made in the refractory wall between the gas producer and the laboratory of the furnace.

When the pieces to be cemented are put in place, in the manner indicated, the retort is covered, carefully luting the edges of the cover so as to obtain perfect closing. Then the plunger *L* is lowered entirely, the tube *D* is screwed to the piece *C*, and the carburizing gas is slowly admitted to the distributor *E* and from this to the retort. The gases of the retort, displaced by the fresh carburizing gas which enters through the distributor *E*, issue through the little tube fixed on the cover *H* of the retort.

In case it is desired to use cements with carbon monoxide as base, which present great advantages, a thin metallic tube is fixed co-axially in the tube *D*, with its longest arm penetrating into the distributing apparatus. This tube passes out from the lowest part of the elbow joint of the tube *D* and penetrates into the interior of the apparatus as far as the distributor of the carburizing gas. The volatile hydrocarbon (benzene, ligroin, etc.) is sent into this tube in the desired quantity, exactly regulated by means of a very sensitive regulator stopcock. Its carburizing action is to modify to the desired extent, according to the rules which I have already pointed out, the specific action of the carbon monoxide which is admitted through the tube *D* into the cementation chamber. Since the little tube carrying the hydrocarbon penetrates through the tube *D* into a region of the retort heated to a temperature (300°–400°) much higher than the boiling point of the hydrocarbon, the latter is already totally in the state of vapor when it mixes with the carbon monoxide.

The velocity of the current of carburizing gas, whether carbon monoxide or another gas, which passes into the tube *D* is indicated constantly by a small apparatus like an anemometer, inserted in the tube carrying the gas. The quantity of gas used is controlled by a meter; for this purpose ordinary illuminating gas meters, of the type called "dry," serve very well.

When the operation has been carried on for a sufficiently long time, with continuous control of the temperature and the composition and quantity of cementing gas which circulates through the retort, the gaseous current is interrupted. The small cover which closes the central opening of the large cover of the muffle is then opened, and the gas issuing from it is quickly lighted; then the large cover is removed and the gas contained in the muffle is allowed to burn. In this way the slight explosion is avoided which the usual carburizing gases would produce if they were lighted after they had mixed with a considerable proportion of air. This being done, all that is necessary is to unscrew the tube *D*, raise the plunger *L* until the terminal cone *M* fits into the hollow of the piece *C*; then the hydraulic cylinder *I* is kept slowly working so as to gradually raise the platform *C, E, F* with the cemented pieces on it. Then a workman, standing above the furnace near to the upper opening of the muffle, takes the cemented pieces as they come near the opening of the muffle and

quenches them in the basin which is also placed above the furnace; if it is desired to harden afterward, she may bury them in hot ashes. All the cemented pieces having been removed in this way, the furnace is ready for a new charge.

The arrangement of the pieces to be cemented in the retort varies with their form and with their dimensions. Pieces of cylindrical form can always be placed "in column" in a manner similar to that described in the example just cited. If the diameter of the objects is small (toothed pinions, drills, rings for ball bearings, etc.), several "columns" can be made in a single charge, but in this case it is well that the pieces be kept in position by rods of iron, upon which the pieces are strung, if they are to be cemented externally (drills, pinions, etc.). For cylindrical pieces to be completely cemented, such as rings for ball bearings, the rods are arranged on the outside of the "column." Pieces of very elongated and irregular form are placed in the retort with suitable supports. Finally, very small pieces are placed in "baskets" formed of iron strips or rods joined together by a network of iron wire. It is well to point out at once that the furnace with fixed cementation chambers, with which we are now dealing, is not well suited for the cementation of very small and very numerous pieces, when used with a gaseous cement. This limitation of the furnace with fixed chambers disappears when it is used for cementing with mixed cement having carbon monoxide as base.

Besides the case just referred to, the furnace with vertical muffles is well suited to the cementation of pieces of considerable dimensions, whether they are single pieces or "bundles" of smaller pieces. This is true even when the pieces or the bundles have very irregular forms or present delicate projections. For pieces of this kind, which are easy to place so as to leave between them large spaces, permitting easy circulation of the carburizing gases, experience shows clearly the uselessness of imparting to the retort any movement whatever, for it would in no wise increase the uniformity of the cemented zone.

A furnace of the type described and of the dimensions represented in the accompanying figures, in which the useful space in each of the two muffles has a diameter of about 45 cm. and a length of about 1.20 m., consumes about 450–500 kg. of ordinary gas-works coke per twenty-four hours when the relatively high temperature of 1100° C. is maintained in the interior of the muffles. For the lower temperatures usually employed, the consumption of fuel is markedly less.

By using gaseous cement with carbon monoxide as base and by working at a temperature near 1000° C., the cemented zones of the thickness usually required for machine pieces (about 1 mm.) are obtained in less than two hours. Counting the time necessary for charging and discharging the pieces, ten cementations per muffle can be made in twenty-four hours. It is seen that the cost of fuel is quite low.

As to the cost of the carburizing gas, that naturally depends on the quality used. In many cases, for example, when gaseous cements with carbon monoxide as base are used, the cost of the cement can be greatly reduced by collecting the gas which issues from the cementation chambers[1] in suitable gasometers and using it again. Before using again, however, it must be subjected to a simple and inexpensive process of purification, varying according to the composition of the gas and the manner in which it has been used. The expense due to wear of the fixed retorts is also quite small, especially when compared with the corresponding expense for the rotating retorts.

Steel retorts, of the kind described, cost from 32 to 40 centesimi (6.4 to 8 cents) per kilogram (3 to 3.5 cents per pound) and weigh, in a furnace of medium dimensions such as described, about 300 kg. (660 lb.). By making a good refractory lining in the space between the steel retort and the refractory muffle, a retort may last from five to eight months when the furnace is continuously heated to 1000° C.

The principal advantages of gaseous cements lie in the ease and certainty with which it is possible to uniformly cement all over pieces of steel of very complicated form and having re-entrant angles and very narrow and deep cavities, such as slits or holes. Similar results can also be obtained with the use of mixed cements with carbon monoxide as base.

Besides these advantages, the use of gaseous cements presents the other great practical advantage, common also to the mixed cements, of not involving, as do solid cements, the use of cementation boxes charged with cold materials. This obviates the disadvantages of the high cost, slow heating, great deformations of the cemented pieces, etc., which are inevitable in cementation in the ordinary boxes.

