CHAPTER II

PARTIAL CEMENTATION OF WROUGHT IRON AND SOFT STEEL

Reference has already been made in the first part of this volume to the development of the industrial process of the partial carburization of objects of soft iron or steel. The recent enormous development of machine technology and the more difficult and complex conditions which the metals required by this industry must satisfy are the causes of the wide diffusion and increasing importance of the processes of partial cementation. It is such processes alone which make it possible to combine, in one piece of steel, surface hardness with high tenacity, and to harden effectively, without serious difficulties and risks, objects which could not be easily hardened if made wholly of hard steel.

We will describe briefly industrial practice for the execution of these processes.

The rational conduct of the individual operations follows in a simple and precise manner from the considerations developed in the first part of this volume; the object of this chapter is to show what are the material conditions best suited to realize these rules in practice in the simplest and surest way.

In the several sections of this chapter we will deal separately with the conditions of use of individual "types" of cements, and with "special" processes of cementation whose application is radically different from those of all other processes.

§1. GENERAL CONSIDERATIONS

The processes of partial cementation, or "superficial cementation," are designated in English, in German and in French by the respective terms: *case-hardening*, *Einsatzhärtung* and *trempe à paquet*, and sometimes in Italian by a name too literally translated from the French: *tempra a pacchetto*. They are almost exclusively used for the surface carburization of objects of soft or low-carbon steel completely or almost completely finished, or at least of pieces which have already undergone, in the parts which are to be cemented, all the necessary treatment with cutting tools and which are only to be machined later, if necessary, on the emery wheel.

Save for a few rare exceptions, the essential practical purposes of surface cementation are four:

(*a*) To obtain, after quenching, pieces of steel which are not brittle and possess sufficient surface hardness to prevent rapid wear by friction. Such is the object of treating toothed wheels for gearing, axles, cams and rods of valve gears, and a large quantity of machine parts destined to stand both friction and considerable strains, such as flections, shocks, etc.

In the greater part of these cases the cementation is limited to a thin surface zone, and the thermal treatment to which the piece is subjected afterward must be studied with the greatest care with the ultimate objects in view of making the cemented zone hard and of giving the maximum tenacity to the "heart" of the piece, thus neutralizing the harmful effect produced by the long heating in the cementation process.

(*b*) To render possible, or at least easier, the efficient hardening of pieces of large dimensions and of complicated and irregular form which, if they were entirely of steel of high carbon content, would be exceedingly difficult to harden without the production of fractures or cracks.

(*c*) To render considerably less the cost of steel objects in which the parts which are to "take the hardness" constitute only a small portion (in general, the outside portion) of the total mass. This is attained by the smaller cost of the raw material and the smaller expense of machining the softer material.

(*d*) To obtain at low cost pieces of steel capable of taking a beautiful polish.

The quality of the raw materials used for pieces intended to be cemented superficially naturally varies within very wide limits, according to the purposes for which these pieces are to be used. It is not possible to establish general rules in this respect. We will take occasion later to cite some concrete and precise data in some special cases.

Whenever it is not necessary that the soft nucleus should possess special qualities of resistance to shock and stress (such is, for example, the case for many cutting utensils), ordinary carbon steel is used as raw material, for reasons of economy. It may be specially noted that, contrary to what is considered good practice in the case of the total cementation of materials intended to be fused or strongly forged after the cementation (see p. 203), it is advantageous, and in many cases necessary, to use steels proper, obtained by fusion, instead of puddled or wrought irons. This might be considered evident *a priori*, when we remember that the presence of veins and granules of slag would not only be in itself a detriment in any piece subjected to strong friction or to other localized forces, but it would give rise to deep-seated irregularities in the cementation and is also the principal, if not the sole, cause of the formation of "blisters" (see p. 215), which would render useless a piece not further worked hot but used practically as it is. Practice confirms the fact that the use of fused steels, free from scoriæ, avoids the formation of the blisters.

In those cases in which it is necessary that the soft nucleus of the cemented pieces should possess maximum tenacity, it is well to use as raw materials soft nickel steels instead of the ordinary carbon steels, since even after carefully executing the thermal treatment most effective in "regenerating" the soft metal of the nucleus, it is difficult to obtain fully satisfactory results with plain carbon steels. The soft nickel steels most frequently used for this purpose are those containing 2 to 3% of nickel, which are cemented under practically the same conditions and according to the same rules as carbon steels, and in which the increase in brittleness due to the prolonged heating in cementation is much less marked than for carbon steels. Moreover, for these special steels the "regeneration" of the metal of the nucleus, by means of thermal treatment carried out after the cementation, is considerably more effective and easy. In some cases steels with 5% of nickel are also used; quite rarely steels of higher nickel content. For steels containing more than 4.5–5% of nickel, the phenomena of negative hardening begin to manifest themselves, especially when the carbon content of the cemented zones is rather high.

The use of complex steels different from those just mentioned is limited to special cases, of which we will give an account later.

A large number and variety of "cements" have been adopted in the practice of these processes. The results of recent investigations have confirmed the opinion of the earlier experimenters that the addition of foreign substances to the carbon used as cement serves to increase its efficacy, making the process of cementation more rapid.

But the most precise, and therefore most reliable, experiments show that only *some* classes of substances, acting on iron together with carbon, exercise on the metal an intense carburizing action, and among these substances the only one capable of acting under well-defined and exactly controllable conditions is carbon monoxide. It is not possible to adduce any well-founded reason for the use of the bizarre and complicated mixtures which many technologists employ at the present time, considering them as possessed of marvelous efficacy and jealously guarding the secret of their composition.

Some of these curious mixtures are still recommended to-day in serious treatises, and protected by costly patents. In the present chapter we will deal only with processes based on the use of rational cements, whose mode of action has been widely studied and controlled in practice, such that their use permits of obtaining, when working under well-defined conditions, much more definite and sure results.

Since the technique of the processes of cementation varies greatly, especially with variations in the state of aggregation of the cement, I have considered it well to subdivide the material of this chapter, collecting in the individual parts whatever concerns the technical applications of the cements used in a definite state of aggregation.

We will therefore treat separately of the solid, liquid, and gaseous cements, and of the "mixed cements," meaning by this last designation those cements formed of carburizing substances belonging to two or more different classes, acting simultaneously. In practice, the only mixed cements used consist of combinations of solid cements and gaseous cements.

For the various cements of each of the classes indicated above, almost identical apparatus and methods of procedure are used in practice; this will greatly shorten the subject matter of the present chapter, making it possible to avoid many repetitions.

We will refer separately to a group of special processes based on the phenomena of diffusion of elements other than carbon into solid iron, and to the processes of cementation of armor plates.

§2. SURFACE CEMENTATION WITH SOLID CEMENTS

The technique of superficial cementation with solid cements is extremely simple to describe, but in practice it must be carried out with the greatest care, as the least error in placing the pieces in the boxes, in filling their interstices with the cement, etc., is sufficient to give rise to the most serious defects in the product obtained.

On account of the extremely variable properties of the solid cements which are found in commerce, much practice is needed in the individual cases to be sure of obtaining precisely the desired results. This, in fact, is the principal difficulty in these processes, which are nevertheless so widely applied at present.

Save for rare exceptions, cementation with solid cements is carried out by placing the pieces of steel in "cementation boxes" of cast soft steel or of sheets of soft steel bolted and joined by means of hinges. Boxes of autogenously welded sheets are also sometimes used.

The boxes of cast steel cost somewhat more than those of sheet steel and can not, in general, be made as light as the latter; as an offset, the life of the former is greater, if well constructed.

The life of the cementation boxes depends greatly on the temperature at which cementation is effected, the composition of the atmosphere of the furnace in which they are placed, and the treatment to which they are subjected during the charging and discharging of the furnace. By cementing at 900°-950° C., in a gas furnace with not too strongly oxidizing atmosphere, charging the boxes in the furnace and removing them from it with the greatest care, placing the boxes as soon as removed from the furnace on a layer of fire clay and at once piling up a part of this against the sides of the boxes so as to protect them from oxidation, a box of bolted sheet steel of the average normal dimensions (30 × 35 × 60 cm., with walls 10 to 15 mm. thick) should last for twelve to fifteen operations. Under the same conditions, a box of cast steel, with sides 20 to 25 mm. thick, may serve for fifteen to twenty operations. By using furnaces with distinctly reducing atmosphere, such as are, for example, the modern heavy-oil furnaces, the life of the boxes may be markedly increased.

