THE ELECTRIC FURNACE.

Frequent reference is made nowadays in describing the production of special steels and steel castings to the use of Electric Furnaces, and it is therefore important that the special details and functions of such furnaces should be understood. It has, of course, been well-known for many years that high temperature could be obtained by passing current through a resistance, but the commercial possibility of using electrical energy in furnace work was retarded both by practical difficulties, which have been now almost entirely overcome, and the cost of operation. With developments in recent years, steel makers have been enabled to employ the electric furnace for many purposes with commercial success.

The electrical furnace possesses some important advantages over a combustion furnace for special purposes, such as the refining of steel. One of the most important is the possibility of obtaining high temperatures, and the concentration of the high temperatures into the space required for the metal alone. The temperature of the electric arc, with carbon electrodes, is in the neighbourhood of 3,500° C, so that it is comparatively easy matter to obtain temperatures of 2,000° C and upwards. With a combustion furnace the temperature limit is much lower. There is a limit to the degree of forcing that can be given, as a point is ultimately reached in which the volume of gases in the blast becomes so great that the gases carry off the heat more rapidly than the fuel can supply it. Also at certain temperatures dissociation of the gases takes place, *i.e.*, the components cease to combine and hence cease to generate heat. Economically it is often found advisable to use both systems, combustion furnaces being used to heat the material to 1500° C and the electric furnaces for melting and refining that involve the use of temperatures above this point. The chemical combinations necessary for refining proceed with much greater facility at these high temperatures and in the manufacture of steel the removal of impurities as phosphorus, sulphur, silicon, &c., which combine with elements forming the slag is greatly facilitated. Better castings can also be obtained owing to the increased fluidity of the metal at the higher temperatures.

In the electric furnace a neutral atmosphere may be obtained as it is possible to seal the furnace and render it practically air-tight. The proportion of oxygen in contact with the molten metal can be therefore reduced at will, a condition that cannot be produced in a combustion furnace. This sealing incidentally has the further advantage of greatly reducing the heat losses, and it is this important feature that leads to a high internal efficiency in the electric furnace and serves to counteract the cost of the electrical power, there being no waste gases to carry off large quantities of heat. Other advantages are :—rapidity of heating, freedom of steel from gases and slag inclusions, absence of impurities introduced by the combustion of the fuel such as sulphur; reliability of control and regulation over wide ranges; a minimum melting loss; high grade steels obtainable from cheap scrap; scrap containing valuable elements as nickel, chromium, etc., are melted without loss of these elements.

There are two main types of electric furnace in common use, viz.: the resistance and arc furnaces. The former is again divided into two types, the direct resistance and the induction or indirect resistance types, the latter so called because the heating is effected by the induction of current in the metallic charge itself, which to all intents and purposes forms the secondary circuit of a transformer. The arc furnace depends for its action on the heat developed in the arc struck between two electrodes or between an electrode and the metal bath. In the direct resistance types the electrodes are immersed in the metal and the current passes through the mass to the lining. For the induction furnace alternating current is necessary, but for the arc and direct resistance furnaces either direct or alternating current may be used.

In practice alternating current is generally preferred, the reason for this being that the generation of heavy direct currents at a low voltage requires costly generators, and direct current introduces possible electrolytic actions which in the ordinary way are not required, although in some extended uses of these furnaces, apart from steel making, such as reduction of refractory compounds, this effect is sometimes of value. With alternating current there is no difficulty in providing the heavy currents necessary.

The varied types of furnaces now in use are so numerous and their details show so many variations that it is intended in this article to confine attention to principles of working and a brief description of one special type of furnace.

Advantages and disadvantages are claimed for all types of furnaces which are, however, interesting to consider.

In the resistance furnaces, the heat is generated through the mass of material to be heated; consequently the heat losses are reduced to the utmost limit. In the arc furnace, heat is generated mainly in the arc and must be to a large extent conveyed to the metal both by radiation and conduction. This involves a certain loss of heat and less rapidity of action, owing to the heat having to penetrate the mass.

No electrodes are required for the induction furnace. This means that the loss of heat by conduction through the electrodes themselves is avoided and it is more easy to make the furnace completely air-tight, or even if necessary to work under vacuum conditions, as there are no glands to admit the electrodes which latter must be capable of motion as they consume. The consumption of the electrodes in the arc furnace forms an additional item in the working costs and a certain amount of heat is lost by absorption in the water-cooled glands by which the electrodes enter.

From the metallurgical point of view, however, which is the most important feature, there is an important advantage with the arc types, the bath of metal being easily accessible from the door and such operations as stirring or " rabbling " (if required) and introducing the flux are in consequence simplified. In some induction furnaces, the bath takes the form of a ring, for this lends itself best to transformer action. This shape is very inconvenient from the practical point of view, as it is very difficult to reach all parts of the bath from the door.

