slag, so as not to be dissolved by or carbonize the bath.   The current used is 110 volts by 4000 amperes, alternating, and the principal resistance and seat of generation of heat is in the slag between the ends of the carbons and the metal.   A disadvantage of this furnace is that it cannot operate without a considerable layer of slag being present.

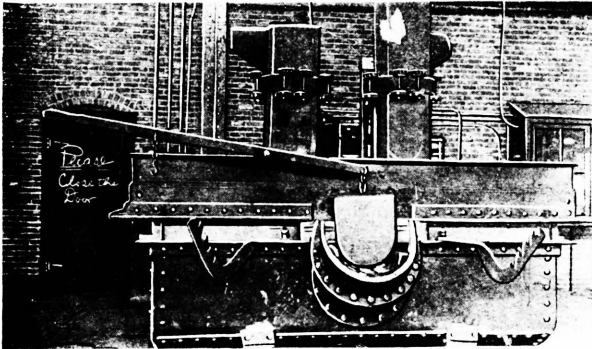In such a furnace steel can be made in a variety of ways.   Mr.

Fig. 8.   Front view of a Heroult furnace.

Héroult has preferred to make it from the cheapest raw materials, by processes similar to ordinary open-hearth practice.   As is well known, this involves the use of pig-iron, scrap iron or steel and iron ore.   The only difference between the two processes is that in the open-hearth furnace there may be considerable oxidation by the gases in the furnace, but in the electric furnace iron-ore must be relied on as the oxidizing agent; it is therefore used to a larger extent than can be used in the open-hearth practice.   Considerable lime is added to help form a fusible and basic slag.   The oxidation of the impurities consumes time, and therefore the amount of electrical energy required per ton of steel is greater than in the cases cited in the Kjellin induction furnace, where
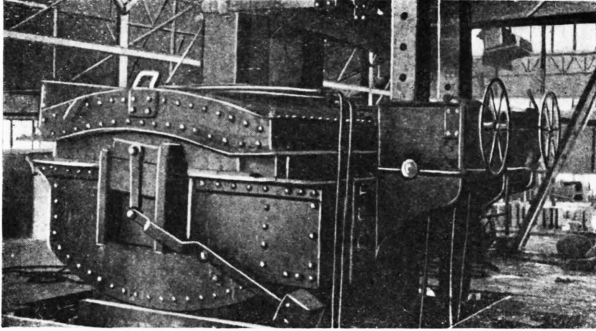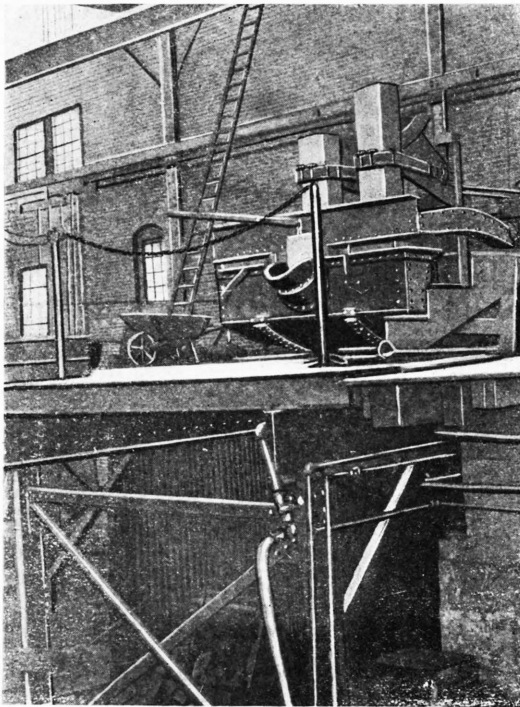
Fig. 9. Back view of same.

Fig. 10. Showing mounting of a Heroult furnace and casting pit.

high-grade pig-iron and clean scrap were simply melted together in proper proportions.

A charge composed of—

Miscellaneous steel scrap. . . . . .5,733 lbs.
Iron ore . . . . 430 "
Lime . . . . 346 "

was placed in a Héroult furnace, and in five hours twenty minutes was completely melted to soft steel, yielding 5161 lbs.   During the melting 1,680 kilowatt-hours of electric energy were used.

Required:—The thermal efficiency of the furnace.

Solution:—The steel scrap is 572 lbs. heavier than the soft steel produced, or 10 per cent.   It is very evident that the iron ore used (probably 90% Fe^2O^3) oxidized some of the carbon, manganese, etc., of the scrap, and that the scrap itself was probably oxidized.   Miscellaneous scrap may easily be rusted so far as to lose 5 per cent. of its weight while melting down.   Calling the soft steel practically pure iron, and the loss of the scrap to represent iron oxide going into the slag, we have as the net result of the melting 5161 lbs. of pure iron and a slag containing silica, iron oxide and lime, weighing approximately:

Ferrous oxide. . . . . . . 860 lbs.
Silica . . . .   43 "
Lime . . . . 346 "
                                 ———
                                 1249

Heat in melted soft steel
$$5161 \times 340 = 1,754,740 \text{ lb. Cal.}$$

Heat in slag
$$1249 \times 550 = \underline{\quad 686,950 \quad} \text{"   "}$$
$$2,441,690 \text{ "   "}$$
$$= 1,109,850 \text{ kg. "}$$

Heat value of current used
$$1680 \times 860 = 1,444,800 \text{ "   "}$$
$$\text{Efficiency} = \frac{1,109,850}{1,444,800} \quad 0.77 = 77\%.$$

In working this furnace, with these materials, the slag produced is a necessary part of the operation, and the heat it contains may be taken as usefully applied heat.