The boxes must in any case be furnished with a cover of iron or steel (cast or sheet), with the edges shaped so as to fit over the box and insure good closing.

The dimensions of the boxes must be such that the objects to be cemented are contained in it easily, so that there may be at every point a free space of not less than 3 to 4 cm. between their furthest projecting points and the wall of the box. This is for the purpose of providing a layer of cement around these salient points thick enough to insure a uniform cementation.

It is always advantageous, however, to give to the boxes the minimum dimensions compatible with these conditions, because the larger the box the longer the time necessary for the heat to penetrate from the outside to the center, and, therefore, for the temperature to become uniform throughout the box. Some of the disadvantages of slow propagation of heat from the outside to the center of too large boxes are: 1. Marked deformation of the cemented pieces, due to the fact that they are heated for a long period of time to different temperatures in different parts. 2. Marked irregularities in the cementation, which is a maximum in the parts of the pieces nearest to the walls of the box and a minimum, sometimes almost null, in the parts nearest to the center of the boxes. 3. Great length of time necessary to obtain a given cementation.

The disadvantages just enumerated vary with the properties of the cement used and the type of furnace available. They are greater the lower the thermal conductivity of the cement and the smaller the quantity of heat furnished to the working chamber of the furnace in the unit of time at a given temperature. It is not possible, therefore, to give quantitative data of value on this topic; we will quote later some particular examples which will furnish concrete data.

Besides these considerations, boxes of large dimensions are difficult to manipulate and, when they reach certain sizes, can be removed from the furnaces only by means of special and expensive mechanical arrangements, difficult to provide in small plants.

Even for the cementation of pieces of rather large dimensions (toothed wheels, sectors, axles, etc.) it is not desirable to use boxes longer than 55–60 cm., nor wider than 45 cm., nor higher than 30 cm. If the pieces to be cemented can not be contained in boxes of these dimensions, it is advsiable to carry out the cementation in fixed built-up chambers. This can be done (although it is not without its disadvantages) even when using solid cements, but considerably better with gaseous cements or with mixed cements.

When the pieces to be cemented are of small dimensions (axles for bicycles, rings and cups for small ball bearings, links for chains, etc.) it is better to employ much smaller boxes, such as parallelepipedons 30 cm. long by 25 cm. wide and 25 cm. high. Boxes of cylindrical form recommended by Guillet,[1] whose diameter must be 10 to 12 cm. greater than that of the pieces which are introduced into them, are sometimes used; but, although they can be obtained easily and at low cost by making them from drawn steel tubes, and although their form is certainly the most rational and that which permits of obtaining the most homogeneous cementations, they are less easy to charge and to empty than those in the rectangular form.

In charging the boxes it is necessary to take care that the cement is in good contact with the entire surface of the pieces to be cemented, and that the layer of cement surrounding them has in no case a thickness less than about 2 or 3 cm. For this purpose the bottom of the box is first covered with a wash of clay made into paste with water; this is well dried before further charging. Then a layer about 4 cm. thick of the finely powdered and well dried cement is placed upon this, carefully compressing it. On this is placed a first bed of the articles to be cemented, arranging them in such a way as to leave between them free spaces of at least 3 cm. Then all the free interstices between the pieces are carefully filled by pressing in the cement, and afterward a layer of cement of sufficient thickness to cover by 2 or 3 cm. the highest parts of the pieces. If sufficient space remains above this, a second series of pieces is placed upon it, repeating the operations indicated for the first series. The last series of pieces to be cemented must be totally covered by a layer of cement at least 4 cm. thick. If the box is not completely filled, as much cement is placed over this last layer as is necessary to fill the box to the edge; then the cover is put in place, carefully luting all around with the usual fire-clay lute.

The box thus prepared can be placed directly in the furnace, taking care to leave it for some time near the door or at a point not too hot, so as to dry the lute well and to allow the small quantities of water vapor, due to imperfect drying of the materials used, to escape slowly.

The furnaces at present most frequently used for the cementation are those heated by illuminating or gas-producer gas, as this means of heating permits of easy and proper regulation of the temperature, and of obtaining a uniform heating throughout the whole laboratory (working space) of the furnace. Furnaces heated by means of the combustion of mineral oils have recently been introduced into practice, and in some works there are still in use furnaces heated directly by solid fuel (*coal* or *coke*). It seems well, therefore, to make some reference to these different types of furnaces.

Whatever the fuel used, a furnace intended for cementation must satisfy some general conditions which, for cementation with solid cements, may be summarized as follows:

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[1] *Mém. de la Soc. des Ing. Civils de France*, February, 1904, p. 193.

The temperature in the laboratory must be able to easily reach 1100°–1200° C. and must be capable of being kept constant during a practically indefinite time at any point between 850° and 1100° C. For any temperature comprised within this interval, it must be possible to obtain so uniform a heating of the whole chamber of the furnace that differences greater than 30° do not exist between various points in this chamber, except, perhaps, in a small zone nearest to the door. In good gas furnaces the maximum differences in temperature in the body of the furnace when in operation are less than 20°, and sometimes even below 10° C. The atmosphere of the laboratory of the furnace, when in operation, must be nearly neutral, but rather reducing than oxidizing.

To obtain maximum uniformity of temperature in the laboratory of the furnace, it is well that the flames should bathe the walls and the arch of the laboratory itself, coming as little as possible in contact with the boxes, so that the latter are heated indirectly by heat reflected from the walls and the arch of the furnace and not by direct contact with the flame or hot gases.

In large furnaces, heating the whole laboratory to a perfectly uniform temperature is sometimes difficult. Guillet proposes to consider the laboratory of the furnace as subdivided into various zones, in each of which the temperature maintained is of the required degree of uniformity. By determining the mean temperature of each of these regions for a given operation of the furnace, and being careful to take into account the region in which each of the cementation boxes is placed, it is possible to know approximately the temperature at which the cementation is being effected in each box.

The doors of the furnace must close well and must be furnished with one or more holes, 2 or 3 cm. in diameter, to permit of taking samples of gas, of observing the interior, and of measuring the temperature by a pyrometer without opening the doors. These holes must usually be closed by means of clay stoppers.

The height and the width of the doors of the furnace must exceed the height and the width of the cold cementation boxes by at least a couple of centimeters; otherwise it may be difficult, or even impossible, to remove the boxes from the furnace after the heat has expanded them.

In general, portcullis or lift doors, balanced by counterweights, are preferable to doors mounted on hinges. In fact, the former, even when opened, are considerably less cumbersome, and always present to the workman their cold side, while hinge doors, when opened, present to the workman their incandescent side, enormously increasing the discomforts due to heat radiating from the furnace.

An arrangement which greatly facilitates the charging of the furnace is the roller, as long as the width of the door, placed horizontally immediately in front of the door in such a way that it projects 5 or 10 mm. above the level of the floor of the laboratory and of the sill of the door. The boxes are slid on this roller, or the bars of iron on which the boxes are placed, both for introduction and removal from the furnace, are rested and moved on the rollers.

The charging and the discharging of the boxes is facilitated in furnaces having a movable body mounted on a car which can be removed from the furnace with its whole charge. This arrangement is, however, rarely used in furnaces of small or medium dimensions, in which the difficulties of charging are not such as to justify the greater complexity and the greater cost of equipment and maintenance which the movable body entails. It is, on the other hand, now adopted almost always in furnaces intended for the cementation and the thermal treatment of large sized pieces, such as armor plate.

