water so as to form a dense paste which is spread in a more or less thick layer on the parts of the steel objects which it is desired to protect, and is then dried slowly before introducing these objects into the boxes. Even this means of protection has various disadvantages, among which the most serious is that of the insufficient adherence between the surface of the steel and the mass of dried earth, which very easily flakes off. Moreover, the porosity of the refractory earths is sometimes quite marked and is increased by the thin cracks produced as the result of the heat, so that the protection is often little better than that by asbestos.

To obviate these disadvantages, at least in part, it is sometimes customary to mix with the refractory clay a little graphite, which diminishes the "shrinking" on heating; this has the effect of diminishing the number and extent of the cracks formed in the refractory mass during the cementation.

Sometimes, on account of the special form of the pieces, it is necessary to keep the refractory earth in place by means of a metallic frame.

Grenet has recently recommended putty as the best means of protection.

A very sure means of attaining a practical result consists in leaving on the parts to be protected an excess of metal thicker by 0.3–0.5 mm. than the thickness of the cemented zone which is to be obtained and in then removing mechanically this excess of metal from the steel object after the cementation but before the quenching. It is clear that this method is very long and costly. It is practically applicable only in those cases in which the removal of the excess of carburized metal is exceptionally easy; for example, in the case of cylindrical objects, in which the removal can be effected on the lathe.

Another method, also expensive and applicable in practice only to objects of simple form, consists in "sheathing" the parts to be protected in a sort of case of soft sheet steel, adhering closely to the surface of the piece and of a thickness somewhat greater (from 0.4 to 0.8 mm.) than that of the cemented zone which is to be obtained. After the cementation and the quenching, the thin case, almost totally carburized, becomes brittle and can be easily removed by breaking it with a hammer.

The only case in which this method can be advantageously applied is that in which the piece to be protected has the form of a cylinder with at least one end free. In this case, in fact, protection can be obtained with relative ease by forcing the cylindrical piece into a tube of soft steel, heated to about 400° C. so as to suitably expand it.

Another process, apparently quite simple, is that patented by the works *de Dion-Bouton* of Paris. This consists in producing on the surfaces to be protected a deposit of metallic copper, obtained by simply washing these surfaces with an aqueous solution of copper sulphate, after first carefully washing with alcohol and ether so as to free them completely from the last traces of fatty substances.

However, under these conditions it is very difficult to obtain a continuous deposit of copper; the metallic skin, very thin and not adherent to the surface of the steel, is extremely delicate, so that a somewhat strong rubbing with the cementation powder is sufficient to tear it, which renders almost null the protective action of the copper. This delicacy is the consequence of the process itself of the "substitution" of the iron by the copper of the copper sulphate with which it is obtained. A more adherent deposit of copper can be obtained electrolytically by making the surface which it is desired to protect act as cathode in a bath of copper sulphate. The process is then more expensive and less simple, but gives good results, and may be applied with advantage to the partial protection of pieces of very complicated form.

In any case, however, the protection with copper can be adopted in usual practice only for cementations carried out at a temperature lower than 950° C. In fact, cementing at higher temperatures, the risk is run of reaching at any moment and at any point of the boxes the temperature of fusion of the copper, which is 1083° C. for pure copper kept out of contact with air but lower when the copper contains small quantities of foreign substances or of oxide.

The objects to be cemented are sometimes of such form that protection of the surfaces which must not be carburized can be obtained easily by simply placing them so that they touch each other along those surfaces. Such, for example, is possible in the case of a series of cylindrical gear wheels of the same diameter, which, when placed in a column surrounded by the cement, are cemented only in the toothed zone.[1]

§ 3. CEMENTATION WITH LIQUID CEMENTS

Leaving aside the use of fused cast iron as a carburizing material, which has been proposed several times but which at present is not applied, the only cements used in the liquid state consist of pure salts or of saline mixtures. Of these carburizing salts, the only ones commonly used are the simple or complex salts of hydrocyanic acid—the alkali or alkaline earth cyanides, the ferrocyanides and the ferricyanides.

Cementation with the cements just referred to can be effected by two

[1] We have already had occasion (see p. 57) to refer to attempts to find substances capable of impeding the carburization of definite regions of the surface of the pieces subjected to cementation.

Various references to the possibility of impeding locally the cementation by the use of definite substances ("anti-cements"), possessing specific "protective" properties, are found here and there in the literature. [See, for example, a note of Lecarme, in the *Revue de Métallurgie*, Vol. II, 1905 (*Mémoires*), pp. 516–525.] But thus far there have not been published precise data on the composition and properties of these substances, the precise knowledge of which would have, evidently, great practical importance.

clearly distinct processes, both furnishing only very thin cemented zones (in general not more than one or two tenths of a millimeter thick) of high carbon content. In other words, these cements are always very "sudden" or "quick."

The first process consists in immersing the objects to be cemented in a fused bath of the salt or of the carburizing saline mixture.

