ELECTRO-THERMAL METHODS OF IRON AND STEEL PRODUCTION.

CHAPTER I

INTRODUCTION

In a small handbook entitled "The Electric Furnace in Iron and Steel Production" published in London in the year 1907,[1] the writer, after describing all the well-known types of electric furnace, summarised the position at that date, in the following words :—

"The use of the electric furnace for iron ore reduction is, therefore, in the writer's opinion, not likely to undergo any industrial development at present, excepting under very special conditions.

. . . .

"In countries like Norway and Switzerland, with abundance of water-power that can be developed at very low cost, it is possible that a native iron-smelting industry might be established, if iron ore and lime are found in the locality of the water-power. But here, again, special conditions will be required to render the industry a financial success, and it is unlikely that the iron will be able to compete in price in the open market, with the product of the ordinary blast-furnace.

. . . .

"Taking the cost of the electrical horse-power year at £2 and the average power consumption in Table 1 we have the following costs :—

1. Steel from molten scrap, 2*s.* 6*d.* (400 kw. hours).
2. Steel from cold scrap and pig, 5*s.* 0*d.* (800 kw. hours).
3. Pig-iron from ore, coke and lime, charged cold, 15*s.* 6*d.* (2,500 kw. hours).
4. Pig-iron from ore, coke and lime-charged hot, 12*s.* 5*d.* (2,000 kw. hours)."

[1] The Electrician Printing and Publishing Co., Ltd.

In the manufacture of best crucible steel, however, it is customary to assume that between $2\frac{1}{2}$ and 3 tons of coke are consumed per ton of steel produced. At the present market price of coke (17*s.*) the advantage is, therefore, on the side of the electric refining furnace.

As regards the electric smelting processes, it is necessary to remember that coke is still required to reduce the oxide of the iron ore to the metallic state, and that the only fuel saved is that used in the blast furnace for heating purposes. In the best modern smelting practice only 16 cwts. of coke are required per ton of pig-iron produced, and of this total 6·5 cwts. are required to reduce the ore. The saving in coke by the electric furnace method of smelting cannot, therefore, exceed 9·5 cwts., or at the present price of coke, 8*s.* 0*d.*

These considerations show that the prospects for the electric refining processes are much brighter than those for the electric smelting processes, since the saving of coke in the latter is too small to balance the large expenditure upon electric power. The horse-power year would, in fact, have to be supplied at the extraordinarily low cost of £1 in order to compete with the modern blast furnace, and the localities where it can be produced at this figure are certainly few in number. For the present, therefore, the application of the electric furnace in the iron and steel industries is likely to be restricted as a general rule to the refining processes by which pig- and scrap-steel are converted into higher-priced products. In these branches it is likely to be very widely employed, and to have a most important effect upon the future development of the whole iron and steel industry.

The developments of the five years that have elapsed since the above lines were written have to some extent proved the correctness of the forecast. Electric steel-refining furnaces and processes are widely employed by progressive steel-makers in both Europe and America, and, as shown by the list of furnaces given in the Appendix of this volume, the electrical steel industry is already well established and of considerable importance. The electric smelting industry on the other hand, has only made headway in two countries where the special conditions referred to above have been found favourable to its development, namely, in Sweden and in California; and in the former country only can a healthy and progressive industry be said to exist. While the annual output of electric pig-iron and pig-steel is still too small to be recorded, the annual production of electrically refined steel has grown from 30,000 tons in 1908 to over 200,000 tons in 1912; and when the larger furnaces that are now being installed commence to produce steel, the output will be greatly increased and may attain 250,000 tons per annum.

Compared with the world's total output of steel, these totals are of course small and insignificant; but when one realises that only ten years ago electric steel was largely a novelty, and that the steel manufacturing industry, owing to its age and importance, and also to the capital invested in it, is one of the most conservative and settled of all industries, the progress made in the period 1907—1912 is seen to have been quite notable, and, considering all the circumstances of the case, remarkably rapid.