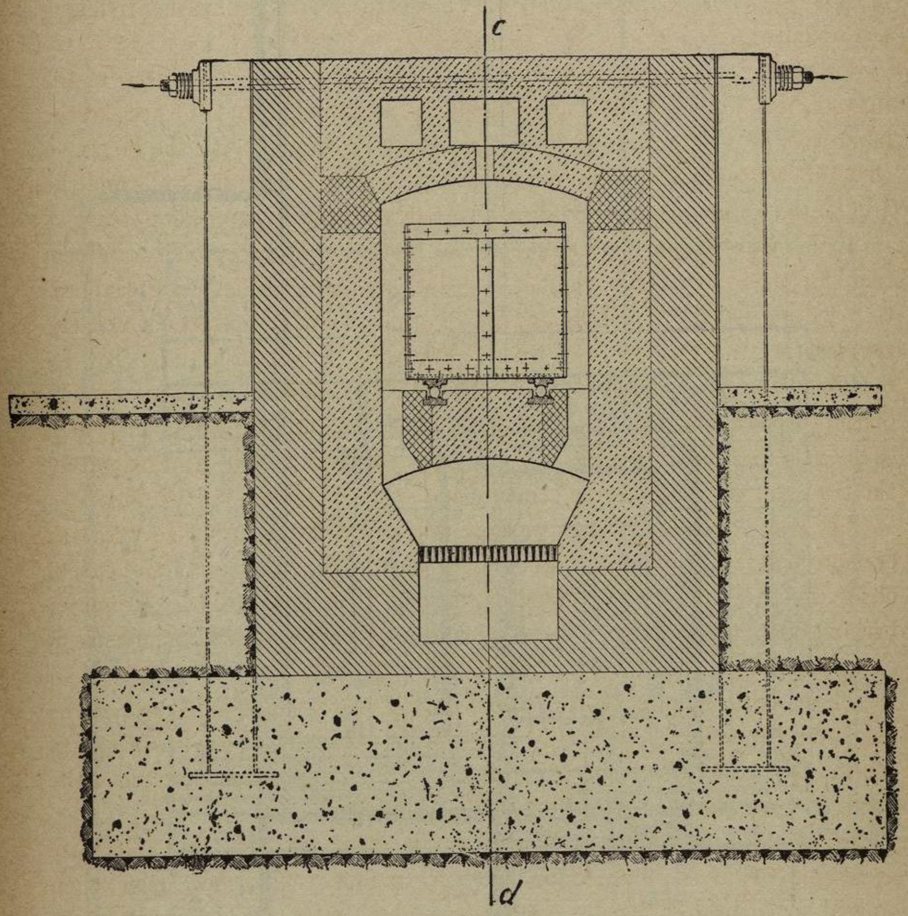
Section a-b.

FIG. 79.

Furnaces in which solid fuel is used *directly* for heating are at present little used, on account of the greater difficulty of obtaining a uniform heating of the whole masses contained in the laboratory and in avoiding the so-called "heatwaves" or sudden rises in temperature which may ruin the entire charge of a furnace. Moreover, in furnaces heated directly with solid fuel it is not possible to avoid the considerable oscillations on the temperature occurring every time fresh fuel is put on the grate. These oscillations, as we have already seen,[1] are the cause of great modifications (difficult to foresee *a priori*) in the properties of the cemented zones which are obtained. This is a serious obstacle to the proper conduct of the operations following cementation, and a permanent menace of total failure.

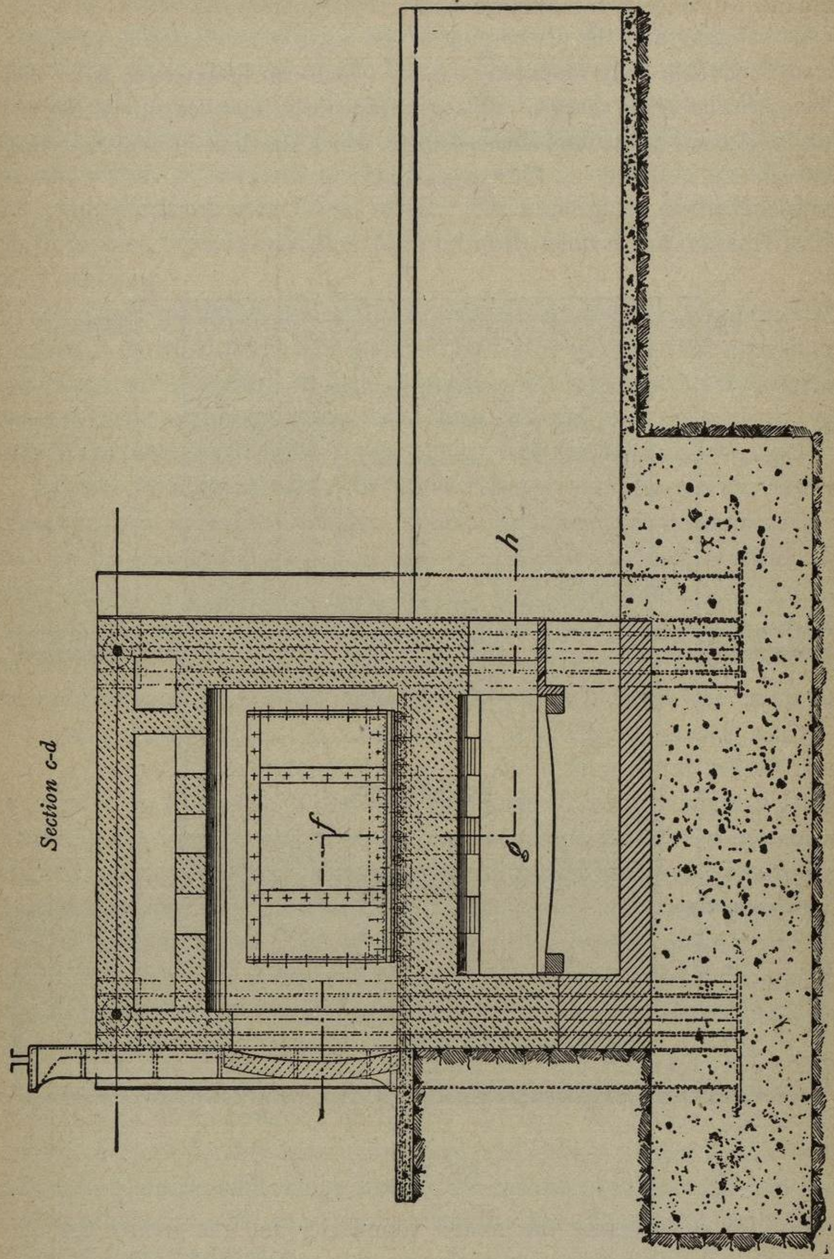

Fig. 80.

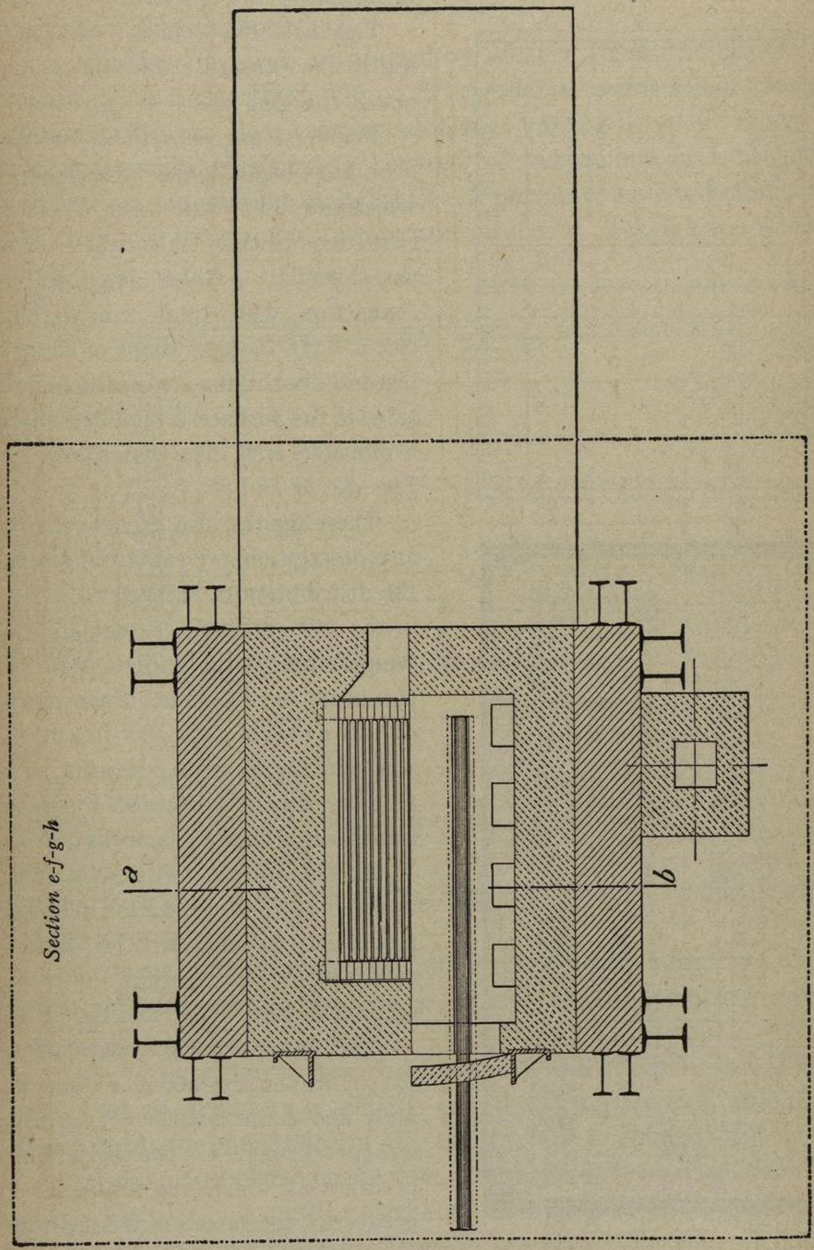

Fig. 81.