The second process consists in spreading over the surface of the object which it is desired to cement a mixture of the finely pulverized carburizing salt combined with other substances capable of giving to the mass sufficient fluidity and adhesiveness; then heating the piece thus prepared, for some minutes at bright red heat, generally in a simple forge fire.

The processes of both the first and the second group find useful application only when there is required in the cemented piece a high degree of hardness, and when it is not necessary to obtain those mechanical properties (resistance to shock, resistance to compression, etc.) which are incompatible with very thin carburized zones having a sudden decrease in carbon content, such as are obtained with liquid cements.[1]

The processes belonging to the first group may also be applied advantageously when it is essential to avoid as much as possible the deformations of the pieces during cementation and quenching, and to maintain their surface unchanged. Such is, for example, the case of engraved steel plates for printing.

It is easy to understand that the action of the liquid carburizing mass on the surface of the steel is considerably more uniform than that of a solid powdery mass, such as the solid cements, and than many of the gaseous cements now frequently used in practice. The latter, being gaseous hydrocarbons or the vapors of volatile hydrocarbons, decompose during the cementation, depositing thick layers of carbon in powdery or spongy masses on the surface of the objects.

As to the deformation of the pieces, it is known to be due especially to lack of uniformity of temperature either during cementation or more especially at the moment of quenching. But it is well known that the best way to uniformly heat a metallic piece is to heat it in a liquid bath kept at the desired temperature.

It is clear, therefore, that cementation *by immersion* in a fused carburizing bath is the process which is most suited to giving the best results.

The furnaces adapted to cementation by this process are, in general, quite simple, since there is no need of as exact and uniform heating of the laboratory of the furnace as with furnaces designed for operating with solid cements.

In fact, the fluidity and uniform temperature of the mass of the liquid cement are assured by the simple movements of heat convection, and overcome inequalities due to the more or less irregular way in which combustion

[1] We have seen (see p. 21) that Mannesmann had already made this observation.

may take place. It follows that in cementation with liquid cements the use of furnaces burning solid fuel is without such serious disadvantages as make its use difficult in other processes of cementation, such as the inequalities in

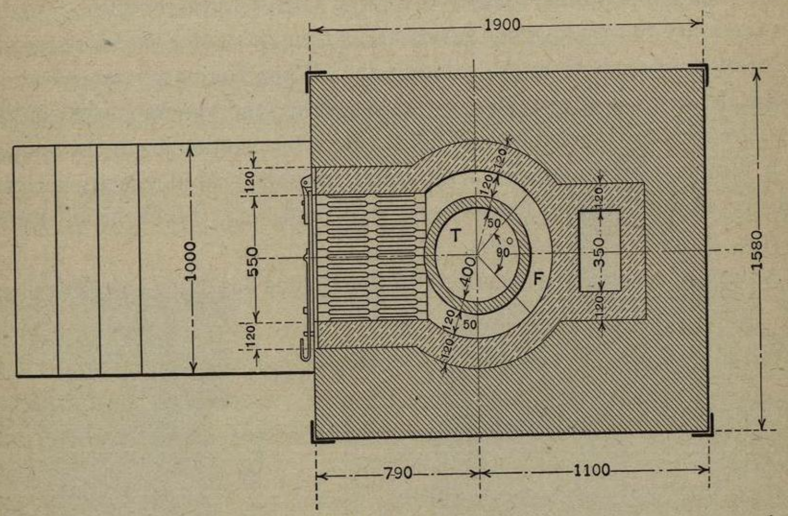

FIG. 121.

the temperature of the laboratory and the danger of waves of high temperature.

Notwithstanding this, however, the use of furnaces burning solid fuel is

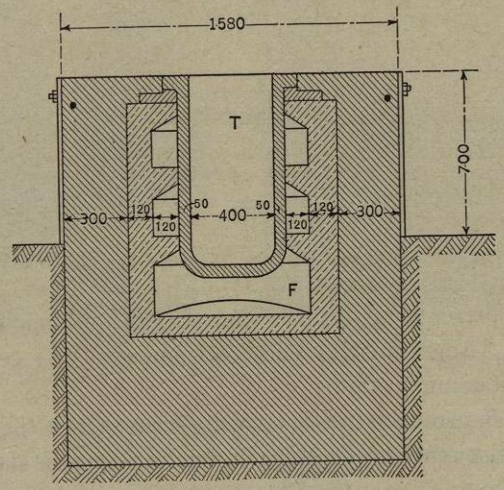

FIG. 122.

not widely diffused, even for using liquid cements, on account of the considerable time necessary to light them and set them in operation.

In almost all the furnaces designed for cementation with liquid cements *by immersion* the carburizing mass is kept fused in a crucible of cast iron or cast steel, of form and dimensions varying according to the shape and size of the pieces to be cemented, and heated from below or around the sides.

