A HIGH-TEMPERATURE ELECTRIC RESISTANCE FURNACE.

(*A Contribution to a* GENERAL DISCUSSION *on* ELECTRIC FURNACES *held by the* FARADAY SOCIETY *at Manchester on Thursday, February* 14, 1918.)

BY WALTER ROSENHAIN, B.A., D.Sc., F.R.S., AND
E. A. COAD-PRYOR, B.A.

(From the National Physical Laboratory.)

THE well-known types of high-temperature electric resistance furnaces, in which the resistor consists either of granulated carbon, of a simple carbon tube, or of a graphite spiral, possess certain serious disadvantages which lessen their utility and convenience in use. The granular carbon resistance is not only liable to extremely uneven heating, but requires liner tubes capable of resisting the highest temperature attained and of withstanding the powerful chemical action of the carbon with which they are in contact. The simple carbon tube, while convenient in smaller sizes, gives much trouble owing to thermal expansion and fragility, and, in larger sizes, demands inconveniently large currents. The graphite spiral, while overcoming many of these disadvantages, is somewhat difficult and delicate to make and becomes entirely useless if broken at any one point during construction or use. It is believed that the type of furnace here described, although still relying upon carbon or graphite for the material of the resistor, overcomes all the disadvantages enumerated, although it does not entirely eliminate the disadvantages associated with the use of carbon in any form for such a purpose, viz. the necessity of keeping the resistor in a neutral atmosphere and the difficulty of avoiding the presence of carbon in some form in the atmosphere of the furnace. The latter difficulty can, however, be overcome to a sufficient extent for many purposes.

The underlying principle on which the construction of the present furnace is based is the utilization, not of the ohmic resistance of the graphite, but of the resistance which exists wherever graphite surfaces are placed in contact. This principle has previously been used by others, especially by Fitzgerald, who describes a furnace based on it in a paper read before the American Electro-Chemical Society in 1911. Fitzgerald formed the heater of his furnace of grooved graphite blocks arranged to form an arch constituting the roof of the furnace chamber, carborundum slabs being used as a lining. Adopting this system, our first experiments were made by arranging series of graphite blocks both horizontally and in a vertical column to form heating elements. Promising results were obtained, but this form of construction proved inconvenient. The device was therefore adopted of forming a tubular heating element by superposing rings of graphite upon one another. These could be produced by machining solid graphite rods or tubes. The first rings were cut with plane top and bottom surfaces, but a tube built of these was found to be unstable and difficult to handle. The device was therefore adopted of making the top and bottom surfaces of the rings conical, in such a way that the rings fit accurately into one another and can be built up into a tube of any desired height, affording a considerable degree of stability.

Since the total resistance of such a built-up tube will depend on the number of contacts in series which it contains, the resistance can be regulated by suitably varying the thickness of the individual rings and thus varying the total number of rings in a given length of furnace-tube. This adjustment is used for the purpose, not only of regulating the total resistance of each furnace, but also for regulating the distribution of the resistance—and consequently of the heat-energy developed—in different parts of the furnace. By the use of thinner rings near the two ends of the furnace, the " end effect " can be considerably reduced and the region of uniform temperature within the furnace correspondingly extended. Rings as thin as $\frac{1}{8}$ in. (3 mm.) have been used.

The resistance of a tube built up out of such rings will further depend upon the area of each contact surface and on the nature or quality of that surface. With increasing size of furnace, the area of each contact surface becomes larger and, as a result, larger furnaces would require undesirably high currents and low voltages. This inconvenience can be avoided by reducing the actual area in contact at each ring by grooving the surface of one of the rings, or otherwise removing part of the surface, thus reducing the area of actual contact to almost any desired extent—the limitation lying in the increased local pressure which results if the contact area is too far reduced in this way. A further increase in contact resistance can, however, be produced by altering the quality of the surfaces in contact, as, for instance, by contaminating the surfaces with a small amount of magnesia either as dust or as a very thin wash. If too much magnesia is used, however, the furnace ceases to conduct at all in the cold, and this renders starting-up difficult or impossible. This device must, therefore, be used with considerable caution.