Nevertheless, furnaces using solid fuel are still found in small cementation works on account of the low cost of equipment and operation, so that it seems well to make a brief reference to the more common types.

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[1] See p. 159, *et seq.*

Figs. 79, 80 and 81 represent three sections of one of the simplest types of furnaces using solid fuel for cementation in boxes. The figures are sufficiently detailed to render further explanation superfluous. A damper permits of regulating the temperature.

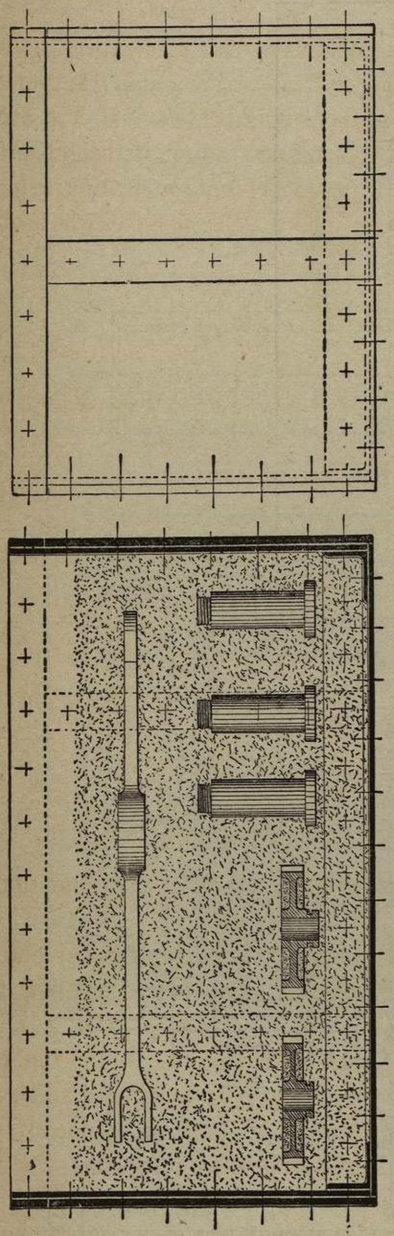


Fig. 82.

Figs. 82 and 83 indicate schematically the structure and the manner of charging a box.

For very long operations, lasting over forty-eight hours, furnaces are sometimes used with fixed boxes of refractory bricks. With these furnaces, similar to those described in connection with total cementation (see p. 207), the operations of charging and discharging are greatly facilitated if the furnace is supplied with a movable arch, like that shown in Figs. 84, 85 and 86.

These figures, also, do not require any description; we call attention to the distribution of the holes *a a*..., in the arch, designed to regulate the temperature in the various parts of the chamber by closing them more or less in such a way as to obtain maximum uniformity of heating.

The fuel best adapted to these furnaces is ordinary gas works coke.

Another furnace with solid fuel, adapted to the cementation of small pieces and recommended for its low cost of equipment, is shown in three sections in Figs. 87, 88 and 89.

The cementation boxes are introduced into the first chamber, immediately above the hearth. When this is kept at 1000° C., the usual temperature at which the cementation is effected, the gases which issue from it, passing through the second chamber, situated above the first, heat it to a lower temperature, varying usually between 650° and 800° according to the fuel used, the dimensions of the various parts of the furnace, etc. This second chamber, which recovers part of the heat which would otherwise be lost, can be usefully employed for heating the pieces before and after cementation.

The furnaces of which I have thus far spoken are fixed. There are also constructed portable coke furnaces, which in many cases are more convenient than the preceding.

One of these furnaces, constructed by Wilhelm Hertsch of Stuttgart, is represented in perspective in Fig. 90, in longitudinal section and in transverse section in Fig. 91. It is constructed in sizes varying between 210 and 800 mm. in the width of laboratory, between 120 and 600 mm. in its height and between 320 and 1200 mm. in its length. It permits of uniform heating, using simple chimney draft, up to a temperature of 1000° C., taking boxes whose dimensions must be at least 50–60 mm. less than the corresponding dimensions of the laboratory.

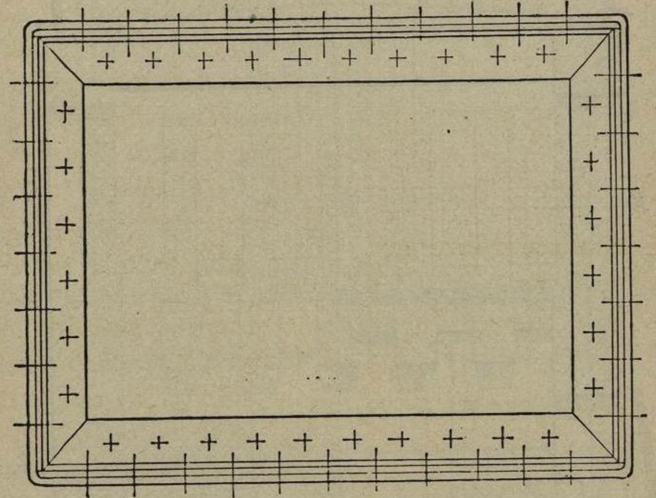


Fig. 83.

The same manufacturer constructs furnaces of a similar type of much greater dimensions, and also with two or more chambers placed one next to the other or one above the other.

In furnaces with very long chambers, such as that represented in Fig. 92 (the working laboratory of which is 5200 mm. long, 350 mm. wide and 250 mm. high), the uniformity of the temperature is obtained by means of several fire-places placed on the sides. Furnaces of these dimensions are no longer movable, but must be fixed and walled in place.

Special types of furnaces are necessary for cementation with solid cements when it is desired to use liquid fuels (hydrocarbons).

The use of furnaces employing liquid fuel has spread very rapidly in the United States of America and is spreading in Europe, especially for small plants intended for intermittent operation. In plants of this kind, where it is necessary that the fires be extinguished every evening and the furnaces be rapidly put into operation the following morning, it is not possible to use furnaces built like those for producer gas, which, because of their considerable mass and that of the gas producers and heat regenerators necessary, are adapted only to *continuous* operation. In these cases also, furnaces using solid fuel *directly* on grates do not give good results, on account of the considerable time which they always require to be lighted and put into operation. The only furnaces which are well adapted for small plants intermittently operated are those burning illuminating gas or liquid hydrocarbons. The former presuppose that the works has a supply of illuminating gas; at times, through special conditions, illuminating gas can be obtained at an extraodinarily low price, but in almost all cases it will be considerably less economical than the burning of liquid hydrocarbons.