In cementation with gaseous cements, and especially when use is made of carburizing gases of simple and accurately known composition, such as those with carbon monoxide as base, it is relatively easier to predict the results which will be obtained by working under definite conditions. When the temperature in the cementation chamber is accurately controlled during the whole operation, for example, it is not necessary in the majority of practical cases to make use of control specimens, which are indispensable in cementation carried out with the ordinary solid cements. This necessity of control by means of test pieces immersed in the solid cements is partly due to the irregularity in the action of these cements caused by variations in the compression of the cement on the surface of the steel, differences in the degree of pulverization of the cement, etc. It is also due to the impossibility of knowing, from the temperature of the laboratory of the furnace or of the muffles containing the boxes, the temperature reached at successive intervals of time in the various parts of the charge, since the velocity of propagation of the heat in the mass of the cement varies within very wide limits with variations in the state of division, of compression, etc., of the cement.

[1] In the furnace with vertical muffles which I have described above, the gas which issues from the retorts can easily be recovered by attaching a flexible tube to the exit tube of the gas, fixed, as indicated in the figure, to the cover *H* of the muffles.

The data given in the first part of this volume establish the results which can be obtained under the conditions usually realized in practice, with several of the more important types of gaseous cements; it is useless, therefore, to further discuss this point.

For every new "type" of gaseous cement which it is desired to use, a few preliminary experiments suffice to establish with precision under what conditions of temperature, pressure, velocity of the gaseous current, etc., the cementation must be carried out to obtain a definite result. This result, contrary to the case of the solid cements, can then be always reproduced sufficiently close for the demands of practice.

Many inexact data are found in print as to the carburizing action exercised by various gases on steel. The use of these data might easily give rise to failures in practice. An example is given in the first part of this volume (p. 67)—the results obtained by Bruch on the carburizing action of carbon monoxide. Another is the data contained in a table given by Lake, on p. 233 of his volume: *Composition and Heat Treatment of Steel.*[1] This table is taken by Lake from a publication by J. C. Olsen and J. S. Weissenback of the Polytechnic Institute of Brooklyn, and contains assertions such as the following: pure acetylene gives cemented zones of very slight hardness but, when used mixed with ammonia, it gives very hard cemented zones; methane, both alone and when combined with ammonia, gives very faint cementations; carbon monoxide, even when used alone, gives the cemented zones which are hardest and have the highest carbon content, etc. Now, these statements, as well as many other conclusions which would seem to result from the data contained in the table, are completely erroneous, being contrary to the results of daily practice, and being negatived by the repeated and accurately controlled work by various experimenters reported in the first part of this volume.

As regards the characteristic mode of action of the gaseous cements, we may, in general, consider Mannesmann's observation (see p. 21) as correct, limiting it, however, exclusively to the case of the hydrocarbons. According to this, the gaseous cements are suited only to obtaining superficial cementation. We have seen, however, that the reason for this fact must certainly not be sought in the assumption of Mannesmann that the gases find difficulty in "circulating in the pores" of the metal.

This same observation is, on the other hand, completely inapplicable to the gaseous cements whose major carburizing action is due to carbon monoxide. In fact, these cements can furnish very deep and perfectly

[1] McGraw-Hill Book Co., New York, 1911.

"gradual" cementations even when using them at very high temperatures so as to obtain very rapid penetration; that is, they permit of realizing perfectly the results which, according to Mannesmann, can be realized, but imperfectly, only by the use of solid cements.

As for the rest, as far as regards the mode of action of the various gaseous cements, the detailed explanations and the experimental data furnished in the first part of this volume are amply sufficient for the choice of the cement and of the conditions of operation which are best suited to obtaining definite results.

§ 5. CEMENTATION WITH MIXED CEMENTS

By "mixed cement" is meant a cement resulting from the simultaneous action of two or more cements belonging to two or more of the classes dealt with in the preceding sections.

For example, some of the liquid cements applied as "varnishes" may in a certain way be considered as mixed cements, and especially those in which, besides the fusible salt, there is present (or is formed during the heating) free carbon, which exercises its specific carburizing action in addition to that of the fused salt, though remaining, naturally, in the solid state.

But the only mixed cements which up to the present have found real technical applications on a large scale are those constituted of a solid cement and a gaseous cement, and especially those in which the gaseous carburizing constituent is formed exclusively, or at least mostly, of carbon monoxide. The first part of this volume contains complete data on their mode of action, and interesting practical results which their proper use makes possible. We also indicated there the lines along which, by suitably modifying the conditions of the operation, it is possible to make the characteristics of the cemented zones vary with certainty as desired within very wide limits.

The principal facts just referred to may be summarized as follows:

1. In cementation carried out with solid cements having carbon as their base, the carburizing action exercised on the iron *directly* by the free carbon, by simple contact and without the intervention of gaseous carburizing compounds, is very slight and in any case entirely negligible in industrial practice. This observation, as we have already seen, has been fully confirmed by the more recent researches of Guillet and Griffith,[1] of Weyl[2] and of Charpy;[3] the last scientist even returns to the conclusion, already drawn by others, that the *direct* carburizing action of carbon, in cementation with solid cements, is entirely *null*.

2. In cementation carried out with the solid cements ordinarily used in practice, the *specific* action of nitrogen (assumed and explained in various ways by many experimenters) is *very slight*. Only in cements containing large proportions of cyanogen compounds (alkali cyanides, ferrocyanides, etc.) does the direct action of volatile nitrogenous compounds occur to an appreciable degree.

3. In the cementations carried out with the solid cements ordinarily used industrially, the *direct specific* carburizing action of carbon monoxide is enormously preponderant over every other carburizing action.

4. Pure carbon monoxide cements iron at all temperatures between 700°–1300° C. at which cementation can be effected by any other cement. In fact, the velocity of the cementation (meaning the *depth* reached in a given time by the carburized zone), when working under suitable conditions, is, all other conditions being equal, greatest with carbon monoxide or a mixture in which carbon monoxide can exercise its maximum specific carburizing action.