Most of these furnaces are similar to those usually employed for heating pieces to be tempered in a bath of lead or of salts. In cementation, however, it is necessary to provide good hoods and strong drafts for the more rapid removal of the vapors from the saline bath. When the bath contains considerable proportions of cyanides or ferrocyanides, the vapors consist of these salts, are strongly poisonous, and constitute a serious danger to the operator.

A furnace for cementation with liquid cements, heated directly with solid fuel, is shown in the figures 121, 122 and 123, taken from Reiser's volume, *Das Härten des Stahles.*

A furnace constructed according to these plans has given excellent results.

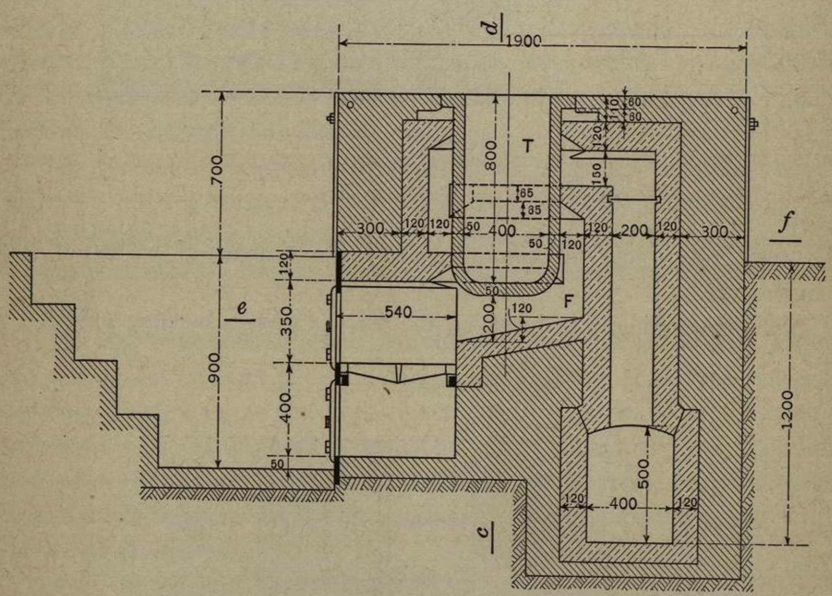

FIG. 123.

Fig. 124 represents a furnace heated with illuminating gas, constructed by the "American Gas Furnace Company," for cementation in a bath of fused potassium cyanide.

The burners *B*, arranged in two opposite series, direct the flames into the space between the refractory lining of the furnace and the steel crucible (shown separately, in *O*, near the furnace) in such a way that, whirling in this space, they envelop directly only the refractory material and not the crucible. The latter is heated, therefore, only by radiation, and is in part shielded from the strongly destructive action of the flames and from local superheating. The products of combustion issue from the laboratory through the flue *F*, which directs them into the large elbow-bend *H*, which leads them to the

chimney. In this way there is produced in the flue *H* a strong draft toward the chimney, and since the flue *H* communicates at its lower end with the sheet-iron chamber *E*, which entirely covers the upper opening of the bath of fused potassium cyanide, all the poisonous vapors which are evolved are rapidly drawn toward the chimney as they are formed.

The following figure (Fig. 125) represents another illuminating gas furnace made by the same firm for the same purpose and on the same principles as the

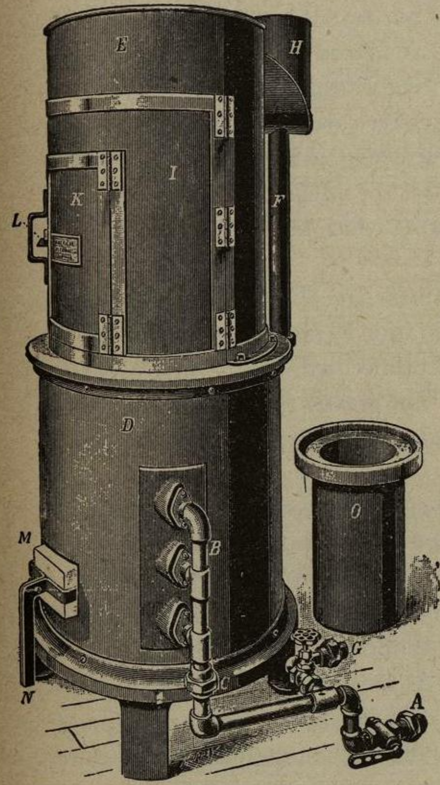

FIG. 124.