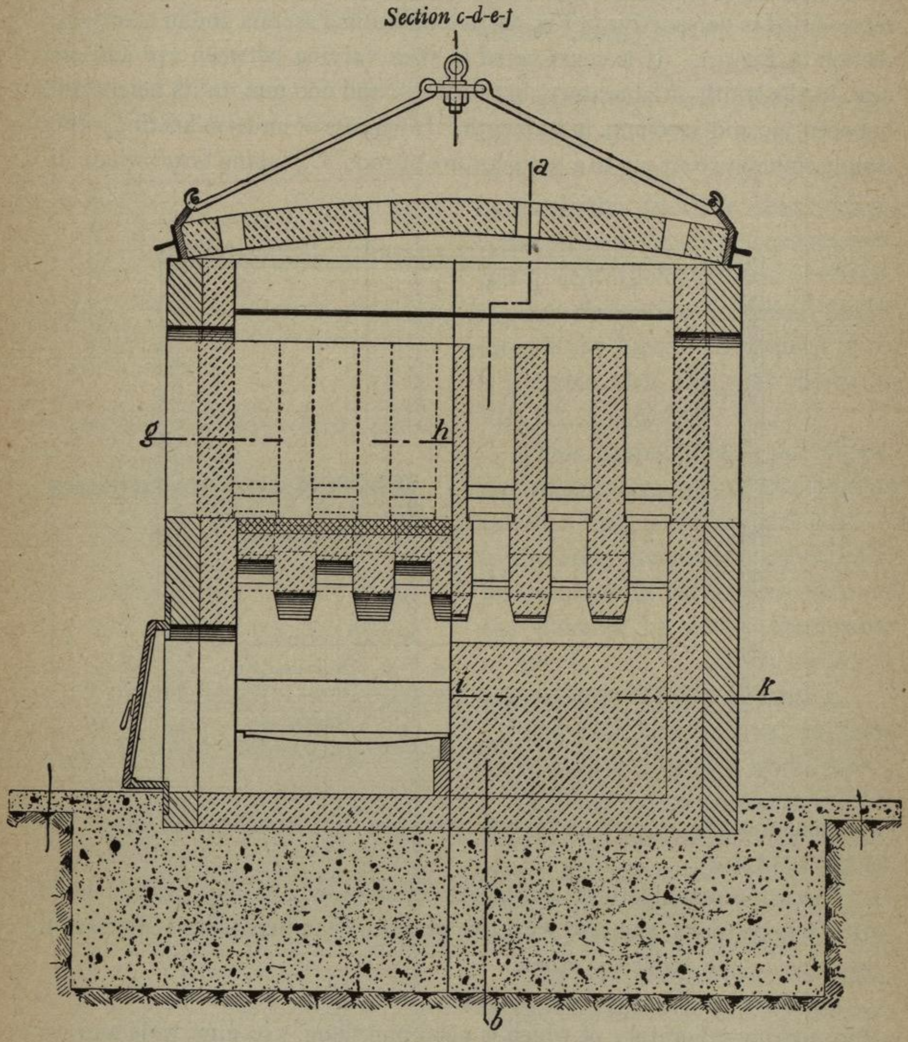


FIG. 84.

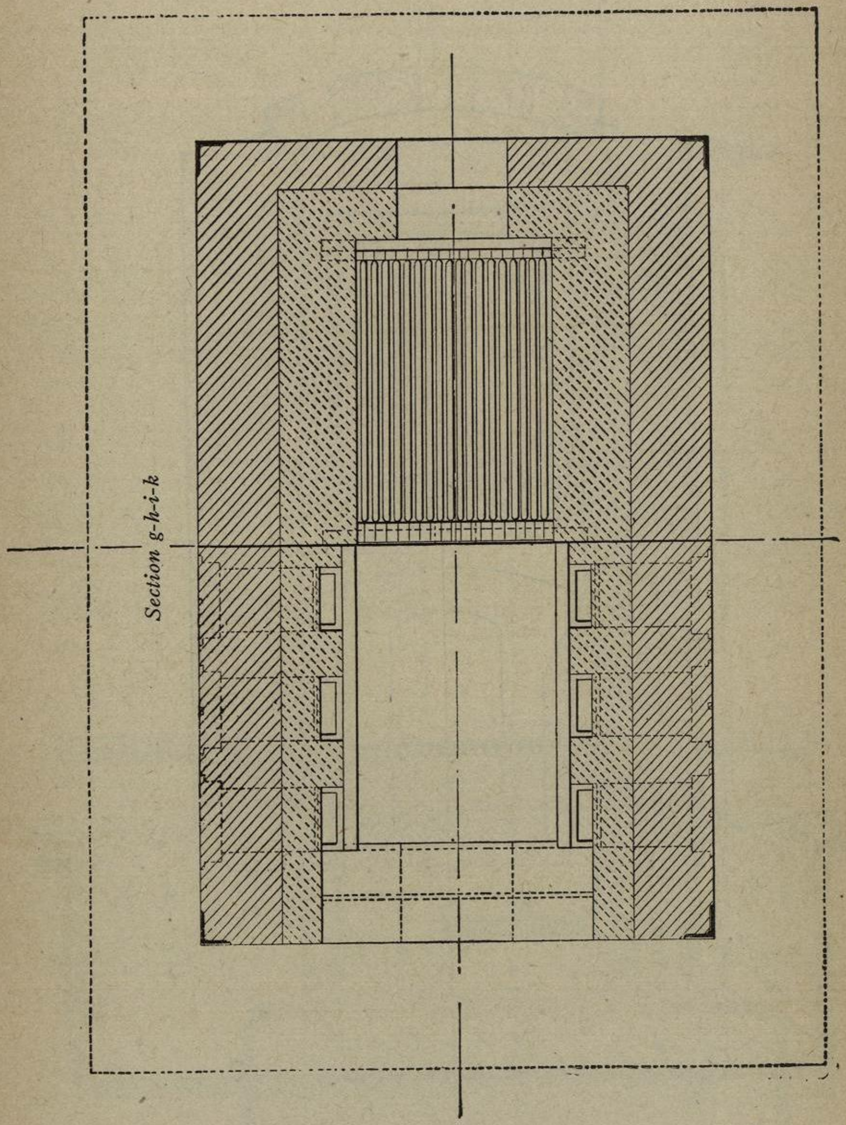


FIG. 85.

Among the many types of liquid fuel furnaces placed on the market, we will refer only to the "Ferguson" furnace, which answers the demands of practice well, both as to regularity and uniformity of heating and economy of operation.

In the Ferguson furnaces air is blown, under a pressure of between 35 and 40 cm. of water, in two jets; the first and principal one carries the hydrocarbon, dropping from an automatically regulated valve, into a vertical chamber in which there is partial combustion of part of the hydrocarbon and complete

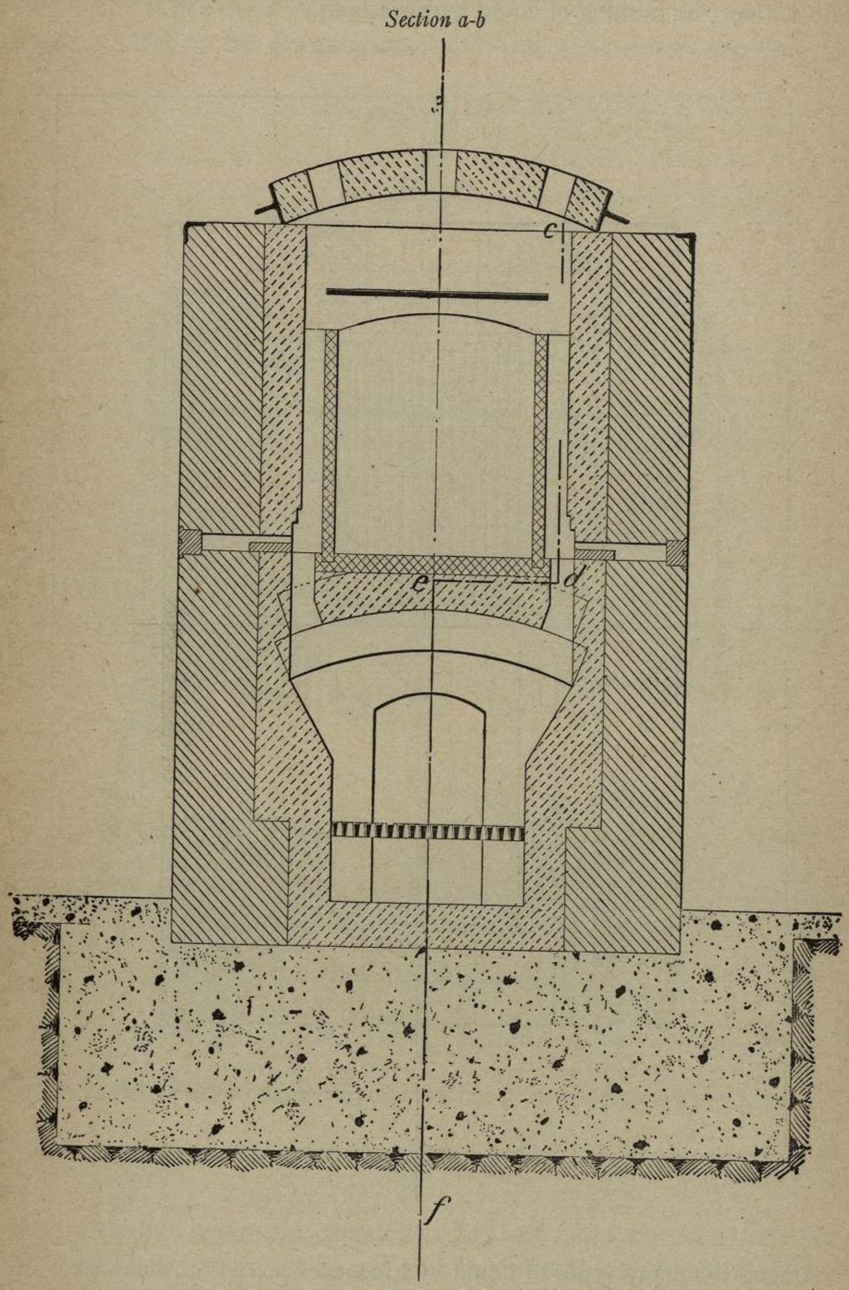


FIG. 86.