As regards the temperature of the slag there is considerable variation with the different types of furnace. In the arc furnace the electrodes are fixed above the bath of metal and as a consequence the slag which covers the bath is at a higher temperature than the metal. This is held to facilitate the re-actions between the constituents of the slag and the impurities in the charge. In the resistance furnaces the contrary is the case, the heat being generated in the metal bath and transmitted from this to the slag which is at a lower temperature than the metal.

From the point of view of the supply of electricity the resistance types give a steadier load as the resistance of the metal does not vary suddenly. Owing to the consumption of the carbons, the boiling of the metal and other causes there is at times a liability in the arc furnaces to great and sudden fluctuations. Automatic regulation of the arc is therefore desirable to reduce these fluctuations as much as possible.

In view of the above remarks it can be appreciated that there are still differences of opinion as to the best main type of furnace, and a considerable variety of furnaces depending for their action on either the resistance or arc principles have been developed and are in use. Variations of the arc type are in greatest favour in this country, and this type may be considered to have established its superiority as a commercial proposition for steel melting furnaces.

The arc furnaces in most common use are of the type in which the arc is struck between the electrodes and the bath of metal so that the current flows through the molten metal. These again may be sub-divided into types in which (1) the current flows from an electrode situated above the bath through the metal to a second electrode also situated above; and (2) those in which the hearth is formed of conducting material so that the current flows from the electrodes and out at the bottom of the bath.

Further modifications exist according as the furnace is adapted for single phase or up to four phase alternating current.

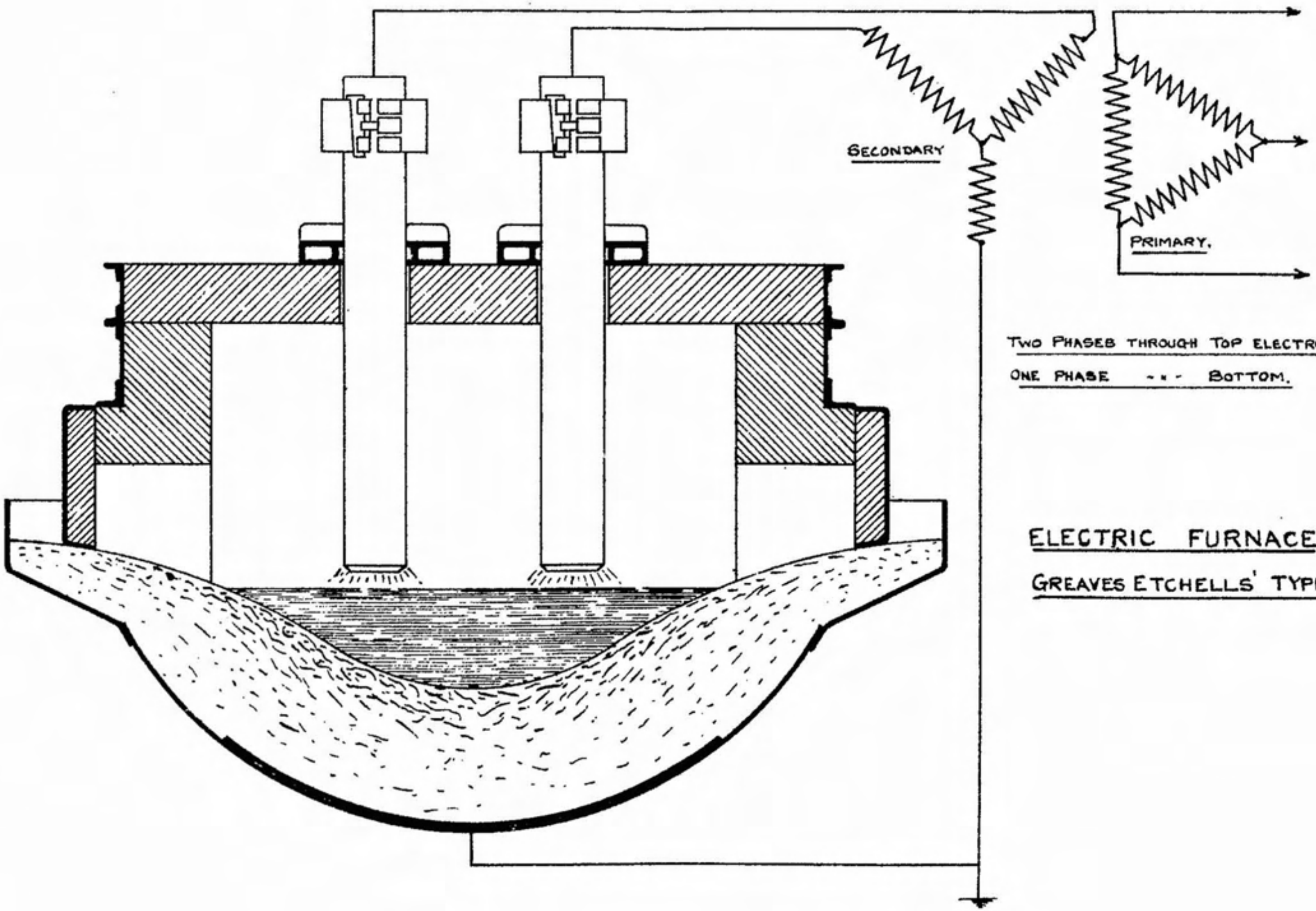
To give a clearer insight into the construction and working of an electrical furnace a special type which is now largely used will be briefly described. This type known as the Greaves-Etchell Electric Furnace is shown in the figure.