Another factor on which contact-resistance depends is the pressure between the surfaces in contact. In the tube built up of rings this may be provided merely by the weight of the tube itself and of the water-jacketed electrode at the top. In some sizes of furnace this weight is sufficient, but it is convenient to have an adjustment provided whereby this weight may be increased or diminished and its distribution around the circumference of the rings arranged so as to give uniform distribution of contact resistance. In the type of furnace here described such adjustment has been obtained by means of set-screws and springs. In the smallest size of furnace, where the weight of rings and electrodes is small, these screws are used to increase the pressure between the rings, but in the larger sizes the weight of the water-jacketed electrode is too great for the rings, and the screws and springs are therefore employed to relieve the rings of part of the load.

The details of construction of one typical furnace, having rings 7 in. internal diameter, may now be given. The general construction of the furnace is shown in sectional elevation in Fig. 1. The graphite rings are shown at (*a*). There are 60 rings in a vertical height of 12 in. At the bottom of the furnace these rest on a graphite block (*b*), which is turned to fit the rings and to form a solid bottom for the furnace chamber. Through the centre of this block passes the tube (*c*), which may be made of iron, and serves as a gas outlet. Above this, resting on the centre of the block, stands a perforated graphite tube (*d*), which forms the support for a crucible or other article to be heated. The perforations allow a free flow of gas from the furnace-chamber to the exit tube (*c*). The graphite block (*b*) fits, externally, into the water-cooled metal electrode (*e*). The general shape of this electrode is shown in the drawing; it consists of a metal (brass) casting which has been cast around a coil of iron pipes

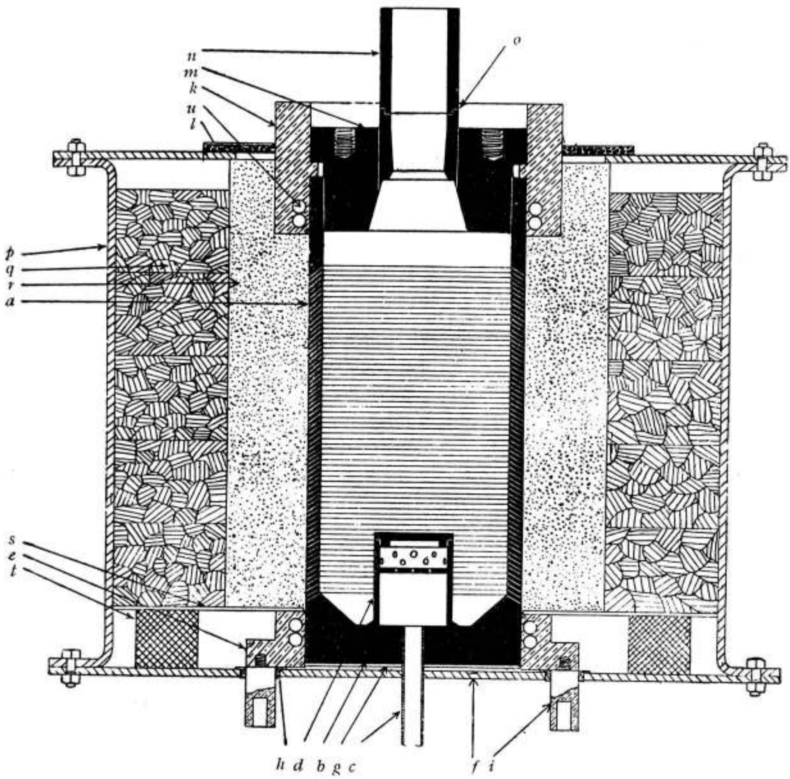

FIG. 1.

(*a*) Graphite rings.
(*b*) Graphite block.
(*c*) Iron tube, for waste gases.
(*d*) Pedestal for crucible.
(*e*) Brass water-cooled electrode.
(*f*) Steel base plate.
(*g*) Uralite insulation.
(*h*) Fibre insulating washers.
(*i*) Cable sockets.
(*j*) Graphite tube.
(*k*) Brass water-cooled electrode.
(*l*) Plate—of aluminium alloy.
(*m*) Graphite plug.
(*n*) Graphite tube.
(*o*) Joint in graphite tube.
(*p*) Steel case.
(*q*) Magnesia blocks.
(*r*) Vegetable black.
(*s*) Uralite sheet.
(*t*) Firebrick support.
(*u*) Iron tube for water circulation.

which are seen in section in the figure. The upper electrode is similar in construction, but the arrangement of the water-cooling pipes is more clearly shown in Fig. 2. It is, of course, important to secure good electrical contact between the brass surface of the electrode and the graphite block or tube fitting into it. In some cases this has been obtained by first coating the surface of the graphite with copper (using the Schoop metal spraying process) and subsequently "sweating" the graphite thus prepared into the brass socket. More recently electrodes of this type have been made of an aluminium alloy, and in that case soldering became inconvenient; a plain conical fit, carefully machined, has therefore been tried and found to work quite satisfactorily.