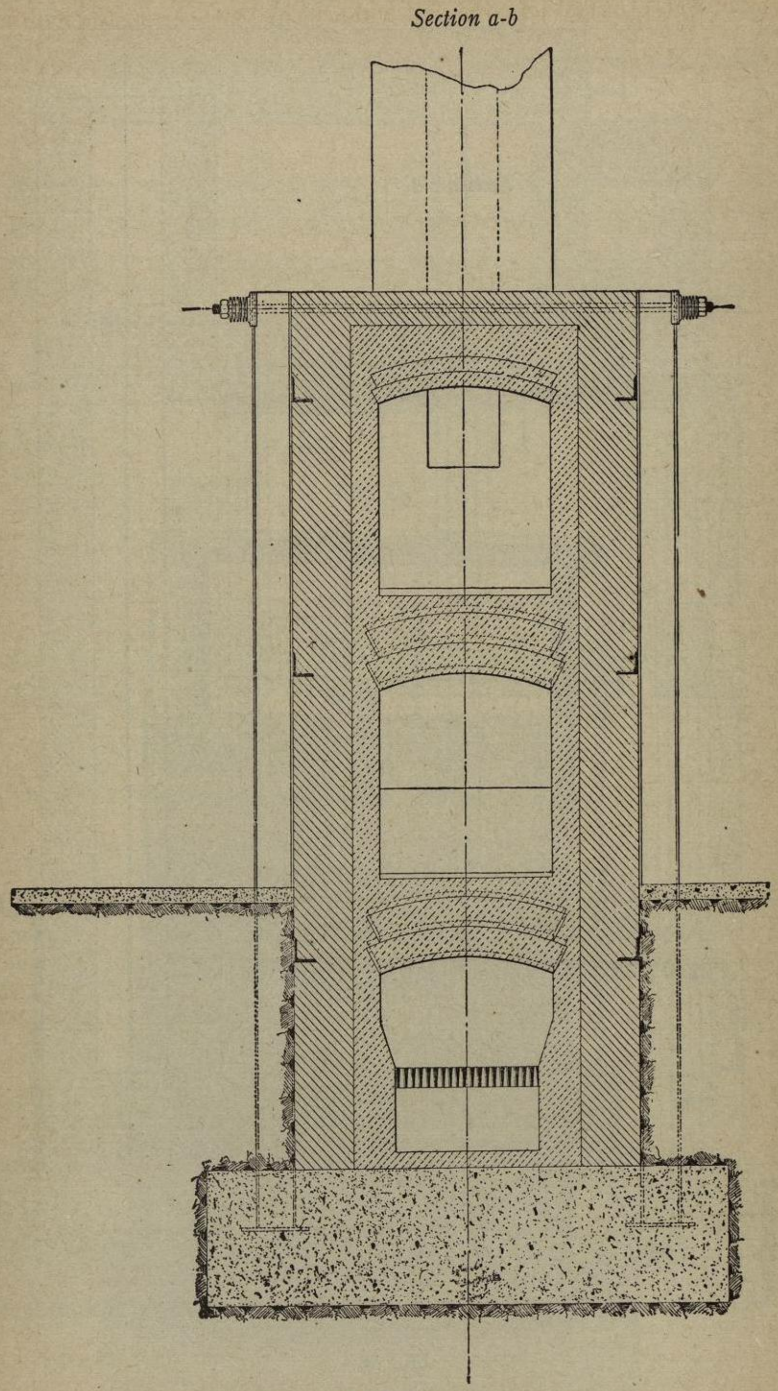
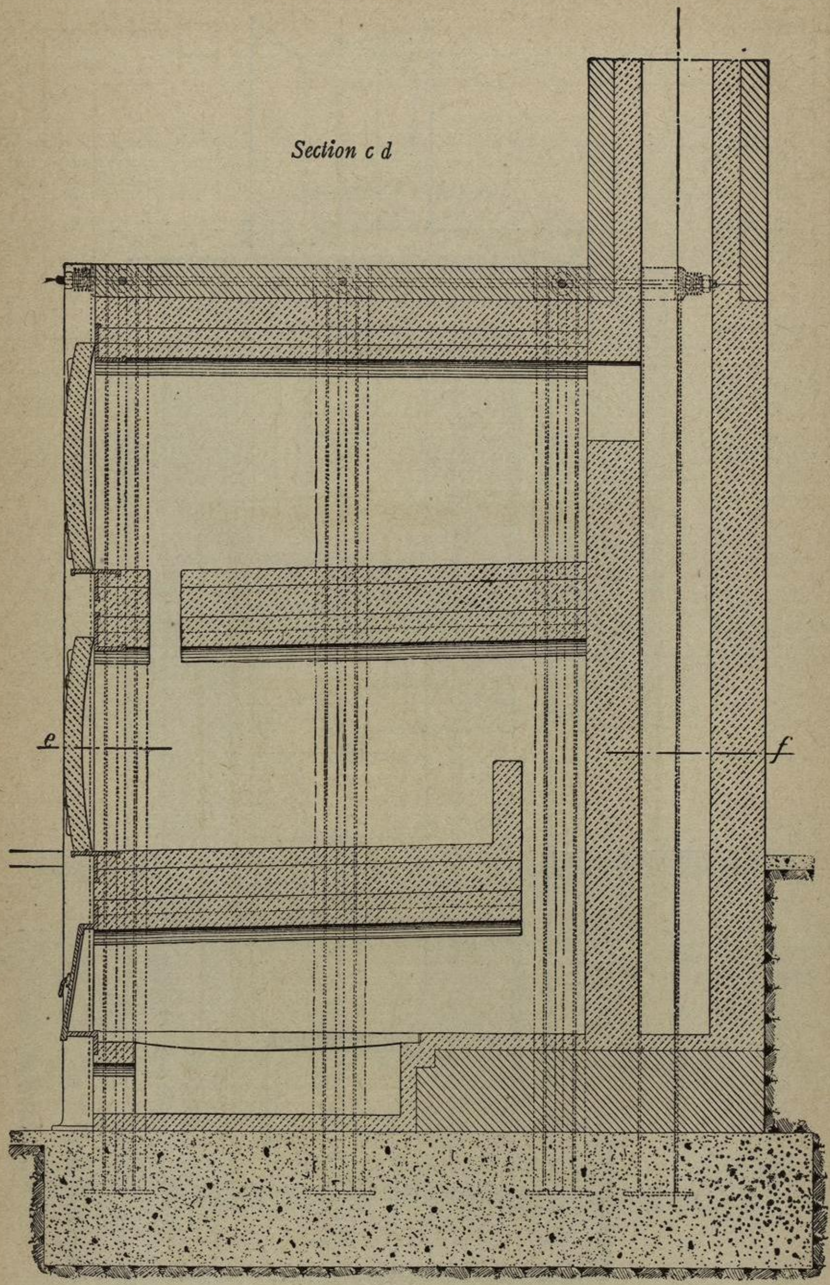
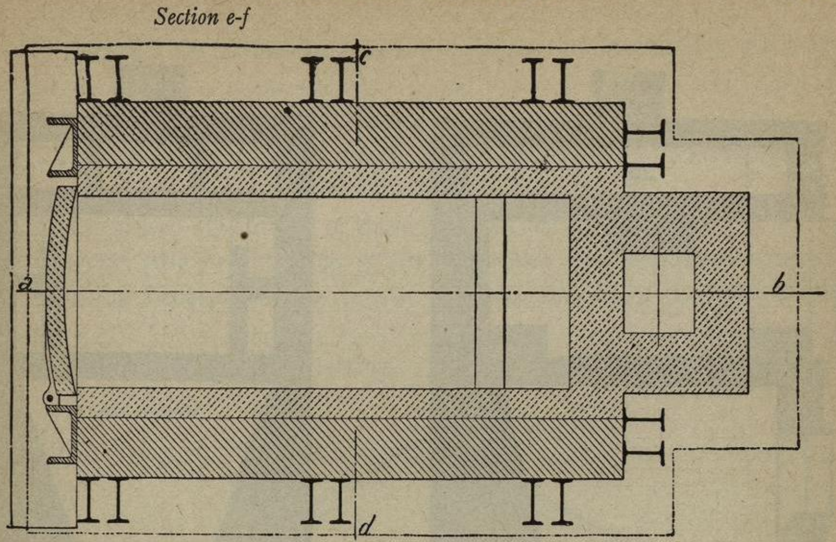


FIG. 87.