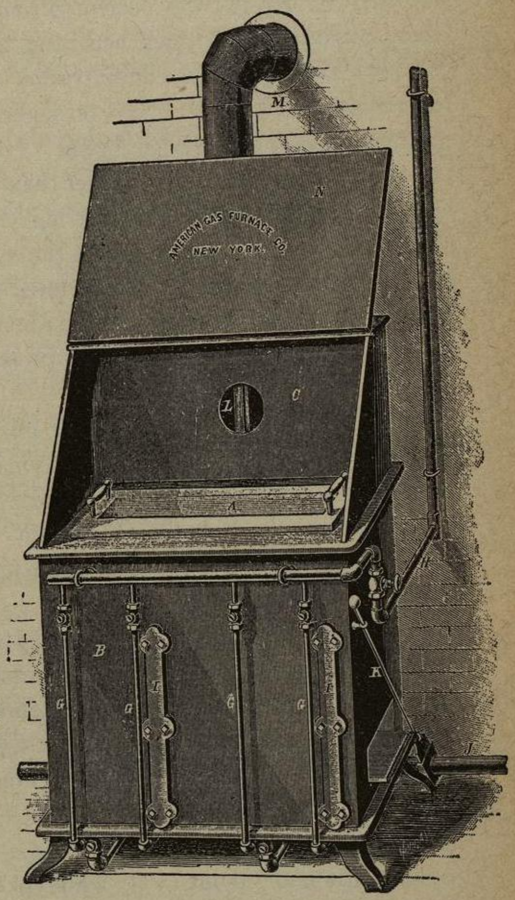

FIG. 125.

preceding one, but of a form adapted to the cementation of steel plates. To this end the crucible has the form of a rectangular prism, and since with a crucible of this form the circulation of the gases of combustion is more difficult and less regular, the four burners can each be regulated independently of the others, and each directs gas and air into the combustion chamber in the form of numerous small jets. In this furnace, also, the poisonous gases are drawn off in the same way as described for the preceding furnace.

The substance most frequently and almost exclusively used as liquid cement for cementation *by immersion* is potassium cyanide. In general, the pieces to be cemented are immersed in the already fused bath, kept between 850° and 900° C., and they are left in it from three to fifteen minutes, according to the depth of cementation desired.

If it is a question of pieces of medium size, say 1/2 to 3 kg. (1 to 6.5 lb.) and of not too irregular forms, the rule can be followed to immerse the pieces cold in the bath, and remove them when their temperature has exceeded 850°–880° C. In this way cemented zones of uniform thickness are obtained, from 0.03 to 0.10 mm. thick, according to the temperature and the length of the cementation. The concentration of the carbon reaches, near the surface of these pieces, 0.9% or higher—sufficient to render them, after quenching, inattackable with the file. It is not advisable to try to obtain with this process cemented zones deeper than 0.15 to 0.20 mm., by prolonging the operation or carrying it out at a higher temperature, since there are then obtained cemented zones in which the excessive concentration of the carbon and its sudden variations give rise, after quenching, to intense brittleness and exfoliation. It is also necessary to remember the intensely poisonous properties of vapor of potassium cyanide—properties which render this process very dangerous.

Many other fusible carburizing mixtures have been proposed for use in place of the potassium cyanide in cementation *by immersion*, but, as far as I have personally been able to determine, I believe that none of these presents any advantages over potassium cyanide. The greater part of these mixtures have as base alkali ferrocyanides and ferricyanides, frequently mixed with potassium bichromate.

Besides the cements acting in the state of complete fusion, like potassium cyanide, some *partially* fusible cements have been proposed, to be used in an analogous manner. In the many mixtures of this kind repeatedly proposed, the infusible constituent is generally carbon in its various forms, such as *coal*, *coke*, etc., while the fusible portion is formed of salts such as alkali cyanides, ferrocyanides, carbonates, etc. As an example the mixtures indicated in the German patent No. 237492 (Kl. 18c. Gr. 3, 1911), consist of sodium carbonate (about 15%), while coke and calcium carbonate constitute the infusible portion.

The variety of mixtures proposed for cementation by the second process is considerably greater; using these "*carburizing varnishes*," the conditions which the mixture must satisfy are considerably more difficult of realization than those for a fused bath. In fact, besides possessing efficacious carburizing properties, the "*varnish*" cement must adhere well to the surface of the steel, even during the heating; it must not burn easily; and after the ignition it must be removable without too much difficulty from the metallic surface, leaving it as smooth as possible.

The simplest of the cements to be used by sprinkling over the surface of the pieces to be cemented is finely powdered potassium ferrocyanide. It is sprinkled on the piece to be cemented heated to redness; the piece thus prepared is again placed in the forge fire and the heating is continued until all the ferrocyanide is melted; then the piece is quenched in water. There are used in the same way various mixtures of potassium ferrocyanide with potassium cyanide, potassium bichromate, or ammonium bichromate.

Even without pulverizing the carburizing mixtures to a very fine powder, good results can be obtained by working as follows The piece to be cemented, first well polished, is heated to about 800° C. and immersed in the powdered carburizing mixture, turning it several times until it is well covered with it; then it is again heated to 800° C. and again immersed in the powder. The operation is repeated until the cement forms on the piece a compact layer of sufficient thickness. In general, two heatings suffice. Then the piece is heated until the cement melts, and is quenched at about 800–850° C.

In all cases it is necessary to take care that during the heating which precedes the first immersion in the carburizing powder there is no oxide formed on the surface of the steel which would hinder the succeeding cementation. This can be assured by not heating too intensely and, when working in a forge fire, by carefully protecting the steel by pieces of coal or even by means of an iron tube from the direct action of the air blast, which, in any case, must be kept as gentle as possible.