The particular furnace indicated, which is of the arc type, is one using 3-phase alternating current, 2 carbon electrodes passing through the roof, while the third phase of the current is connected to an electrode embedded in the furnace chamber in a carbonaceous mixture, at the bottom of the hearth. There are variations in particular types of Greaves-Etchell furnaces according to the type of current used, but the principle is the same in each. The hearth lining is never less than 20 inches thick, and is constructed of dolomite, magnesite and carbon mixture, the part in contact with the metal being highly refractory. The electrical resistance is high at the inside in proximity to the charge and decreases to a small quantity at the embedded electrode. The current flowing through the hearth generates a considerable amount of heat immediately below the liquid metal, while the electric arcs maintain the slag and surface of the charge at the desired temperature. This bottom heating is instrumental in causing convection currents in the molten metal which greatly assist in producing a uniform product. Mechanical stirring which is necessary in furnaces with top heating only is therefore not required with this type.

The high tension electric supply is transformed to low tension in the vicinity of the furnace to obviate heavy losses in the low tension connections. Arrangements are fitted to give a damping effect to the rushes of current that may occur during the melting process when pieces of metal fall against the electrodes, but the fact that there is always a permanent resistance in the path of the current through the hearth limits to a considerable extent the effects of these short circuits.

The energy supplied to the furnace is regulated by raising or lowering the carbon electrodes and this can be done by means of automatic regulators which maintain the current at a predetermined figure. Hand control is also possible. Arrangements are also fitted in moderate and large size furnaces for varying the voltages across the arcs, giving a high voltage during the melting period, and a low voltage during refining. The ratio of the heat generated above and below the bath is also susceptible of regulation over a wide range.

The whole furnace can be rocked during the operation of melting and refining and is further tilted as necessary when required to pour. The consumption of electrodes in the first types of these furnaces was about 30 lbs. per ton of steel melted, but improved devices have reduced this figure considerably, and in later types it may be kept as low as 12 lbs., and with elaborate arrangements even lower. Furnaces of this type range from ½ ton up to 6 tons for ordinary work, but larger sizes have been fitted for special cases.



TWO PHASES THROUGH TOP ELECTRODES.
ONE PHASE -"- BOTTOM.

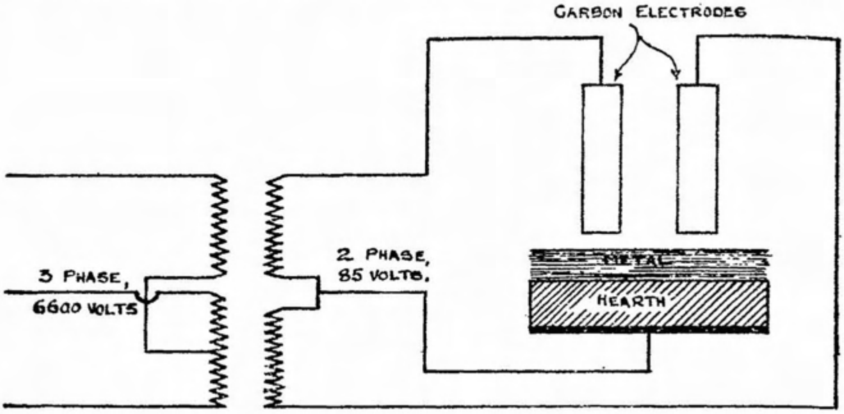
ELECTRIC FURNACE.
GREAVES ETCHELLS' TYPE.