Two other forecasts of the writer relating to the development of electric steel refining are also now in course of realisation, namely, the restriction of the electric furnace to the last stage only of the steel-making process, and the use of blast-furnace or coke-oven gases for generating the electric energy required. In Germany, at the works of Le Gallais Metz & Co., at Dommeldingen, and also in America, at one of the large works in Chicago owned by the United States Steel Corporation, gas-engines using the waste-gases of the blast-furnaces, provide a large portion of the current required by the electric refining furnaces. A similar system of power generation is to be employed at a large iron works in the North of England, where an electric plant is now being installed. In this last case, coke-oven gases are to be used in conjunction with the waste gases from blast-furnaces for driving the gas-engines; and the whole plant, including rolling-mills, blowing-engines, auxiliary motors, and electric and open-hearth furnaces, will be operated without burning a single ton of solid fuel for either power or heating purposes. According to Campbell, the costs of power at this installation will be under ·25*d.* per kw. hour, and if the plant is well designed and repairs are not unusually heavy, the cost may be found to work out 25 per cent. below this estimate.

As regards the advances in other directions, the capacity of the furnaces has been increased five-fold, and the power consumption reduced by 33 per cent. in the period under review. In 1907, the Heroult furnaces at La Praz, taking 480 kw. and producing 3 tons of metal at one heat, were the largest in actual use; whereas in 1912 furnaces producing 15 to 25 tons of metal per charge, and consuming 2,000 to 3,000 kw. of electrical energy, have been installed both in Germany and America, and are yielding good results.

The chief advantages obtained with these large furnaces are that radiation losses are reduced, and that a metal possessing more uniform chemical and physical properties can be obtained than from a succession of small heats. As regards power-consumption, the best average results obtained in 1907 were 800 kw. hours per ton (2,000 lbs.) of metal produced, using cold scrap as raw material, whereas to-day, returns for a recently erected refining furnace show a reduction of 28 per cent. on these figures and a consumption of only 575 kw. hours under similar conditions of work. The consumption and cost of electrodes have also been reduced 50 per cent. during the past five years, by many improvements in the method of manufacture and of use. Further savings in this direction may no doubt be expected.

Turning now to the field of application for the electric furnace in the steel industry, we find that whereas five years ago, only the finer and higher priced varieties of tool-steel and special alloys were being manufactured, to-day it is being employed for a great variety of products, including steel for axles and tyres, gun-steel, billets for wire and plates, and rail and girder steel. The application of the electric furnace as a heating furnace only, in the production of fine castings is also extending, and in Germany, France, England and America, several installations of this character can now be found in operation. The advantage here is, that the higher temperature obtained by the electric method of heating yields a more fluid metal, and a better separation of the gaseous and other impurities of the steel is thereby obtained.

According to Heroult (*Transactions of the 8th International Congress of Applied Chemistry*, New York, Sept. 1912), it has been found quite unnecessary to anneal some of the low-carbon steels for casting purposes made in the electric furnace, the chemical and physical properties of these steels being quite equal to those of the best brands of rolled or hammered mild steel made by the ordinary methods.

Another application of the electric furnace which has been found most valuable, is as a melter and mixer of the miscellaneous scrap alloys and scrap steels which accumulate in all foundries where the special steels are made. Chrome, nickel, and vanadium steels for automobile castings can be manufactured by melting miscellaneous steel alloy scrap, and by making the necessary additions to bring the composition up to the required specification. Another application which is being developed at the present moment is that of using an electric furnace for maintaining steel in a "resting" state at a pouring heat, for one or two hours, in order to allow a more complete separation of the slag and gases entangled in the molten metal.

The extension of the field of application of the electric furnace in the steel industry, from the production of high-class crucible steel, through the intermediate grades of steel, to that of rail and constructional steel has, however, been one of the most striking features of the development of the past five years.

The question that now demands an answer is:—Can this extension be justified by the results obtained, and can the electric finishing process be employed to supplement the open-hearth process of manufacture, for ordinary rail and girder steel? On this particular point, opinion at present is sharply divided; and in the writer's view, it will only be by the practical test of some years' experience that the question will be decided. Both in America and in Germany large quantities of rail-steel have already been made in the electric furnace, and these rails are now undergoing the tests of actual service on the railway systems of the two countries named.

Five thousand tons of electric steel rails have been laid on railway tracks out in the Western States of America, and it is reported that, so far, not one single electric rail has failed. In Germany also very favourable experience has been obtained with these rails, and it is quite possible that the savings resulting from their longer life and greater freedom from breakage, may more than counterbalance the extra cost of the electrical treatment. For it must be understood that the electric furnace when applied to the production of rail and girder steel does not seek to eliminate the Bessemer or open-hearth furnace, but to take the metal they produce, and, by the application of special heat treatment in a neutral atmosphere, to carry the refining operations a stage further, and thus to produce a purer and more durable metal.