5. The specific carburizing action which carbon monoxide exerts on iron at a high temperature is due to a series of chemical reactions whose course and states of equilibrium are at present known with precision. Moreover, the conditions of equilibrium of the systems in which these reactions are effected are in general comprised within the intervals of temperature and pressure ordinarily used in industrial practice. As a consequence it is possible to obtain a predetermined result with full certainty by using cements whose activity is due, if not exclusively at least mostly, to the specific carburizing action of carbon monoxide. It is even possible to thus obtain cemented zones in which the concentration of the carbon does not exceed a pre-established maximum limit and varies in a well-defined manner in the various layers of the zone. These definite results, variable at will within quite wide limits, are obtained by varying, according to definite rules, the temperature at which the cementation is effected, the pressure of the carburizing gas and the quantity of the carbon monoxide which in a given time comes in contact with unit surface of the iron or steel.

6. The results which are obtained by using carbon monoxide as cement vary in a well-defined way, all other conditions being equal, with variations in the chemical composition of the metal subjected to the cementation.

7. It is possible to vary the characteristics of the product in a well-defined way and within wider limits by using with the carbon monoxide substances capable of modifying the conditions of equilibrium of the existing chemical systems. These may be gases such as the hydrocarbons, nitrogen, etc., or solids such as carbon in its various forms. They can be made to act together with the carbon monoxide during the whole cementation, or only during a part of it.

8. The cements whose action is due to the specific carburizing action of carbon monoxide permit of obtaining with ease and certainty, with any kind of iron or steel, "mild" or "gradual" cementations, or "cemented zones of the intermediate type," in which the concentration of the carbon is low in the

[1] See p. 122.
[2] See p. 124.
[3] See p. 124.

external layers and decreases slowly and continuously in the successive deeper layers. This is the essential condition for avoiding the dangerous phenomena of brittleness and of "exfoliation" which show so frequently in steel objects cemented by the ordinary industrial processes.

9. The chemical reactions to which the carburizing action of the cements in which the active element is cyanogen is due are at present known only imperfectly, especially as regards their conditions of equilibrium, on which will depend the concentration of the carbon in the cemented zones. It is certain, however, that under practical conditions the states of equilibrium just referred to are strongly displaced in the direction corresponding to high concentration of the carbon passing into solution in the γ-iron. It results that the cyanides, the ferrocyanides and other derivatives of cyanogen, when used alone as cements, always give too "sudden" cementation, or cemented zones in which the concentration of the carbon is excessively high in an external layer of definite thickness and then suddenly and greatly decreases in the next layer beneath. Zones of this type give rise to dangerous phenomena of brittleness and "exfoliation" in the hardened product.

10. The gaseous or volatile hydrocarbons also, when used alone as cements, give too "sudden" cementations. The reasons for this are identical to those for the cements whose action is due to cyanogen or its derivatives.

The experimental proofs and the theoretical explanations of all the above ten statements are given and discussed in the first part of this volume.

On the basis of the facts above given, it follows clearly that those cements should be used in practice whose activity is due, if not exclusively at least mostly, to the specific carburizing action of carbon monoxide. To obtain the best results with one of these cements, with the maximum certainty, it is necessary to satisfy the following fundamental conditions:

1. The chemical composition of the cement must be perfectly *definite* and known with precision.

2. The composition of the cement must be as *simple* as possible.

3. The reactions which take place during cementation, between the various constituents of the cement and between these and the iron or steel, must be simple and lead rapidly, under the conditions most easy to realize in practice, to well-defined states of equilibrium corresponding to definite concentrations of the carbon in the cemented zones. From the theoretical point of view, the cement which best satisfies these conditions is carbon monoxide.

Nevertheless, the concentrations of the carbon in the cemented zones which correspond to the conditions of equilibrium with pure carbon monoxide are in general too low when working within the intervals of temperature and pressure ordinarily desirable to keep to in practice, and when the metal subjected to the cementation is an ordinary carbon soft steel or a steel of low nickel or chromium content. These disadvantages are not presented when using with the carbon monoxide, during the whole operation or during only a part of it, small and well-defined quantities of hydrocarbons or of solid carbon in a definite state of division. Such mixtures fulfill quite well the three conditions indicated above. The cements based on the simultaneous use of free carbon and of carbon monoxide are those best adapted to the greater number of ordinary technical applications, since they combine maximum simplicity in the operations with maximum certainty of reaching perfectly definite results. The principal technical advantages of the "mixed cement" based on the simple simultaneous action of carbon and of carbon monoxide may be summarized as follows:

1. Great "velocity of penetration" of the carburized zone. This fact, although it is not, as many practitioners still believe, the *most important* item of a given cementation process, is certainly very advantageous for many self-evident economical and technical reasons.

2. Great uniformity in the distribution of the carbon in the cemented zones. This easily permits of reducing to a minimum the phenomena of exfoliation of the cemented and hardened pieces.

3. Possibility of regulating (either by "diluting" the carbon monoxide with nitrogen, by limiting the contact of the carbon with the surface of the steel, or, finally, by suitably varying the temperature of the cementation during the operation) the concentration of the carbon in the cemented zone in such a way as to keep it within the limits (varying according to the composition of the steel subjected to the cementation) best suited to obtaining at the same time maximum hardness and minimum brittleness in the carburized layer.

4. Possibility of establishing *a priori* with full certainity the conditions necessary for obtaining a definite result, which can be chosen within quite wide limits and can be obtained with great precision.

5. *Continuous* use of the same carburizing materials (carbon and carbon monoxide), which never become "exhausted" but can be entirely utilized. This permits also of obtaining cementations of any depth whatever, without its being ever necessary to "renovate" the cement.

6. Absolute certainty of not introducing into the steel any foreign substance other than carbon, a condition which does not occur with the greater part of the cementation powders usually employed, containing organic nitrogenous substances, alkali cyanides, ferrocyanides, etc. This presents very great advantages in many cases.

7. Ease in keeping the surface of cemented pieces perfectly unaltered. In many cases this may be most useful, permitting of even dispensing with mechanical work upon the cemented pieces.

8. Possibility of reducing to a minimum the deformations and the variations in volume which the steel pieces undergo as the result of cementation,

and, in any case, the possibility of determining with precision *a priori* the variations in volume just referred to.