Among the mixtures proposed for use as "*varnishes*," containing infusible constituents, together with the fusible ones, we may cite the following:

(*a*)	Powdered potassium ferrocyanide	2 parts
	Powdered potassium bichromate	1 part
	Dextrin paste (as much as is necessary to obtain a pasty mass).	

This cement, very rich in potassium ferrocyanide, is dangerous on account of the violent poisonous action which it exercises if it comes in contact with even slight scratches in the skin. It is therefore necessary for the worker using it to protect his hands with rubber gloves.

(*b*)	Potassium cyanide	5 parts
	Sodium borate	2 parts
	Potassium nitrate	2 parts
	Lead acetate	1 part

(*c*)	Animal charcoal	20 parts
	Horn filings	6 parts
	Potassium nitrate	8 parts
	Sodium chloride	40 parts
	Glue	5 parts

These two mixtures are used in the state of powders in one of the ways indicated above.

(*d*)	Calcined horn scrapings	16 parts
	Cinchona bark	8 parts
	Yellow prussiate of potash	4 parts
	Potassium nitrate	2 parts
	Salt	4 parts
	Black soap	30 parts

The ingredients are mixed in a mortar, forming a paste, which is then dried. To use it, it is diluted with water until it forms a dense liquid which is spread by means of a brush on the objects which it is desired to cement.

It is easy to find a large number of recipes similar to these in manuals on case-hardening and cementation. The more complicated ones are, in general, not worth more than the simpler ones which I have cited above. The cemented zones which are obtained with cements used as "*carburizing varnishes*" do not exceed, in general, a thickness of 0.05 to 0.15 mm., and show individual characteristics entirely similar to those of the zones obtained with liquid cements used "*for immersion;*" their uniformity in the various regions of the cemented surface is, however, considerably less.

§ 4. CEMENTATION WITH GASEOUS CEMENTS

Only within the last four or five years have the processes of partial cementation of steel based on the use of gaseous carburizing substances been generally applied. Before then they may be considered as having been limited, save for a few rare exceptions, to very deep cementations, more than 20 mm. thick, such as those on armor plates.

If we leave aside these special cases, it may be said that the technical applications of cementation with gaseous cements have developed simultaneously with the studies which cleared up their true mode of acting; that is, within the last four or five years.

The first part of this volume has already dealt with the properties of the various gaseous cements, their various modes of acting, the characteristics of the various types of cemented zones which can be obtained with them, and with the great variety and the certainty of the results which a proper use of these cements assures. The information thus set forth contained all the data for properly performing cementation with gaseous cements, both as regards the choice of the cement in relation to the composition of the steel to be cemented, the type of cemented zone which it is desired to obtain, and the most suitable conditions of temperature, pressure, velocity of the gaseous current, etc., which it is necessary to use to cement a given steel with a given gaseous cement to obtain a certain desired result.

In the present chapter we will limit ourselves, therefore, to making brief reference to the apparatus used in practice for cementation with gaseous cements, together with a summary of the methods used to produce "typical" gaseous cements whose carburizing action is well defined and exactly controllable.

Of the few types of furnaces for cementation with gaseous cements at present used in plants of considerable importance, I shall refer only to two, with which I have been able to experiment personally for a long time.

The first is made according to the designs of Machlet by the "American Gas Furnace Co." of Elizabeth, New Jersey, United States of America.

The complete equipment comprises two separate parts: the cementation apparatus proper and the apparatus for the production of the carburizing gas. We shall see shortly, however, that the cementation apparatus may also be used with other carburizing gases than that proposed by the inventor. At any rate, I shall briefly describe both apparatus.

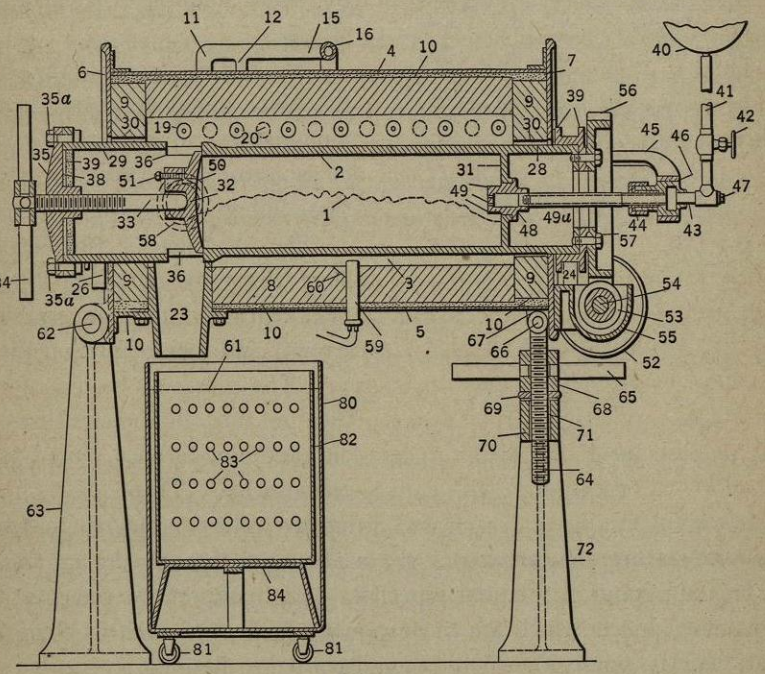

Fig. 126.