Serious railway accidents, due to rail breakages, have been increasingly common (especially in U.S.A.) in recent years, and any improvement in the quality of the rail steel that will lead to a reduction in the number of these accidents, may be quite worth paying for.

However, whether such an extension of the use of the electric furnace is to occur at once in the United Kingdom, in Germany, and in America, or only with the gradual exhaustion of the coal supplies, its field of utility is already sufficiently wide and important, to justify a close study on the part of steel-makers of the developments of the past five years.

The following extract from a paper read by Mr. Donald F. Campbell, in London, in the autumn of 1911 (*Transactions of the Faraday Society*, Vol. VII., 1912), proves the necessity for study of what has already been achieved in this particular branch of electro-metallurgy, and may serve as a foreword to that more extended study of the subject which this book is designed to promote.

It must be remembered that a large number of engineers of the highest technical training and international experience, are constantly engaged in improving furnace design and metallurgical methods, on behalf of powerful industrial organisations. Careful and expensive experimental work has been going on for years, and many of the furnaces and processes, which are continually being patented and published, have been tried and abandoned by those controlling large electro-metallurgical works. *Improvement must be looked for by increasing the general efficiency of the best processes we have at the present time, rather than by radical changes in furnace construction.*[1]

In all questions of design, it is essential to bear in mind, first and foremost, the metallurgical requirements; the electrical considerations always must take a purely secondary place. The neglect of this principle has caused the failure of the majority of the numerous furnaces that in recent years have been described in technical journals, but abandoned because they were based on incomplete theoretical data, with little or no commercial practice; whereas *the most successful electric steel furnace of to-day follows as closely as possible the best basic open-hearth practice, with the simplest possible application of electrical heat energy.*[1]

[1] The italics have been inserted by the author.

CHAPTER II

GENERAL PRINCIPLES AND METHODS

The electric furnace is an apparatus for developing and for applying the heat energy of an electric current to chemical or metallurgical purposes.

All solids and liquids that allow an electric current to pass through them, while themselves undergoing no change, are called conductors. The amount of heat that can be generated by the passage of an electric current through a conductor, depends upon two factors only, (1) the strength of the current, and (2) the resistance offered by the conductor.

Joule's law with regard to the development of this heat in solid and liquid conductors is expressed by the following equation, in which C represents the current in amperes, R represents the resistance of the conductor in ohms, and H represents the heat produced in calories per second :—

$$H = C^2 R \times \cdot 24$$

The *temperature* to which the conductor can be raised by the current must not be confused with the *amount of heat*, as calculated above and expressed in calories. The temperature to which the conductor can be raised, is limited by the losses due to convection, conduction and radiation; and is expressed by the equation :—

$$T = \frac{(H - Ha)}{Ws}$$

in which H represents the calories (as before), W represents the weight of metal heated, s represents the specific heat of this metal, T represents the rise in temperature in degrees centigrade, and a represents the fractional heat losses due to radiation, etc.

These two equations do not apply however to the arc type of furnace, in which the arc produced by the disruptive discharge of an electric current of high potential, through air, is employed as heating agent. As the temperature of the electric arc formed in air between carbon electrodes lies between 2,500° and 3,500° C. (4,500° and 6,300° F.), great heats can be attained in arc furnaces, and the ordinary laws of heat conduction and radiation are modified by dissociation phenomena, and by the change in the specific heats of molten metals and gases at these high temperatures. For each particular type of furnace there is also a limit, due to the creation of a state of equilibrium between the heat evolved per second and the heat dissipated per second by radiation and other causes. These losses are of course greater, the higher the temperature of the furnace walls.

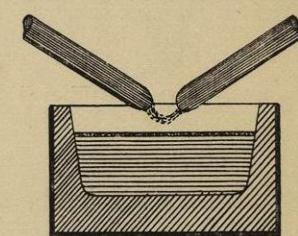

Fig. 1.—Diagram of Electric Arc Furnace with inclined Electrodes.