The metal electrode rests on the steel base-plate of the furnace, (*f*) being electrically insulated from it by a layer of uralite (*g*), fibre washers (*h*) being used to ensure insulation at the points where the cable sockets (*i*) pass through the base-plate. Cables from the transformer are attached to these cable sockets at both top and bottom of the furnace.

The construction at the top of the furnace is very similar, with only such modifications as are essential in order to allow the furnace to be

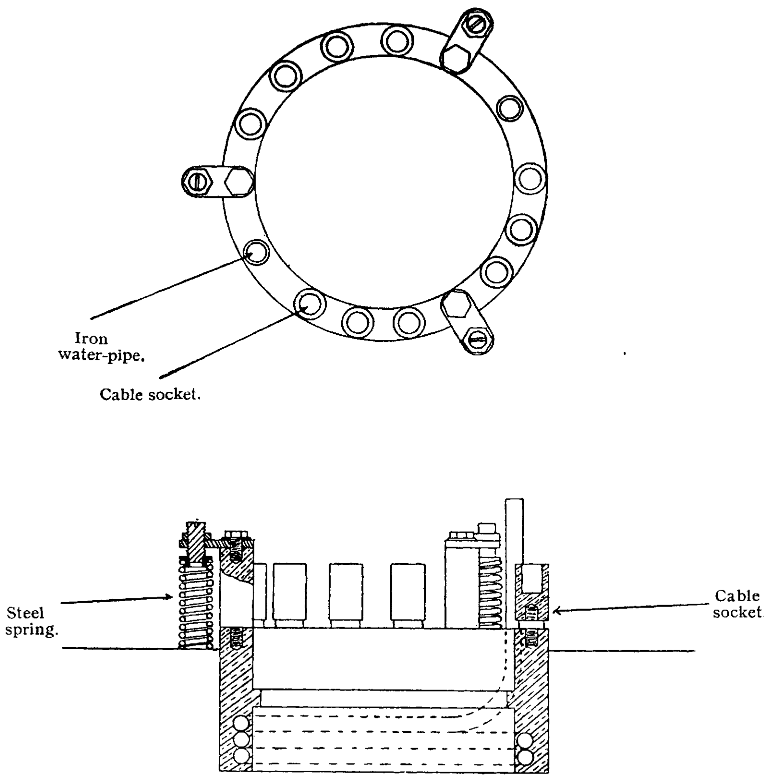

FIG. 2.

completely opened, and to allow of ready access to the interior during working. In place of the solid graphite block used at the bottom, a graphite tube, of the same diameter as the rings, is used to make contact with the top ring. This tube (*j*) in turn fits into the upper water-cooled electrode (*k*), which is provided with a flange in order to transfer its weight to the graphite tube. This electrode is machined on the outside and passes as a good fit through a plate of aluminium alloy (*l*), which is electrically insulated from, but firmly attached to, the top cover-plate of the furnace casing. This arrangement allows for the thermal expansion of the graphite and of the electrodes by permitting the electrode to slide up or down through the aluminium plate, this joint being, however, kept as gas-tight as possible.

A more detailed view of the construction of the upper electrode with its cable sockets and spring adjustment for pressure is shown in plan and vertical section in Fig. 2. One cable socket is seen in section at the right-hand side and one of the adjusting springs at the left-hand side of the figure. There are, in all, ten cable sockets and three adjusting springs. The mode of operation of the latter is readily seen from the figure. The spring is in compression and bears part of the weight of the upper electrode. By adjusting the screw seen above the spring, the amounts of weight carried by each spring can be delicately adjusted as required.