Section c d

FIG. 88.



Section e-f

FIG. 89.

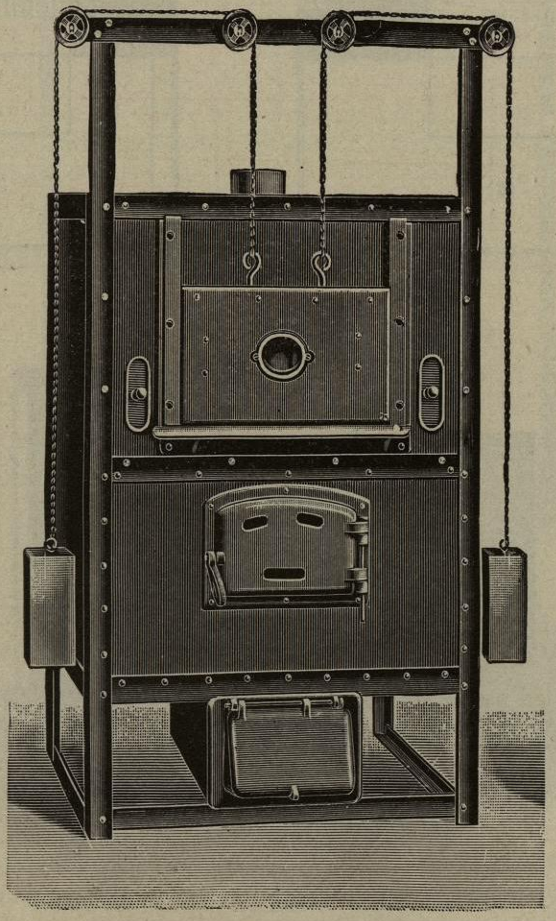


FIG. 90.

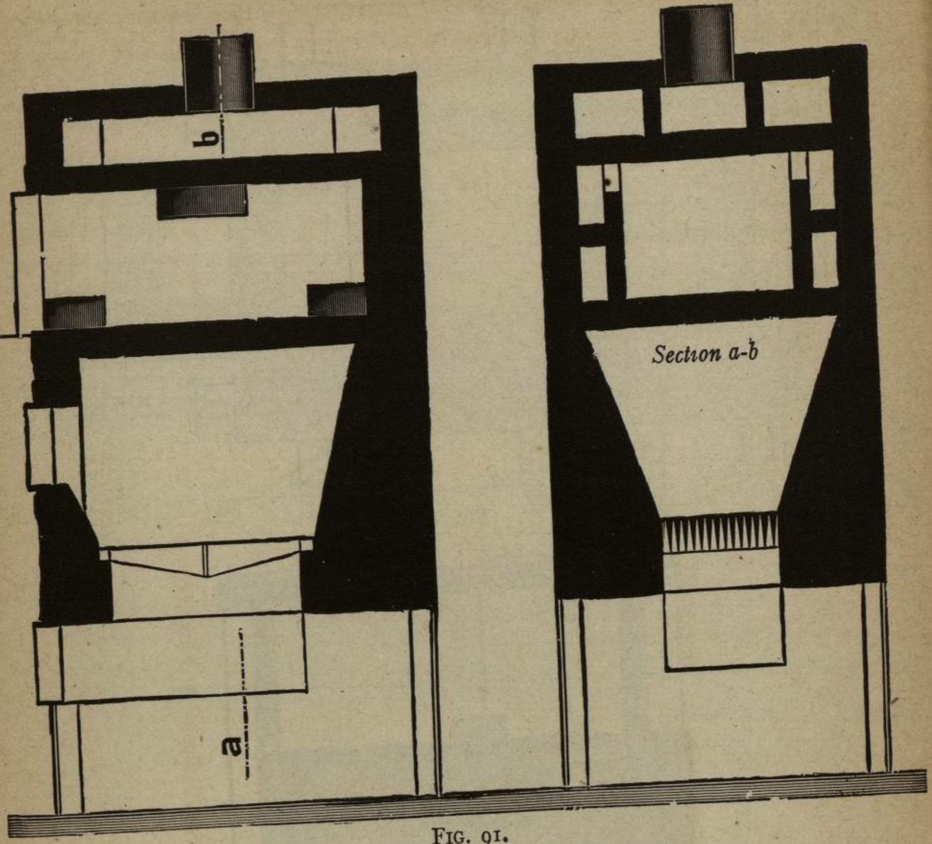


FIG. 91.

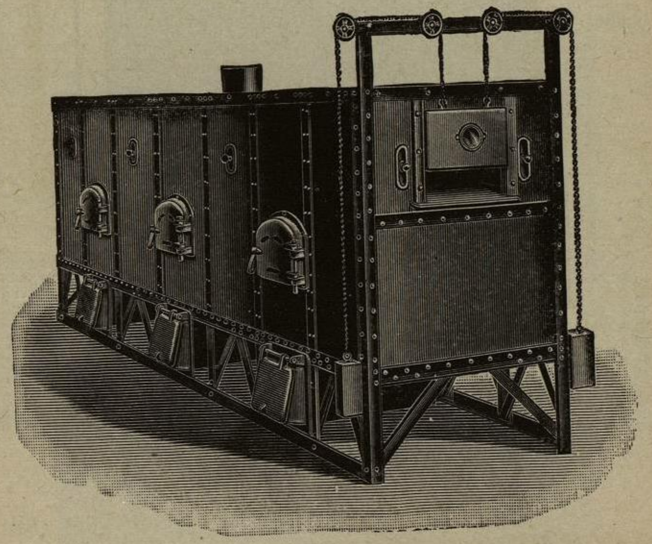


FIG. 92.

volatilization of the remainder. In the upper part of the chamber the vapor of the hydrocarbon meets the second and minor jet of air, with which it mixes intimately and burns completely.

The hydrocarbon oil must come to the furnace under a pressure between 500 and 1000 grams per sq. cm. (7 to 15 lb. per sq. in.).

The principal advantages of these furnaces are the following:

1. Great ease in obtaining in the laboratory of the furnace a neutral or reducing atmosphere; this greatly increases the life of the cementation boxes.

2. Ease and rapidity in starting.

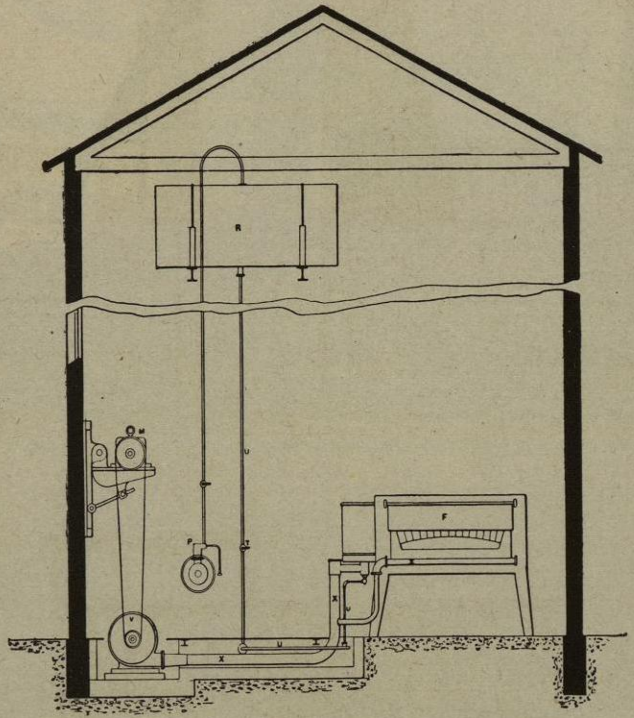


FIG. 93.