The electric furnaces used for iron and steel production may be divided into three classes: (1) Arc furnaces; (2) Resistance furnaces; (3) Induction furnaces, according to the different methods of applying the above principles of electric heating.

In the *Arc furnaces* the heat effect is produced by radiation or conduction from an electric arc. This arc is formed by the passage of an electric current at 50 to 120 volts pressure or E.M.F. across the air-gap that exists between two carbon electrodes, or between one or more carbon electrodes and the surface of the molten metal, which then acts as the second pole of the electrical circuit. In the former case the carbon electrodes are fixed at an angle of between 30° and 45° with the horizontal plane, and their terminals are held just above the surface of the metal being heated. The Stassano represents the first type; the Heroult furnace the second.

In Class (2), *Resistance furnaces*, the heat effect is produced within the metal itself (according to Joule's law) by the resistance offered to the passage of the current through it. Since the temperature attained by this method of heating cannot equal that attained in arc heating, the radiation and conduction losses are lower, and the thermal efficiency of the furnace is higher. On the other hand, certain refining operations that can be carried out with ease in the arc furnaces cannot be successfully performed in resistance furnaces. The Röchling-Rodenhauser or "Combination" furnace is the best known type of resistance furnace.

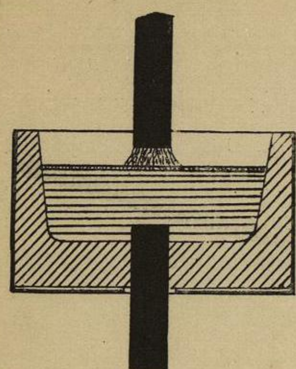

Fig. 2.—Diagram of Electric Arc Furnace with Vertical Electrodes.

The *Induction furnaces* form only a sub-division of the resistance type of furnace, since the thermal effect is again due to the resistance of the metal to the flow of the current through it. In this case, however, "induced" currents of electricity are used, in place of direct currents. An "induced" electric current is one that is created in any closed conducting circuit when an alternating current is allowed to pass through a neighbouring (or parallel) circuit. The induction furnace is, in fact, nothing but a huge step-down transformer, in which a ring of molten metal forms the secondary circuit and becomes the focus of currents of large intensity but low E.M.F.

Fig. 3.—Diagram of Electric Resistance Furnace.

The disadvantages of this type of furnace are its comparatively low temperature, and the necessity for retaining a certain proportion of every melt in the annular ring, in order to carry the current for melting the next charge. The great advantage is that

electrodes are dispensed with, and that this costly item of the running charges is wiped out. A secondary advantage is that the capital expenditure upon cables and conductors is greatly reduced.

The Kjellin and Frick furnaces are the best known examples of the induction type of furnace.

Figs. 1 and 2 are diagrammatic sections of the two forms of arc-furnaces; Fig. 3 is a similar section of a simple resistance furnace, and Fig. 4 is a diagrammatic section of a simple induction furnace. The core and primary circuit in Fig. 4 are shown in the centre, the sections of the annular trough on each side contain the molten metal.

The distinguishing feature of arc-heating is that a very high temperature effect is concentrated chiefly on the surface of the metal, or of the slag covering it; whereas in resistance-heating (whether by direct or induced currents) a more moderate and uniform heat effect is produced within the body of metal contained within the furnace. As will be seen in the succeeding Chapters of this book, the different types of furnace are tending to approach one another in design; for it has been found that the washing-out processes, by which the impurities phosphorus and sulphur are removed from the molten metal by means of suitable slags, can only be effectively and rapidly carried out with the aid of high temperatures.

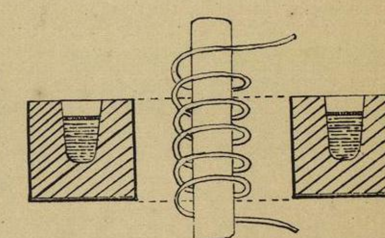

Fig. 4.—Diagram of Electric Induction Furnace.

Turning now from the consideration of the general principles and features of the design of electric furnaces for iron and steel production to a study of particular furnaces, we find that the first electric furnace for steel-melting was patented by Charles William Siemens, of London, in the year 1879 (see British Patent No. 2110 of 1879).