The top of the furnace chamber or tube is closed by another solid block of graphite (*m*), which lies upon the flange of the upper electrode already referred to. This block can be easily removed. For this purpose two holes, shown in the figure, are provided in the top surface of the graphite

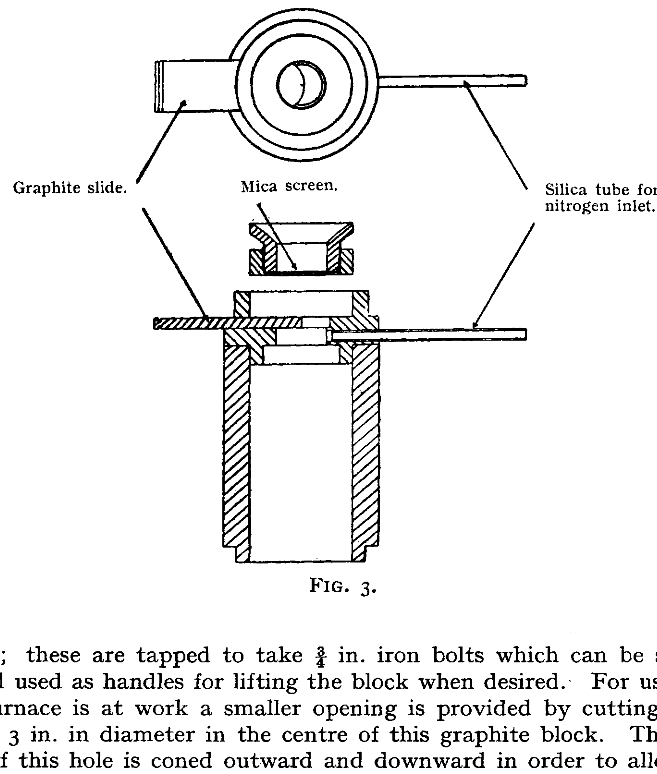

FIG. 3.

block; these are tapped to take ¾ in. iron bolts which can be screwed in and used as handles for lifting the block when desired. For use while the furnace is at work a smaller opening is provided by cutting a hole about 3 in. in diameter in the centre of this graphite block. The lower half of this hole is coned outward and downward in order to allow of a wider field of view from the aperture above; the upper half of this hole is slightly tapered upward, and into this taper fits the slightly coned end of a smaller graphite tube (*n*). This tube, having an internal diameter of 2 in., is for convenience made in two parts, the upper fitting on to the lower at a stepped joint (*o*). The part above this stepped joint is shown in fuller detail and to a larger scale in Fig. 3. The top of this tube is provided with a cap, provided with a wide mica window for inspection purposes. Below this a graphite sliding plate or shutter is fitted by which the opening can be completely closed just below the mica window. The necessity for providing such a shutter arises from the fact that the window becomes seriously obscured by matter (chiefly silica) which is liable to be volatilized in the hottest part of the furnace and then condenses on the colder parts. By closing the graphite slide, the mica window can be bodily removed, without admitting air into the furnace, and cleaned or replaced. This is particularly important where observations with an optical pyrometer are to be made. Immediately below the shutter or slide is the inlet tube—of silica—by which nitrogen gas is supplied to the furnace. This gas admission tube is purposely placed at the top end of this view tube in order to make it possible to blow away, with a temporarily increased stream of nitrogen, any fog or fumes of silica which may form in the furnace.

The parts so far described constitute the working portions of the furnace; the graphite resistor and parts of the electrodes are, however, enclosed in a substantial steel case in order to render the whole apparatus as gas-tight as possible. The manner in which the electrodes pass through the top and bottom cover-plates of this case has already been indicated. The barrel of the case (*p*) consists of a steel tube with a flange at top and bottom, to which the cover-plates are bolted. In the furnace described this steel tube is 18 in. high and 22 in. in external diameter. This steel casing is lined with magnesia blocks (*q*), which form a satisfactory thermal insulation. Between these blocks and the graphite rings, however, is a layer (*r*), about 3 in. thick, of vegetable black (a form of light, finely divided carbon), which serves as additional heat insulation and also serves to surround the outside of the graphite rings with an atmosphere rich in carbon. This vegetable black, which has previously been used for similar purposes by Harker, proves to be a satisfactory protection for the outside surfaces of the graphite rings. Provided that the joints of the outside casing are kept thoroughly gas-tight, no serious loss of this vegetable black by combustion occurs. Special apertures for refilling the case with vegetable black are, however, provided.