9. Ease in obtaining a good "protection" of the parts of the steel pieces which it is not desired to cement.

We have seen in the first part of this volume that normal cementation extends to a small distance from the parts of the metallic surface in contact with the granular carbon, even when the gas can circulate around the pieces with the greatest freedom, and that experiment shows that this distance becomes exceedingly small when the gaseous carburizing mixture ($CO + CO_2$) can circulate around the parts not in contact with carbon only through small channels, opposing considerable resistance to its flow. This is the reason that, working with the mixed cement, efficient "protection" of parts not to be cemented can be obtained when using protecting substances not altogether impermeable to gases, such as lean refractory clay, deposits of copper obtained by "dipping," loose covers of sheet metal, etc.

The form of furnace which, in general, is best suited to the industrial working of the process with which we are now dealing is that with vertical muffles, in which the pieces to be cemented and the solid cement are introduced successively above, while the gas is admitted below. The desirability of such an arrangement was shown in the laboratory experiments on the study of the mixed cement, which were described in the first part of this volume.

Nevertheless, it may at times be desirable to carry out cementation with mixed cement using an ordinary horizontal muffle furnace of the type described in the preceding pages. This may occur especially in two cases: First, when a large equipment of ordinary cementation furnaces with horizontal muffles would be an obstacle to the setting up of new special furnaces. Second, in the quite frequent cases where the pieces to be cemented have special forms, for which it appears, *a priori*, to be advantageous to work in horizontal furnaces.

While, therefore, the vertical muffle furnace presents very great advantages in those cases, most frequent in practice, in which the surfaces to be cemented are surfaces of revolution as, for example, gear-wheels, whether conical or cylindrical, axles, ball-bearing rings, the great majority of ordinary cutting tools, etc., yet the horizontal furnace, on the other hand, may be usefully employed in the less frequent cases of a different nature, for example, in the cementation of rails, sectors, etc.

The apparatus which is best adapted to this purpose will now be briefly described.

Since the gaseous current (ascending or descending) should traverse a layer of heated carbon of sufficient thickness (in general, at least 8–12 cm.) before enveloping the objects, the process with which we are dealing is possible only in furnaces holding rather tall muffles.

The muffle reproduced in the accompanying drawings must be considered

as the lowest which can be practically used. The use of lower muffles would hinder the operations of charging, discharging, etc., while they would be facilitated by the use of muffles having a height even twice that shown. A greater height of the muffle also permits more advantageous proportions to be given to the various parts of the apparatus.

The cementation chamber consists of a retort of cast mild steel, of such form and dimensions that it can be placed inside the muffle of the furnace which it is desired to use. It should fit well, but in such a way that there is at least a centimeter between the upper wall of the retort and the arch of the muffle. Fig. 97 on p. 245 shows exactly the position occupied by the retort in the muffle, in an ordinary gas furnace with natural draft, made by Fletcher, Russell and Co. of Warrington.

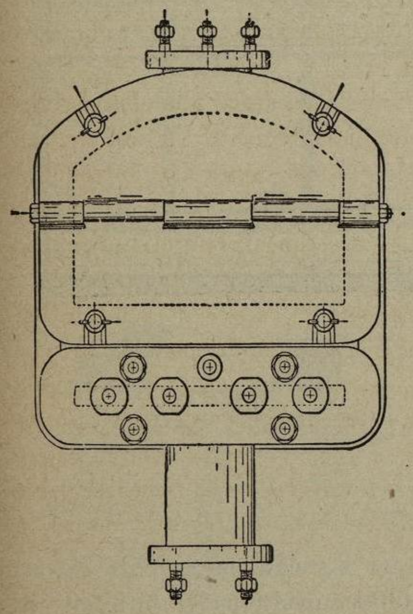

Fig. 132.

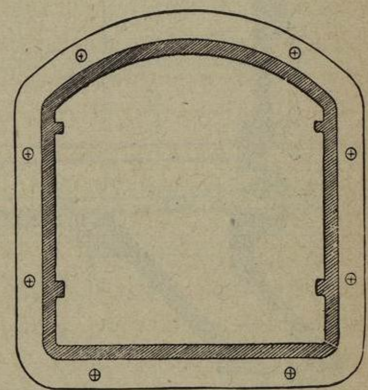

Fig. 133.

As is always advisable in such cases, the preservation of the muffle of refractory material is favored by ensuring that the retort should not be in direct contact with the muffle; this is obtained by interposing between the two, and especially on the floor of the muffle, a layer of refractory clay.

Two pairs of parallel rails, whose form and position are shown clearly in Fig. 133 (transverse section of the retort) and in Fig. 134, are fused on the inside lateral walls of the retort.

An "extension" or "head" of cast iron, shown in longitudinal section in Fig. 134, together with the retort connected with it, is fixed by means of eight set screws and nuts to the flange of the retort, which projects several centimeters from the furnace. This extension carries two channels designed for the charging and discharging of the granular carbon, and two openings, closed by covers fixed with set screws and nuts, as shown in Fig. 132, from the front, with the covers in position.

The cover which closes the upper larger opening is in two parts, connected by hinges, as seen in Fig. 134; this connection is so made as to be easily rendered impermeable to gases by placing a simple layer of the usual packing employed for boilers or steam cylinders. Other similar packings secure the tightness of the two covers set on the extension, and of the connection between the extension and the retort.

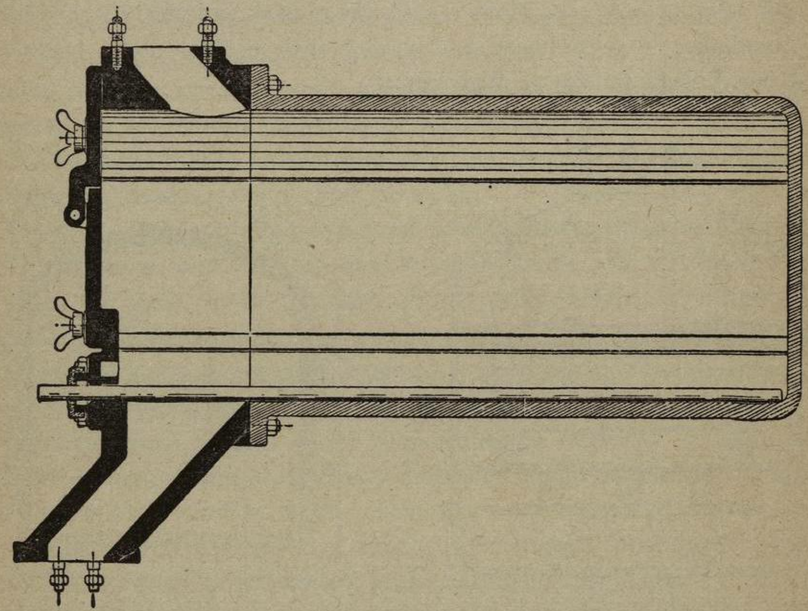

FIG. 134.