As this patent is of considerable interest the following extracts from the original Patent Specification are given:—

"In the Specification to Letters Patent granted to me on the 22nd of October, 1878, No. 4208, I described the cooling of the terminal of an electric lamp by means of a stream of water passed through a cavity formed in the terminal. My present invention relates to arrangements in which, by the use of such water-cooled terminals, I am enabled conveniently to apply the electric current to the production of light as in electric lamps, or of intense heat within a crucible, for the purpose of fusing refractory materials.

. . . .

"In applying the electric current to the production of intense heat for the fusion of refractory substances, I employ two carbon rods fitted to slide towards each other horizontally through holes in the opposite sides of a crucible made of highly refractory material, such as lime or alumina, which may be water-cased if necessary. The substance to be fused is introduced into the crucible, and the carbon rods are advanced sufficiently near to each other to form the voltaic arc within the crucible. They are, therefore, made to advance by clockwork or other suitable motor, each at a speed proportioned to its rate of consumption so as to maintain the arc always within the crucible. The clockwork which advances them may be retarded, arrested, or reversed by the action of a thin metal strip or solenoid, as in the electric lamps above described. As the heat in the crucible increases, the resistance to the voltaic arc within it diminishes, and consequently the arc can be elongated, an effect which results from the automatic retardation, stoppage, or reversal of the feeding clockwork. The crucible may be closed by a cover, having apertures through which air or other gases may be blown or drawn, to act on the substance under treatment. In some cases, instead of employing carbon for the terminals, they may be made of the material that is to be fused, when it has sufficient conductivity."

Figs. 5 and 6 give a diagrammatic representation of the two forms of crucible furnace designed by Siemens, who also demonstrated that with this type of furnace he could melt 10 kgs. of iron or steel, with comparative ease, in one hour.

Though no industrial application of Siemens' furnace was made, for the simple reason that electricity was at the time much too expensive a form of energy to be used for heating purposes outside the chemist's or physicist's laboratory, yet

Siemens' invention was the prototype of the successful Heroult and Stassano furnaces which are now so widely employed in the steel-refining industry.

Henri Moissan was the first chemist to apply with success, electric arc methods of heating in the laboratory, and the remarkable series of researches carried out, and of discoveries made by this famous French chemist, in the years 1890—1895, have found a fitting record in his classical work "La Four Electrique," published in 1896.

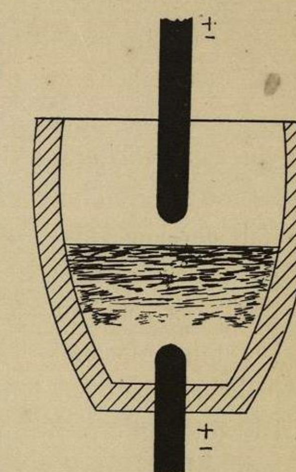

Fig. 5.—Siemens Crucible Furnace.

The furnace used by Moissan in these researches and discoveries was formed by two solid blocks of lime, fitting closely the one over the other, but hollowed out at the centre to form a small cavity, in which his high temperature effects were obtained. The arc was formed between carbon pencils or electrodes by aid of a low-tension electric current.

The electric arc furnaces used for steel refining are similar in principle, but are constructed on a much larger scale. The Stassano type of furnace most closely resembles that of Moissan, for it has the electrodes arranged at an angle of 30 degrees, and the heating effect is obtained by radiation from the arc formed above the surface of the metal. The Girod and Heroult furnaces are designed with vertical electrodes, and the molten metal itself acts as one pole, from which the arc springs. In these cases, therefore, there is actual contact between the metal, or slag, and the electric arc, and the heat transfer is partly by radiation and partly by conduction.

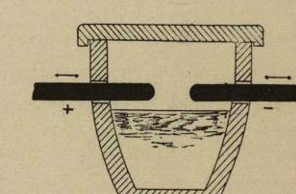

Fig. 6.—Siemens Crucible Furnace.

As Charles William Siemens may be regarded as the originator of the arc type of steel-melting and refining furnaces, so may S. Z. de Ferranti claim to be the inventor of the induction type of furnace, though here again many years elapsed before any practical developments occurred.

Ferranti's first patent for the induction form of furnace construction was taken out in 1887 (Patent No. 700), or thirteen years in advance of the first British patent granted to the Swedish Engineer *Benedicks* for a similar type of furnace. The successful furnaces of Kjellin, Frick, Hiorth, and Röchling-Rodenhauser are all developments or modifications of Ferranti's original design.