These furnaces lend themselves very well to use in connection with melting pig-iron from cupolas or blast furnaces, or melted steel from the Bessemer converter or open-hearth furnace. The electric furnace is fitted to take hot metal, the product of the ordinary steel furnace, and by reason of the higher temperature available to make a slag which will entirely de-phosphorize the metal.
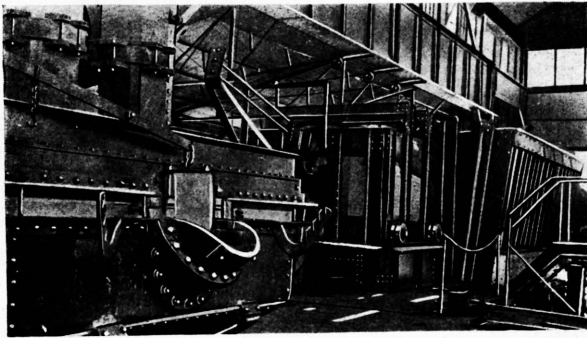

Fig. 11. Showing Heroult furnace alongside an open-hearth furnace, and worked in conjunction therewith.

Such working leaves on the other furnaces the calorific burden of melting the charges and giving them to the electric furnace fully liquid, leaving to the latter merely the task of raising the temperature a little higher and smelting upon them a very basic slag. In such cases, steel corresponding in quality to crucible steel is obtained at but a small cost per ton advance upon that of the Siemens or Bessemer steel from which it is made. The electrically imparted heat is here mostly used to supply radiation losses, and only a minor fraction to increase the temperature of the steel. We cannot, therefore, in justice to the furnace, calculate its thermal efficiency in the manner applied to the case of melting a charge down. In fact, in such cases we can only compare different furnaces on the basis of weight of metal *kept* melted per given time, *c. g.*, per ton of metal kept melted one hour.

ELECTRO-THERMAL REDUCTION.

The most interesting application of electric furnace methods to the metallurgy of iron is in the line of producing cast-iron, pure iron or steel direct from iron-ore. To this may be added the production of ferro-alloys, either by the reduction of other metallic oxides in the presence of iron or mixed with iron ore.

THE FERRO-ALLOY INDUSTRY.

This field has already attained commercial importance in the ferro-alloy line, such as in the manufacture of ferro-manganese, -silicon, -chromium, -tungsten, -vanadium, -boron, -titanium, etc., and a large and steadily increasing industry has been built up. There are probably a dozen electrical ferro-alloy works now in operation, and the industry is flourishing.

The *raison d' être* of this industry is as follows: In the blast furnace, metallic oxides more difficult to reduce than iron oxide are decomposed to varying and often to only trifling degrees. The blast-furnace will easily reduce 99 per cent. of all the iron oxide put into it, losing only 1 per cent. of it in the slag, unreduced. Manganese oxide is not so completely reduced; perhaps 50 to 75 per cent. of it is reduced to manganese and alloys with the iron, forming a product as high as 85 per cent. manganese, while the slag contains the rest, as unreduced Mn.O. Since good manganese ores are scarce and expensive, this loss is annoying and costly. Silica is always present in the blast furnace, and up to 25 per cent. of it may be reduced to silicon, forming a 10 or even 15 per cent. silicon pig, but there the blast furnace reaches its limit; the temperature is not high enough to produce a richer silicon alloy. A low per cent. chromium alloy may be made in a blast furnace, but a great waste of chromium in the slag; a high per cent. chromium alloy cannot thus be made. Tungsten oxides can be reduced to ferro-tungsten in crucibles, but only to a low per cent. tungsten alloy and with much unreduced tungsten in the slag. Titanium, vanadium, boron cannot be reduced to any appreciable extent by carbon and non-electric heating. In all these cases cited, alloys much richer in the non-ferrous metal, and much more complete reduction of the material used, can be obtained in the electric furnace.

Just as electrically-made steel has first found a footing as a competitor of the most expensive kind of steel—crucible steel—so electrical reduction has first found footing in the metallurgy of iron in the production of the most expensive and difficult ferro-alloys.

As an example of the calculations attaching to this branch of the subject, and of methods applicable to all the ferro-alloys, I would cite the production of ferro-silicon, which is attaining constantly increasing commercial and industrial importance.

(To be concluded.)