3. Ease and certainty in regulating the temperature, which can be kept satisfactorily constant within very wide limits; in general, at any point between 700° C. and 1400° C.

4. Marked economy in operation, due to the fact that fuels of the lowest commercial value (crude petroleum, heavy oils, coal-tar oil, etc.) can be completely consumed, utilizing their full calorific power.

Fig. 93 represents schematically one of the most convenient arrangements for the setting up of one or more Ferguson furnaces. The centrifugal ventilator *V*, set in motion by the motor *M*, furnishes the necessary current of air under the desired pressure (35–40 cm. of water); in the drawing it is seen that the air supply X is divided to supply the two jets of air spoken of.

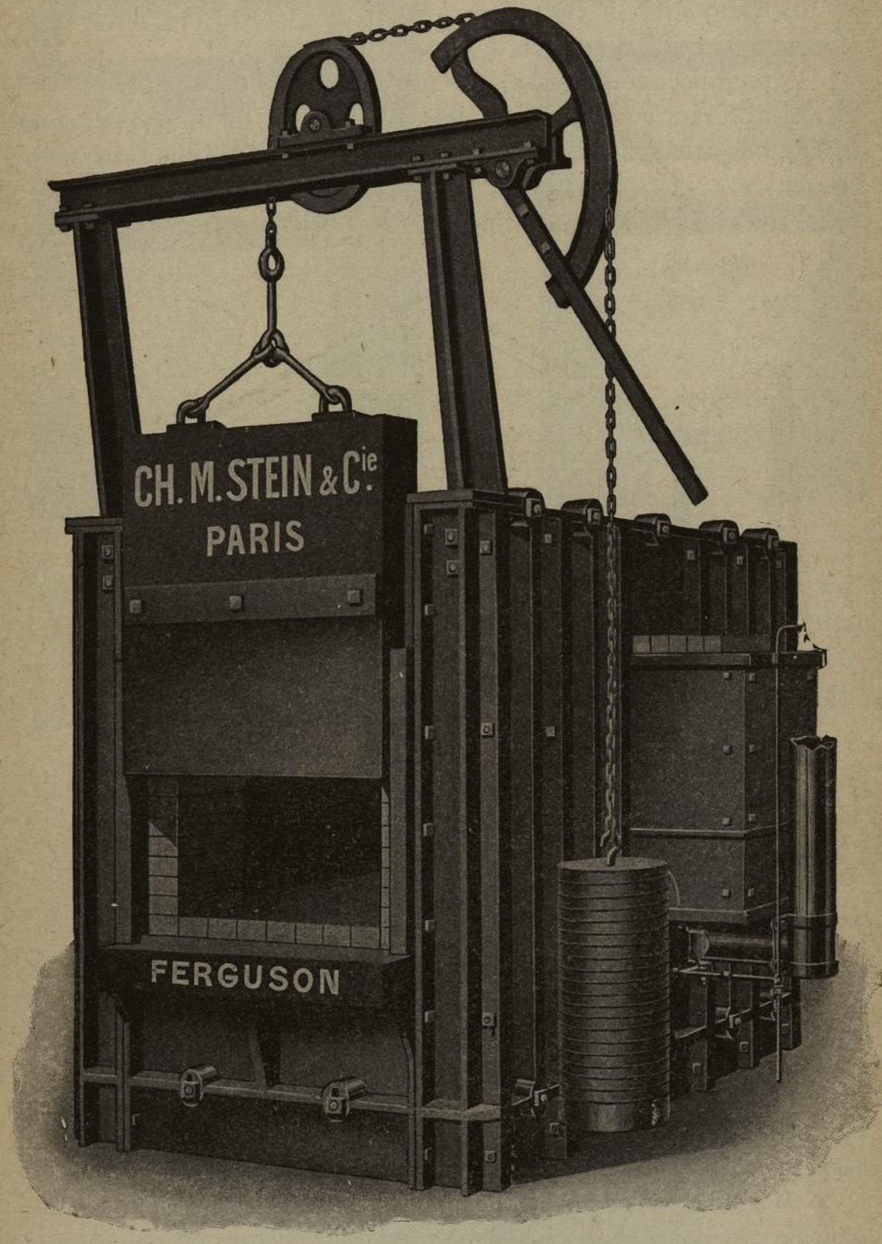


FIG. 94.

The hydrocarbon oil, contained in the reservoir R, reaches the furnace F through the tube U. The pump P serves to fill the reservoir R.

The Ferguson furnaces are constructed in a large number of shapes and sizes, according to the use for which they are intended. Fig. 94 represents one of the types which is best adapted to cementation in boxes, using solid cements. The furnace shown in Fig. 95 contains, besides the chamber intended for the heating of the cementation boxes, two other chambers adapted for the annealing and quenching of cemented pieces.

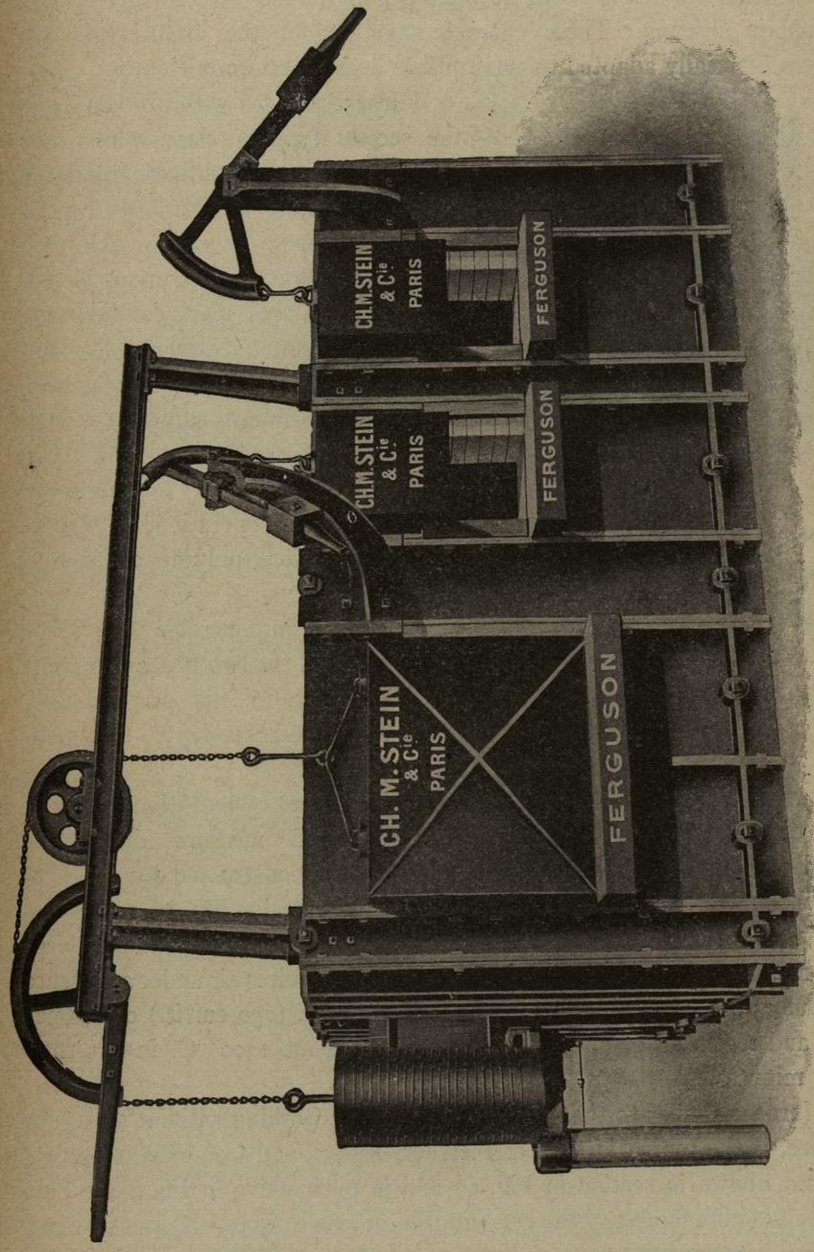


FIG. 95.