With regard to the general dimensions of the furnace which has been described in some detail above, it may be remarked that while quite satisfactory for temperatures up to 1,500° C., the ratio of length to diameter is not adequate for really high temperatures, partly because of the relatively large heat-losses from the ends and also because the ends themselves, away from the actual water-cooled electrodes, attain too high a temperature for convenient working. In the case of a furnace having rings with an internal diameter of 9 in., an internal height of 28 in. has been adopted.

The preparation of the graphite rings by turning from a solid rod or tube of graphite has already been mentioned. For the furnaces so far constructed the rings have been cut from solid rods (electrodes) of Acheson graphite, and the machining operation is quite simple and easy. It is quite possible to obtain series of rings of successively smaller diameters from the same large rod of graphite. None the less, the cost of graphite for this purpose is appreciable, and an attempt has therefore been made to use rings of carbon prepared by pressing and baking in the same manner as arc-lamp electrodes, etc. Rings for experiments in this direction have been made for the authors by the courtesy of the General Electric Company, Ltd., Carbon Department, Witton, Birmingham. At first considerable difficulty was found in obtaining such rings sufficiently flat, owing to the tendency of the carbon body to warp during baking. The rings also proved somewhat fragile and apt to break in transit, but it has been found quite possible to work with broken rings in the furnace, whether of carbon or graphite. A more serious difficulty with the carbon rings was their tendency to undergo conversion into graphite locally where, owing to warping, local heating took place. The resulting shrinkage soon led to failure. The indications obtained, however, suggest that if the production of carbon rings for this purpose were carefully followed up, this material could be successfully used in furnaces of this type.

With regard to the life of the graphite rings in these furnaces, it is evident that everything depends upon the extent to which oxygen or oxidizing gases can be kept away from the heated carbon. Where this is done completely the life of the rings appears to be very long indeed, but, even in less perfect conditions, a very considerable length of life is attained. In the first furnace of this type set up by the authors, with rings 2¼ in. internal diameter, about 100 heats at temperatures ranging from 1,500° C. to 2,400° C. (including fusion of alumina) were obtained in a period of six weeks. The rings were then taken down, and it was found that only a few rings at the top of the tube were seriously burnt away. Six new rings were used to replace these and the furnace was then as good as new. Other furnaces have, so far, given equally satisfactory results.

The temperature which can be obtained in a furnace of this type is, within the limits of endurance of the graphite itself, limited only by the power available and the adequate cooling of the ends. Some examples of temperatures attained and current consumed may, however, be given.

A furnace 2¾ in. internal diameter attained a temperature of 1,500° C. with a consumption of 8 kilovolt-amperes in about 30 minutes, and 1,700° C. with a consumption of 10 kilovolt-amperes, the actual current in the latter case being about 400 amperes (alternating current) with a pressure of approximately 25 volts. If it were desired to heat a plain carbon-tube resistance furnace of the same dimensions to the same temperature, a current of 1,500 amperes would be required.

In a furnace having an internal diameter of 3¼ in., pure iron can be melted with a power consumption of 11 kilovolt-amperes, taking a current of 550 amperes. In a larger furnace having an internal diameter of 7 in., corresponding to the one described in detail above, a temperature of 1,650° C. was attained with a power consumption of 23 kilovolt amperes (2,000 amperes). This last result indicates a considerably lower efficiency than the others, but this is due to the fact, already indicated, that in this furnace the ratio of length to diameter is unduly small.

The furnace described above has been designed and developed largely for the purpose of studying and testing special refractories, such as alumina, zirconia, carborundum, etc., at very high temperatures—work which has arisen out of researches on the production of optical glass. The cost of the work has accordingly been borne out of a grant for researches on optical glass made to the Laboratory by the Department of Scientific and Industrial Research. The authors also desire to express their thanks to the Director of the National Physical Laboratory, Sir Richard T. Glazebrook, C.B., F.R.S., for his continued interest in the work, and to a number of their colleagues in the Metallurgy Department of the Laboratory for valuable assistance, particularly in the casting of the water-cooled electrodes.