The operation in the electric furnace is essentially a basic process, and the same re-actions resulting in the oxidisation and removal of phosphorus which are carried out in the basic open hearth process can be applied in the first stage of melting a charge of common steel scrap in the electric furnace. The electrical process goes further however; after removing the phosphate slag, another slag can be made up with lime, sand and fluorspar, which on closing up the furnace doors and spreading finely powdered coal on, the slag can be worked under reducing conditions. This results in the removal of sulphur and the de-oxidising of the steel by the silicon in the slag. These actions are facilitated by the higher temperature available which enables this type of slag to be maintained in a fluid state. The slag is light and non-cohesive, and rises easily to the surface of the metal so that when teemed the product is comparatively free from slag inclusions. The steel is also particularly free from occluded gases and due to the high temperature and increased fluidity obtainable the mechanically included gases may easily escape.

The electric furnace is therefore of great value in the production of high class steels, free from impurities, but it is too expensive for the ordinary commercial grades. It is especially useful for the alloy steels containing rare elements as these elements are conserved in the furnace and are not partly lost during the operations. Owing to the increased fluidity and freedom from gases, the electric furnace is greatly favoured for the production of intricate steel castings. It can safely be stated that steel properly made in the electric furnace has better physical properties than can be obtained by any other process and on account of its freedom from gases and non-metallic inclusions its endurance when subjected to repeated or alternating stress is particularly good.

It will be understood that there is not a great deal of scope at present for electric furnaces in repair yards and dockyards, but a type of arc furnace has been installed in one of the dockyards and is used for the production of steel castings. This furnace is of the Heroult type, supplied by the Electro Metals Co., and is similar in general principle to the one previously described, but it is constructed to use two-phase current, the diagram of connections being as shown on page 72. The primary supply of current is 3-phase at 6,600 volts, and is transformed to a maximum of 85 volts. The two electrodes are 14 inches diameter and are power controlled. The capacity of this particular furnace is 30 cwts., and the time required to melt the full quantity is 3½ hours, the further time for slagging and refining being 1 hour.

Electric furnaces have also been adopted for heat treating. As constructed, such furnaces consist essentially of a strong steel shell with a heavy thickness ranging from 13 in. to 20 in. of brick lining. The heating element consists of nickel-chrome ribbon distributed over the inside walls (and in some cases the roof of the furnace) insulated from the brick lining. This nickel-chrome has been found to possess very lasting qualities under the conditions in which it has to be worked, the maximum temperature being about 1000° C. The ribbons are distributed so that a uniform temperature is maintained over the whole furnace, a condition which it is practically impossible to obtain with other types. The temperature of such furnaces are arranged to be automatically controlled by special devices. A thermocouple placed on the surface of the metal being heat-treated actuates a recording controller. When a predetermined setting is reached, the current is cut off and is switched on again when it falls to a slightly lower setting. It is claimed that this control can be made very sensitive, *e.g.*, within 10° when working at any temperature between 200° and 1800° F.



There have been a few limited uses in recent years of electric steel furnaces for the production of synthetic cast iron. This cast iron is found to be denser than the ordinary grey cast iron as the conditions under which it is made ensure a very efficient de-oxidisation and freedom from dissolved, occluded or combined gases. It is possible with this iron to obtain a tensile strength in the neighbourhood of, or even higher than 20 tons sq. inch, and there are possibilities of developments in the application of such furnaces in the near future.

The electric melting of non-ferrous metals is coming into use but is still very limited in its application. It can be appreciated that the arc type of furnace suitable for melting steel would not be suitable for melting brass, bronzes, aluminium and other metals and alloys easily vaporised or overheated. The intense heat of the electric arc which is not less than 3500° C. will readily vaporise even copper, this metal being volatile at 2310 °C.; zinc boils at 930° C. and lead at 1580 ° C. and it is therefore clear that such metals must be kept from contact with the arc when melted.

One type of furnace for non-ferrous metal work consists of a cylindrical shell with small doors located on the axis at each end and the electrodes enter through these doors. The only other orifice in the shell is the charging or tapping hole which is provided with a door. The furnace rotates on the axis and this rotation by rolling the charge over continually exposes fresh surfaces to the heating action of the arc and the heated lining. This results in a very uniform temperature gradient during the melting and in an efficient heat transfer to the metal. Another type has a trough made of carborundum crossing the furnace above the hearth. This trough is filled with carbonaceous material and the electrodes enter it from each end. The resistance of the material in the trough to the passage of current generates heat which is radiated to the charge beneath, directly from the trough or indirectly from the roof and walls. As there is no arc in this furnace, the risk of volatilisation losses is considerably reduced.

Furnaces of the induction type have also been developed for melting non-ferrous metals, but their application is still very limited.