Through the lower cover, and by means of stuffing boxes (Figs. 133 and 134), there pass into the retort two iron tubes provided inside the retort with holes about 1 mm. in diameter every 2 cm.

The two closing apparatus represented in Figs. 135, 136, 137 and 138 are fixed with set screws and nuts to the external openings of the channels. Figs. 135 and 136 show the longitudinal section and plan of the closing apparatus which is to be applied to the upper channel of the extension. It consists simply of a steel muff, fixed at one end to a disk which permits of connecting it gas-tight to the channel of the extension, and closed at the other end with a hinged cover. In the wall of the muff, moreover, is inserted a side tube for the exit of the gases from the retort.

The second apparatus, shown in Figs. 137 and 138, consists simply of a steel draw valve to be applied, as in Fig. 137, to the bottom of the lower channel of the cast-iron head of the muffle. The draw can be pressed against

the flange of the channel by means of a screw and stirrup, so that, with the aid of a disk of packing, it is easy to make it properly gas-tight.

The dimensions of the individual parts of the apparatus follow with sufficient precision from the drawings, on each of which is indicated the scale of reduction.[1] A good choice of the proportions of the various parts, and especially of those through which the granular carbon must pass, has great

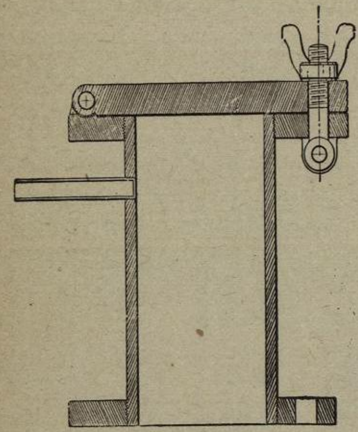

FIG. 135.—Scale 1/3.5.

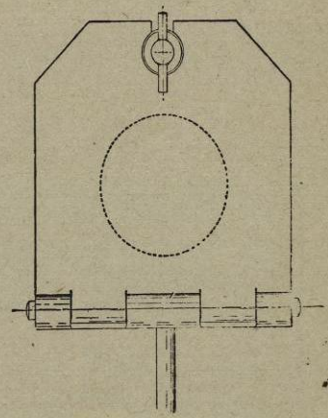

FIG. 136.—Scale 1/3.5.

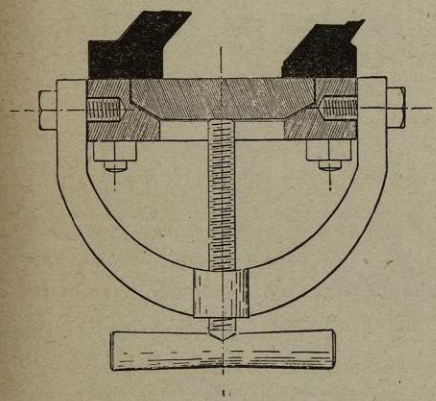

FIG. 137.—Scale 1/3.5.

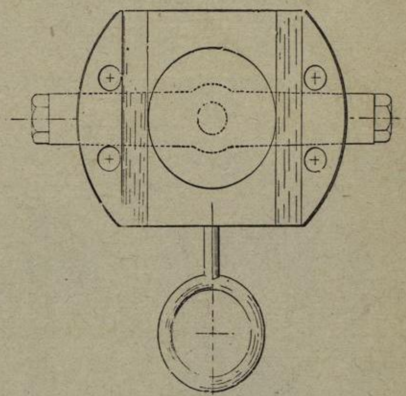

FIG. 138.—Scale 1/3.5.

importance for successful operation. Only an exact knowledge of the physical properties of the granular carbon of various "gradations," acquired after long practice and many unsuccessful trials, has established the proportions indicated in the accompanying figures as best for the special case we are examining.

[1] The scales of the drawings here reproduced do not coincide with those usually adopted, because these drawings (made on a considerably larger scale) were reduced by a photomechanical process.