The first successful industrial application of electric heat to steel-refining appears to have been made at La Praz, France, in 1899, by M. Paul Heroult, a well-known French metallurgist. M. Heroult in the years 1886—1888 had worked out the details of and had patented a successful electro-metallurgical process for the production of aluminium, and, at the date named, he had already seen this process develop into the basis of a prosperous industry. It was therefore natural that he should attempt to apply the knowledge and experience gained in the period 1888—1896 to other branches of metallurgical industry. An electric furnace for the manufacture of ferro-alloys was first designed, and was applied with success to the production of ferro-chrome, ferro-tungsten, ferro-silicon and other similar alloys.

In 1899 and 1900 Heroult designed and put into operation at La Praz his first furnace for refining steel by aid of electric heat, and about the same date Keller, another French metallurgist (at Livet), and Stassano, an Italian Army Engineer (at Rome), commenced similar trials with the types of electric furnace which they have since patented and developed.

The next few years witnessed a great rush of activity in the designing of electric furnaces for the iron and steel industry. The Patent Office files of all countries bear witness to the number and fertility of inventors in this new field of applied

electro-metallurgy. For the reasons already stated in the previous Chapter, the majority of these inventions have failed to bring their patentees any credit or pecuniary reward, and the number of different types of electric steel-refining furnaces in successful operation at the present day, can be numbered on the fingers of one hand.

It is the opinion of the author and of many authorities that future improvements and developments will occur in connection with details of furnace working and control, rather than in any alteration of the broad lines of furnace design. The improvement of electrodes and their holders, and the discovery or manufacture of more durable refractory materials for furnace linings, are the most pressing needs of the moment.

With regard to the first of these, the cost of *Electrodes* is still a very serious item of the total refining charges, and any improvements that would lengthen their life or cheapen their first cost would prove of great benefit to the electric iron and steel industry. Although graphite is a better conductor than carbon, and electrodes of graphitised carbon are the more durable, ordinary carbon electrodes on account of their greater cheapness are employed usually for electric furnace work.

These are made for the iron and steel furnaces up to 24 ins. in diameter and 72 ins. in length. A round section has been found to give more economical results than the square shape formerly used. A method of jointing carbon electrodes has also been introduced which avoids the formation of, and loss arising from, butt ends. It is quite possible, however, that some substitute for the ordinary carbon electrodes may be found, since carbon has one great defect for electric furnace work, namely, its great affinity for oxygen, and the constant wasting away which occurs by its combination with this gas both inside and outside the furnace. The fact that this slow wasting away of the carbon, at the point where it enters the furnace roof can be minimised by water-cooling, does not altogether surmount the difficulty, for the water-cooled carbons abstract heat from the furnace. Water-cooling, though generally practised as the lesser of two evils, thus leads to a direct loss of heat. Furnaces of the Resistance type escape this problem of carbon electrodes; but, as pointed out above, these furnaces have some difficulty in attaining and maintaining a temperature which permits of the rapid and efficient refining of impure raw materials.

In this connection the suggestion contained in Siemens' Patent Specification, already quoted, that the material being fused might be employed as electrode material, is worthy of consideration. The history of the electric glow-lamp is not without interest for electro-metallurgists; and if fine wires of tungsten, tantalum and other metals have replaced the carbon filament in glow-lamps, it is perhaps not indulging in a vain hope to expect and believe that sooner or later a solid or molten *metallic* conductor may be discovered suitable for electric furnace work. The design of the Girod and Chaplet furnaces indicates how carbon can be dispensed with in steel-refining for the lower electrodes of the furnace; and the problem is therefore now reduced to the discovery of a metal or material suitable for the upper electrodes of arc furnaces.

The use of iron or steel electrodes, alloyed with one or more of the rarer metals that raise the melting-point, and that would be required as additions to the finished steel, would seem to afford the simplest and most practical solution of the problem. The writer believes that experimental trials along these lines are now proceeding.