The Machlet cementation apparatus, a longitudinal section of which is shown in Fig. 126, consists essentially of a furnace laboratory in the form of a cylinder placed horizontally. In the interior of this, and placed coaxially with it, is the cylindrical steel crucible 2, whose ends protrude from the furnace (leaving a small space between the steel walls and the circular openings made in the two ends of the laboratory) and rest on two pairs of rotating rollers. The crucible, which constitutes the cementation chamber, is kept slowly revolving during the operation by means of the toothed wheel 56, fixed at one of the ends and engaging with the endless screw 53, controlled by a chain drive.

In the upper part of the laboratory of the furnace there are gas burners 19–20, arranged alternately in two series along two generatrices of the cylindrical body of the furnace, as indicated in Fig. 127, in transverse section.[1]

The illuminating gas is burned by air under pressure and the flames, circulating in the space between the refractory lining of the furnace and the walls of the retort, heat the latter uniformly to the desired temperature.

In the retort are two steel disks, 31 and 32, arranged in such a way as to retain the objects to be cemented, placed between them, in that part of the retort which is heated uniformly to the temperature suitable for the cementation. The two disks are traversed at their center by two tubes, one for the entrance of carburizing gas into the retort and the other for the exit of gas.

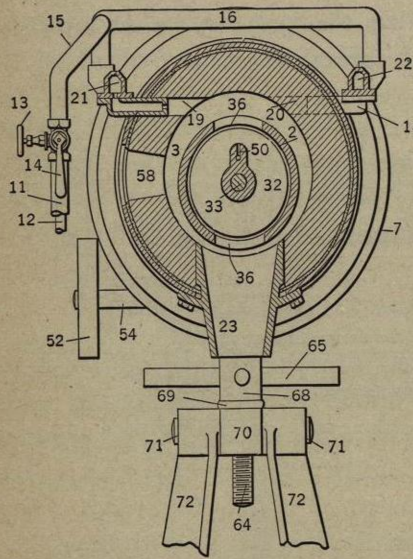

Fig. 127.

The metallic parts of the apparatus which might be heated to a high temperature are protected by linings of asbestos and of fire-clay; some of these linings are seen in Fig. 126.

The charging of the furnace is done easily by removing the door 35 (kept in place by simple set screws), and together with it the disk 32. The pieces to be cemented are then put into the cementation chamber, and the furnace closed for the cementation. Then, slowly revolving the retort 2, heated to the suitable temperature, the carburizing gas is circulated through the apparatus.

This apparatus is adapted especially well to superficial cementation of very small objects which are to be cemented all over, such as chain links, small buckles, small axles, bolts, threaded cutting dies, etc.

In fact, it is quite difficult to cement well objects of this kind with other apparatus, in which it is necessary to surround them carefully with solid cement, or to place them on special supports in such a way that their surface may be totally enveloped by the carburizing gases, when gaseous cements are used. In both cases the operations are much longer, and therefore more costly, than they are with the Machlet furnace, where the objects may be rapidly piled in, without special placing.

The Machlet furnace is less advantageous for the cementation of large pieces, especially when they must be protected from carburization at parts

[1] This apparatus is protected by patents in the majority of countries. The drawings are from the German patent 191394 of 1907 (class 18c.).

of their surface, or when two of their dimensions are exaggerated with respect to the third.

In fact, protection of the parts which must not be cemented cannot be efficaciously obtained in the Machlet apparatus, either by using layers of refractory earth or by means of layers of electrolytic copper, for none of these protective substances resists the repeated shocks which each of the pieces charged into the retort receives from the other pieces by the rotation of the retort, and their continually rolling over each other. It is necessary, therefore, to use in this case one of the two quite costly and difficult processes which I have already described (see p. 278), either protecting by "cases" of steel or by a layer of excess metal to be mechanically removed after the cementation and before quenching.

In various cases, it is true, it is possible to collect the different pieces into "bundles," held together by means of straps and screws, so that they shall touch each other along the surfaces which must be protected from the action of the carburizing gases. But the necessity of making "bundles" of considerable dimensions, so as to reduce to a minimum the number of the pieces forming the ends of each bundle (which, as is evident, have no protection) makes the rotation of the cementation chamber useless, and causes other disadvantages.