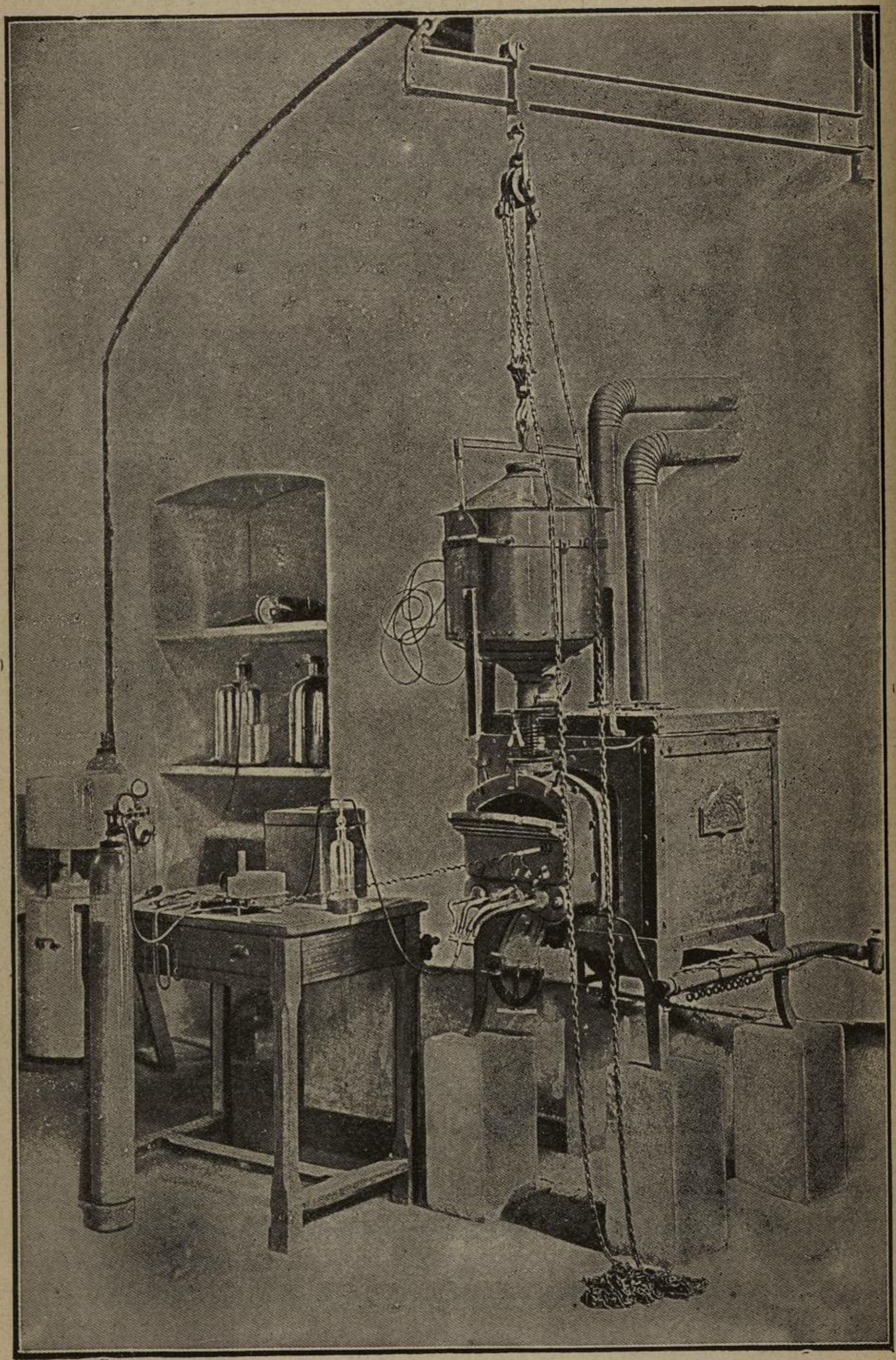

FIG. 139.

The various pieces described, connected in the manner indicated, constitute the whole furnace, shown with other accessories in Fig. 139.

As to the manipulation of the furnace, first of all a rectangular iron frame of slightly smaller dimensions is placed in the retort. This frame, consisting of a framework of T-iron on which is woven a net of iron wire with meshes about 10 mm., is placed in the retort in a horizontal position, resting on the two rails of the retort (see Fig. 133). Its purpose is to prevent the pieces approaching too close to the openings for the admission of gases. Having

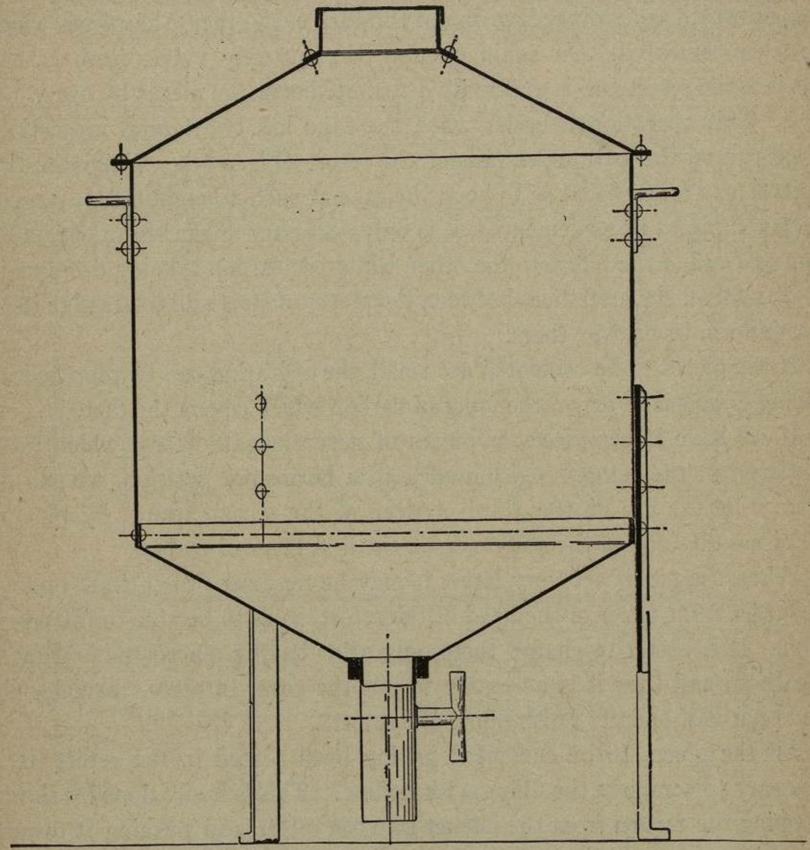

FIG. 140.

then closed the lower valve, the front lower cover and the lower half of the larger cover, the cover of the muff placed on the upper channel of the head of the retort is opened, and the lower exit tube of the receptacle which contains the granular carbon is introduced into the muff itself. This last receptacle, of sheet steel, is shown in section in Fig. 140, which requires no explanation. It is easily manipulated by suspending it by tackle, as shown in Fig. 139.

At the moment of beginning the charging, the apparatus is arranged just as shown in Fig. 139.

In practice, considering the short time between the charging of the furnace and the succeeding discharge, the granular carbon contained in the bucket can be at a high temperature. This is a point of great practical importance.

On gradually opening the butterfly valve which closes the lower opening of the bucket (see Fig. 140), there falls into the retort a certain quantity of granular carbon. This is rapidly spread over the bottom by the aid of an iron rake introduced through the upper half of the larger cover, so as to form a uniform layer reaching 4 or 5 cm. above the wire frame.

There is then placed on this first layer of carbon a second frame, like the first, on which are arranged, so as not to touch each other, the pieces which are to be cemented. On again opening the butterfly valve, fresh carbon falls into the retort and is uniformly distributed over the pieces by use of the rake. This operation is easier when the rake has two lateral projections which run on the two upper rails of the retort (Fig. 133). When the two projections are so placed as to keep the rake at such a height that it can not touch the pieces to be cemented, it is only necessary to run the rake rapidly from one end of the retort to the other while the carbon is being dropped in for it to fill all the interstices between the pieces of steel and to arrange itself in a uniform layer over them.[1]

If the pieces to be cemented are small, the operation can be repeated by placing a second series on the layer of carbon which covers the first.