As regards the *Refractory Materials* used for the hearths, linings, and roofs of furnaces, the magnesite and silica bricks used at present have not proved entirely satisfactory, and electric steel makers are on the look out for, and are quite prepared to give a fair trial to, any refractory material suitable for their purpose, that may prove more durable and can be produced at a reasonable cost. At the moment no satisfactory substitutes for tamped magnesite and tar or silica are known; but trials are about to be made with electrically-fused alumina bricks, for

which high claims are made. The roofs of arc furnaces, and the upper portion of the sides of resistance furnaces, are the parts where the most destructive action occurs; and a refractory material that is to prove durable in these places must be able to stand the action of high temperatures, and of lime, silica and iron, all in the vapourised state. Whether the new "Alundum" bricks will stand the combined attack of these powerful physical and chemical forces remains to be seen.

As regards the question of *Electricity Supply*, direct current generators can be employed for arc and simple resistance furnaces, although the tendency is more and more towards the use of alternating current (either single-phase or three-phase) for electric furnace work. For the benefit of those readers who do not understand electrical terms, it may be stated here that a direct current is one in which the flow of current is constant in one direction only. An alternating current, on the other hand, is a current the direction of which is reversed at regular intervals; the number of reversals per minute being indicated by the figure for the frequency, and the number of phases being expressed by the terms "single-phase," "two-phase" and "three-phase."

The construction of large dynamos is simplified, and the danger to the workers is considerably minimised, when three-phase current is generated, and as the modern tendency is all in the direction of large generating units, electric furnace designers have many sound reasons for adapting their needs to the requirements of the generating stations. In the majority of installations the iron and steel furnaces are provided with their own power stations, operated either by water, or by the waste-gases from blast-furnaces and coke-ovens. In Sheffield and in a few other centres, steam-power is employed for generating the current required.

Concerning the *Chemistry of the Refining Process*, it must be clearly understood that no electrolytic action occurs in the furnace, and that the effect of the electric current is simply of a thermal character. The refining action is due to the washing out and removal of sulphur, phosphorus, etc., by the aid of suitable slags. As the theory of the action of the slag upon the steel is of great importance in its bearing on the practical results attained, an abstract of a recent valuable paper by Amberg upon this subject has been included in the Appendix (see p. 223).

In concluding this general discussion of the principles of electric steel refining, it may be of interest to present some figures, showing the power required to produce one ton of steel from various raw materials. Table I. contains a summary of figures collected by the author and published in 1907 in the handbook already referred to.[1] Table II. contains figures compiled by V. Engelhardt and published in an article contributed to the paper named below.[2]

A comparison of these two sets of figures with each other, and with those given in the last Chapter of this volume, will indicate the progress that has been made in electric steel refining between 1907 and 1912:—

TABLE I.

Kw. hours required for the production of one ton (2,000 lbs.) of iron or steel, in different types of furnace (1906).

—	I. *Heroult.*	II. *Keller.*	III. *Stassano.*	IV. *Girod.*
Steel from scrap and pig (cold) . .	864	730	1,164	1,136
Steel from scrap and pig (hot) . .	329	631	—	—
Pig-iron from ore, coke and lime (cold) .	2,693	2,292	—	—
Steel from ore, coke and lime (cold) .	—	2,800	2,804	—
Nickel pig from ore .	2,342	—	—	—

[1] See Chap. I., p. 1.
[2] *Zeitschr Vereines Deutsch. Ing.*, November 19th, 1910.

TABLE II.

Kw. hours necessary for the production of one ton (2,204 lbs.) of iron or steel, in a Röchling-Rodenhauser furnace (1910).

	Kw. hrs.
Pig-iron direct from the ore	2,000
Steel direct from the ore	3,000
Steel from cold pig-iron	1,500
Steel from liquid pig-iron	1,100
Steel from cold pig and cold scrap . . .	700
Steel from liquid pig and cold scrap . .	600
Steel from cold scrap	900
Refining molten open-hearth steel for special tool steel	250
Refining molten open-hearth steel for rail steel	120
Maintaining heat in a casting ladle . . .	50

The actual costs of production, when working under various conditions as regards raw materials, are given by Engelhardt for a 5-ton Röchling-Rodenhauser furnace as follows:—

Steam-power.—From 94·5 marks to 123·3 marks per ton.

Water-power.—From 78·6 marks to 96·1 marks.

The cost of the former is taken at 5 pfgs. (or three-fifths of a penny) per kw. hour; and of the latter at 2 pfgs. (or one farthing) per kw. hour.