If we except the cases in which the pieces to be cemented are of approximately spherical or very elongated cylindrical form, in which cases the pieces "roll" easily over each other during the rotation of the retort, the very large pieces undergo, by the rotation of the retort, successive "falls," which result in harmful shocks against each other and against the walls of the retort. The damage produced by these shocks is evidently more serious the more irregular the form of the pieces and the more delicate their outline.

If the pieces have a "flat" form, they end by arranging themselves in the retort in such a way that one of their faces lies on the wall of the retort and slides along it, always adhering to the wall of the retort and never subjected to the desired degree of carburizing action of the circulating gases. Such is the case with disks for king-pin bearings, cups for ball bearings, sectors, keys for dies, etc.

In these cases it is sometimes possible to make up the objects to be cemented into bundles of large dimensions having approximately the form of very elongated cylinders; these are placed with their axes parallel to that of the retort and roll regularly during its movement. The objects in question can also be fastened to other suitable objects which modify, so to speak their form, making the rolling in the rotating retort easier.

Whichever of these expedients is adopted, however, we always have the disadvantage of markedly increasing the weight of the object to be cemented. When it is desired to use supports or bundles, the rotating cementation chamber becomes practically useless.

The Machlet furnace, used for the cementation of small pieces under the conditions referred to, gives excellent results and permits of cementing in very large numbers pieces which, by reason of their small size and low price, could not be conveniently cemented by other methods. In these cases the complete treatment has been made still more easy and economical by the use of ingenious apparatus for automatic tempering, devised and made by the same firm which manufactures the Machlet furnace.

In the large Machlet furnace the available space in the cylindrical retort is 120 cm. long by 38 cm. diameter. In the smaller furnace made by the "American Gas Furnace Co." this available space is 75 cm. long by about 18 cm. diameter.

The manufacturers guarantee that the furnace of small model may be used for the cementation of pieces up to 15 cm. in diameter and 50 cm. in length, with a consumption of about 10 cubic meters (350 cu. ft.) of illumi-

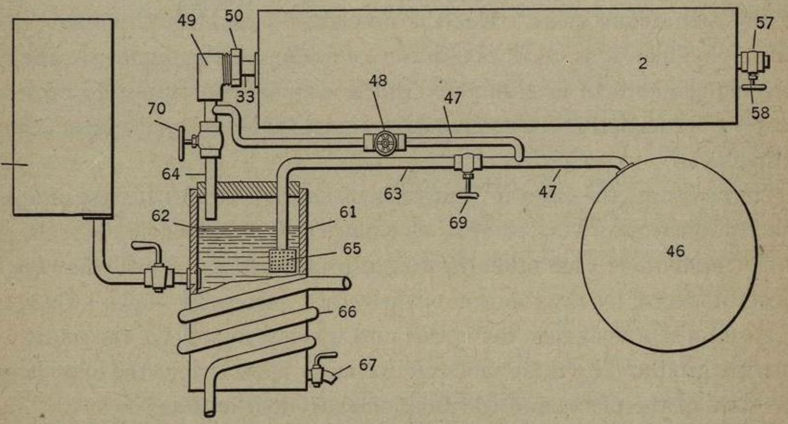

FIG. 128.

nating gas per hour. The firm does not say what depth the cementation is designed to reach in one operation, but it is to be supposed (and experience confirms this) that this depth is about the average ordinarily required for machine pieces; that is, from 0.7 to 1.2 mm. The retort of this small furnace costs little more than 100 lire ($20). It is said to last for about 400 hours of heating under the above conditions. The larger furnace consumes about 15 cubic meters (525 cu. ft.) of illuminating gas per hour. Its retort costs about 250 lire ($50) and also lasts, on an average, about 400 hours.

The apparatus which the "American Gas Furnace Company" constructs for the production of the carburizing gas necessary for the operation of the Machlet furnace is also patented. It is based on the idea of "diluting" the carburizing vapors of oils of various densities, petroleum, etc., with an "inert gas" which acts as a "vehicle" for the carburizing gases, carrying them into the cementation chamber, and preventing their forming a deposit of carbon

by their decomposition at the high temperature of the cementation. This deposit might be so abundant as to obstruct the tubes and the interstices through which the carburizing gases must circulate.

A diagrammatic section of the apparatus is reproduced in Fig. 128, taken from the German patent No. 236007 (Kl. 18 cs. Gr. 3, 1911).

The receptacle 61 contains the carburizing liquid whose vapors are to be carried into the cementation chamber, the rotatory retort 2, through the action of the inert gas coming from the receptacle or generator 46. The inert gas bubbles through the liquid 62, reaching the latter through a distributor 65, which admits it into the liquid in the form of small bubbles. The carburizing liquid can be heated by means of the spiral 66 so as to increase at will the proportion of its vapors which, all other conditions being equal, are carried by the inert gas into the cementation chamber. To regulate with greater precision and within wider limits the proportion of the carburizing vapors carried by the inert gas into the cementation chamber, use is made of the connecting tube 47 and the stopcocks 48 and 49, arranged as indicated in the figure. By suitably regulating these, it is possible to modify at will the relation between the volume of inert gas which reaches the cementation chamber after having bubbled through the carburizing liquid and that which reaches it directly without carrying carburizing vapors; in this way it is clear that it is easy to regulate with great precision the amount of the carburizing vapors which reach the cementation chamber with a given volume of the inert gases.