If we have larger pieces or pieces of very elongated form which must be placed in the retort longitudinally, in a horizontal position, we can do away with the use of the third or even of the second frame, by placing the pieces directly on the second or on the first layer of carbon.

When the pieces are very large, it may be necessary to entirely remove the larger front cover of the head of the retort, so as to be able to introduce them. It is better to charge them only after having placed the first layer of carbon, and then it is necessary to put the cover in place, leaving only the upper half open to finish filling the retort.

All the pieces to be cemented having been placed in the retort, it is necessary to complete the filling with carbon. This is easily done by slowly dropping the carbon from the bucket into the retort and pushing it toward the end by means of the rake resting with its lateral projections on the two rails.

The operation is facilitated if the "blade" of the rake is fixed to the handle with a hinge such as to keep it perpendicular to the handle when pushed toward the end of the retort, but leaving it free to turn 90° when the handle is withdrawn. It greatly facilitates the final filling of the retort, especially when the pieces placed in it are of large dimensions and of irregular forms, to place in the retort a kind of hopper of sheet iron of elongated form,

[1] If the retort is taller, this operation can be made easier by placing the two rails at a greater distance from the pieces to be cemented.

supported on the two rails by means of lateral extensions. When the hopper (which has about the form of a plane slightly inclined toward the end of the retort) has been pushed until it touches the end of the retort, the carbon is slowly dropped on the front end. As the carbon accumulates on the front end of the hopper, it is pushed, by means of the rake, along the surface of the hopper toward its other end, dropping it from here into the retort. If the hopper is gradually withdrawn at the same time, it is easy to completely fill the retort. This operation is naturally easier the higher the retort.

The operation being finished, the upper half of the larger door of the retort is closed; then there is dropped into the retort through the butterfly valve

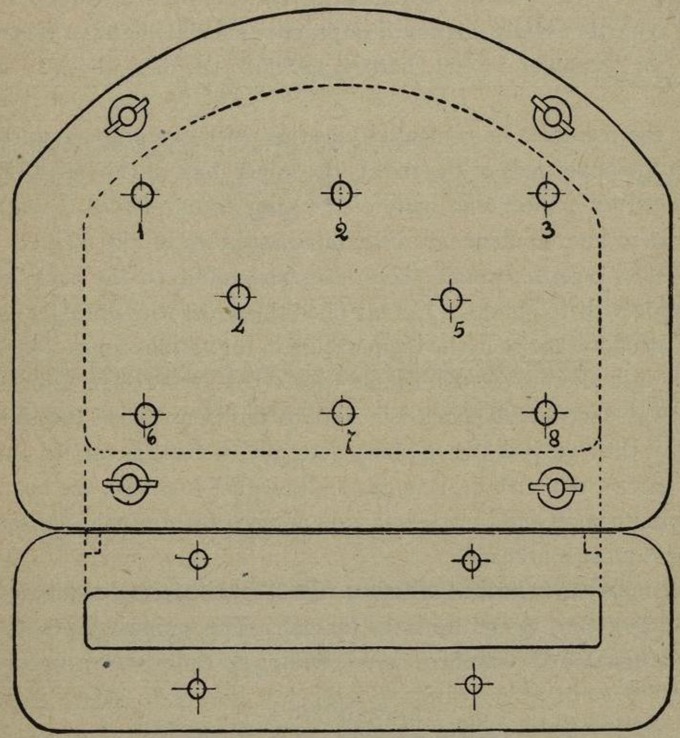

FIG. 141.—Scale, 1/5.

the small quantity of carbon which is still necessary to fill the last space near the front door. Finally the butterfly valve is closed, the carbon hopper is removed, and the door of the upper muff, through which the carbon has been introduced, is closed.

With a furnace of the dimensions and form shown in the accompanying figures, *the total time for the complete charging* of the furnace as just described varies *from six to eight minutes.*

The retort having been charged and closed, there is admitted, by means of the iron tubes connected to its floor (see Fig. 134), a slow current of dry carbon dioxide so regulated that for every square decimeter of surface of steel to be cemented there circulates through the apparatus from 2 to 3 liters of carbon dioxide every hour. The gases issue by means of the tube fixed laterally to the upper muff (see Fig. 135), and may be collected in a gasometer, to be used again.

At the same time the furnace is lighted. It is well to give some precise data as to the course of the heating of the materials in the retort, for the comparison of these with those obtained when charging materials already heated will show the great advantages which can be obtained by working in this latter way. These data as a whole also present great interest as rules for regulating the time of heating in cementation carried out with solid cements in the ordinary boxes, since the specific heats and the thermal conductivities of the solid cements usually employed in practice are but slightly different from those of the "granular" wood charcoal to which the data about to be given refer.

Since the pieces to be cemented, together with the granular carbon, are placed in the upper half of the retort, the upper door of the retort (Fig. 132) was replaced by a sheet-iron plate of the same form, pierced by eight holes each about 10 mm. in diameter, distributed as shown in Fig. 141.

Iron tubes passed through these holes, extending to the back end, and closed inside with iron plugs. Having filled the retort with granular carbon, it was easy to follow the rise in the temperature in the various zones of this carbon by means of a thermo-electric couple (protected by porcelain tubes), whose junction was successively placed in various positions inside the iron tubes.

We give the results of two of many determinations thus carried out. The first was carried out with heating gas under higher pressure; the heating was therefore more rapid and the irregularities in temperature at the various points of the mass more marked.

The temperatures indicated below refer to points on a transverse plane section of the retort 20 cm. from the far end. The various points of this section are designated by numbers corresponding to those shown in Fig. 141.

Experiment I

(*a*) One hour after lighting the furnace

Region	Temperature	Region	Temperature
1	680° C.	5	580° C.
2	400° C.	6	570° C.
3	670° C.	7	less than 300° C.
4	330° C.	8	320° C.

(*b*) Two hours after lighting the furnace

Region	Temperature	Region	Temperature
1	940° C.	5	580° C.
2	800° C.	6	600° C.
3	960° C.	7	300° C.
4	670° C.	8	520° C.

(*c*) Three hours and twenty minutes after lighting the furnace.

Region	Temperature	Region	Temperature
1	990° C.	5	1000° C.
2	990° C.	6	1010° C.
3	990° C.	7	1000° C.
4	1000° C.	8	1000° C.

Experiment II

(*a*) One hour after lighting the furnace

Region	Temperature	Region	Temperature
1	less than 300° C.	5	less than 300° C.
2	less than 300° C.	6	less than 300° C.
3	less than 300° C.	7	less than 300° C.
4	less than 300° C.	8	less than 300° C.

(*b*) Two hours after lighting the furnace

Region	Temperature	Region	Temperature
1	500° C.	5	450° C.
2	500° C.	6	480° C.
3	520° C.	7	420° C.
4	480° C.	8	420° C.

(*c*) Four hours and ten minutes after lighting the furnace

Region	Temperature	Region	Temperature
1	1000° C.	5	1000° C.
2	1000° C.	6	1030° C.
3	1000° C.	7	1000° C.
4	1000° C.	8	990° C.

From the data reported in the preceding tables, it follows most clearly that when the heating of the furnace is pushed rapidly, very great inequalities in temperature manifest themselves between various parts of the cementation chamber, which disappear (at least partially) only when the furnace has remained for a sufficiently long time at a high temperature. Now, the results of many experiments have shown that it is precisely these inequalities in temperature, manifesting themselves to an even greater degree in the usual cementation boxes filled with the ordinary solid cements, that are the principal cause of the great deformations which pieces subjected to ordinary cementation show.

If it is sought to avoid these inequalities in temperature by heating more slowly (as in the second experiment), we fall into the other disadvantage, which is practically a very serious one, of greatly prolonging the time of the cementation. And, moreover, as is seen from the figures, we succeed thus in diminishing only the extent of these inequalities in temperature, but not in entirely eliminating them.

The suitable temperature (900–1100° C.) having been reached, it is kept constant, being determined by a thermo-electric couple introduced from time to time into the retort through two or three openings made at suitable places in the covers and provided with iron tubes like those described in the above experiments.

In Fig. 132 one of these openings is shown in the lower cover. In Fig. 139 two are seen; in one of these (that near one side of the large upper door) is seen the thermo-electric couple, connected with the millivolt-meter.

The cementation having been finished, the screw which presses the slide of the lower opening of the head of the retort (Figs. 137, 138) is loosened, the stirrup which holds this screw is thrown aside, the hopper for the carbon (Fig. 140) is placed under the slide and the latter is opened by pulling the ring fixed in it. In this way, in less than two minutes, there passes from the retort into the receptacle beneath enough carbon to leave the cemented pieces wholly uncovered. The upper half of the larger door of the retort is then opened, or, if the cemented pieces are large, the door itself is removed directly, after first having opened the upper half. In carrying out this operation, the workman must take care to remain at one side of the apparatus, for when the upper half of the door is lowered air penetrates into the retort and forms with the carbon monoxide contained in it a combustible gaseous mixture which ignites and burns.

Having thus opened the retort, the cemented pieces are removed from it and it is at once charged again, using the still hot carbon collected in the hopper.

The removal of the cemented pieces takes, in general, less than two or three minutes, for only when they are of large dimensions and therefore few in number are they removed one by one. In case the pieces are small and numerous they are all removed together from the retort by simply removing the frame on which they were placed. On the whole, an operator who has acquired some practice in the manipulation of the apparatus can easily carry out all the operations for the complete discharging and recharging of the furnace in not more than ten or twelve minutes.

The interval between the dropping of the carbon from the retort and the charging of the same carbon again into the retort, for the successive charge, is hardly sufficient to produce any appreciable cooling of the carbon. Only a layer a couple of centimeters thick which comes in contact with the cold wall of the sheet-iron receptacle is decidedly cooled; the rest of the granular mass, protected by this external zone, which is a poor conductor of heat, does not appreciably cool. This causes the quantity of heat yielded by the granular carbon to the walls of the hopper to be small, so that the average temperature of the mass of granular carbon is not markedly lowered.

Accurate measurements made on the apparatus reproduced in the accompanying figures have shown that the carbon discharged from the retort at a temperature of 1000° C. can be replaced in it for the succeeding charge at a temperature of about 800°–900° C.

If we take into account the fact that only about half of the carbon contained in the retort is removed during the discharge, it is seen that the quantity of heat subtracted from the apparatus, besides that which is necessarily subtracted by the cemented pieces, is very much less than that which is lost in the ordinary processes of cementation, in which not only the cement and the pieces to be cemented but also the cementation boxes are charged cold into the furnace. The immediate consequence of this circumstance is the great rapidity with which the temperature of cementation is reached in the second and all succeeding charges. Thus, in a long series of experiments, cementing at 1000° C. with the furnace represented in Fig. 139, and keeping the pressure of the gas as in the second experiment cited above (in which, starting from the cold charge, the uniform temperature of 1000° C. was reached only after four hours and ten minutes) and recharging the granular carbon at a temperature of between 850° and 900° C. onto the new pieces to be cemented, placed *cold* in the retort, the uniform temperature of 1000° C. was again reached, on an average, in about twenty minutes after closing the retort.

When it is considered that the mean duration of a cementation of the depth usually adopted for machine pieces (0.5 mm. to 1 mm.) does not exceed two hours by this process, even when working below 900° C., and that a total of thirty to thirty-two minutes only is necessary to charge and discharge the furnace and to bring back the temperature to that suitable for cementation, it is evident that more than nine operations can be carried out in twenty-four hours in a small furnace like the one in question. The same furnace would give not more than two runs in the same time and with an equal consumption of fuel, when working with the ordinary cements and with the usual boxes.

If in addition we consider the economy of the cement and the much smaller wear of the fixed retort as compared with that of boxes which must be removed from the furnace at every operation, the great advantages of the new process are still more evident.

The possibility of charging the cement hot, has, besides its marked economical advantage, a great technical advantage, for it eliminates almost completely those inequalities in temperature which manifest themselves especially during the first period, when the cement is introduced cold into the furnace. Such inequalities are the principal cause of the deformations which the metallic pieces undergo during cementation. Every one who has carried out cementation industrially knows how serious and harmful, and often irreparable, are the effects of these deformations.

Besides this, the lack of uniformity in temperature of the materials contained in the cementation boxes in the ordinary processes, even if limited to a part of the total time of the operation, is the cause of great irregularities