The quantity of carburizing liquid contained in the receptacle 61 is kept constant by the reservoir 68, connected to it by an easily regulated stopcock.

The same patent just referred to also claims, inversely, making the carburizing gas bubble through a liquid in the receptacle 61 capable of developing inert gases, adapted to diluting the carburizing gas which reaches the cementation chamber 2. As a liquid capable of developing an inert gas, the patent names ammonia water. I do not know whether this second procedure has found practical application.

In the apparatus made by the "American Gas Furnace Co." the *inert* gas is producer gas.

In general, one gas generating apparatus is sufficient to furnish the cement for two cementation apparatus.

As to Machlet's choice of the composition of the carburizing gas we have seen on p. 184 that the most efficacious "vehicle" for the diffusion of carbon into the solid steel is carbon monoxide, and that nitrogen, hydrogen and other inert gases produce this diffusion only to a very small and practically negligible extent. We have also seen and given the very simple theoretical reasons why hydrocarbons are very "sudden" cements and shown that this characteristic is profoundly modified when they act in the presence of carbon monoxide. This modification may, with increase in the proportion of the carbon monoxide, become so marked as to produce "mild" cements, whose "intensity"

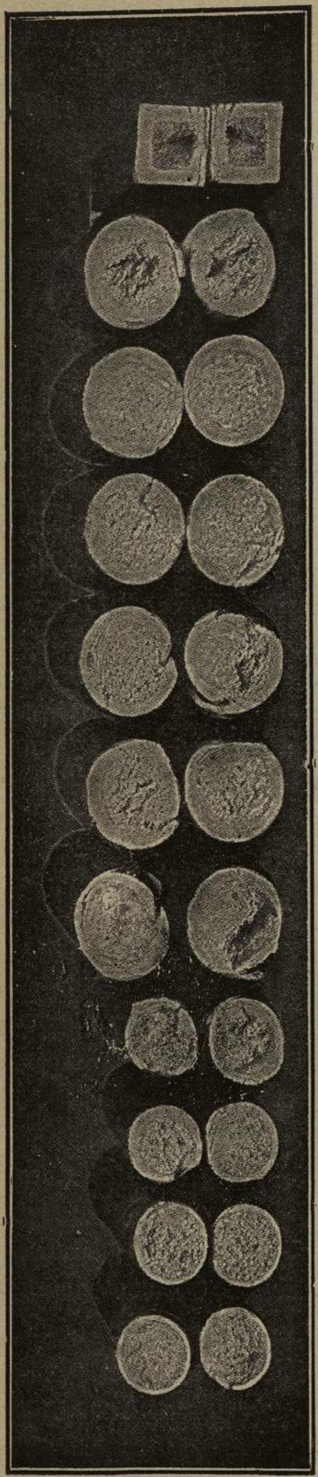

Fig. 129.

can be regulated when the concentration of the carbon monoxide is such that it plays the major part in the carburizing action of the gaseous mixture. The hydrocarbon then intervenes only as a modifier of the conditions of equilibrium of the system carbon monoxide-carbon dioxide-carbon in solid solution in the γ-iron. On these conditions of equilibrium depend the concentration and the distribution of the carbon in the cemented zone. From these known facts it can be deduced *a priori* that the action of the cement proposed by Machlet, in which the *inert* gas does not contain such a strongly preponderating quantity of carbon monoxide as is necessary to radically modify the specific carburizing action of the hydrocarbons, must be entirely similar to that of the hydrocarbons used alone. The use of this cement, therefore, can show no other advantage, as compared with the simple hydrocarbons, than that of producing a smaller deposit of pulverulent carbon from the decomposition of the carburizing gas. This last advantage, which certainly has great practical importance, is obtained equally well with the gaseous cements with carbon monoxide as base; these, however, present the far greater advantages of furnishing "gradual" cementations which can be regulated with precision and certainty, even as regards the concentration and distribution of the carbon, and of preserving the efficacy of "penetration" of the carbon even when the cemented zone has reached a considerable depth. This latter characteristic, which manifests itself to an even more marked degree in the "mixed cements" with carbon monoxide as base, is due to the

specific action of the carbon monoxide acting as a "vehicle" for the diffusion of the carbon into the iron.

What I have just said is fully confirmed by the examination of the fracture surface of the specimens cemented with those cements and quenched. Fig. 129, taken from a booklet illustrating the Machlet process and published by the "American Gas Furnace Co.," represents the surfaces of fracture of a series of specimens cemented in the Machlet apparatus during the periods of time indicated under each specimen, and hardened. In all the specimens there is to be seen a sudden variation in the structure of the steel at the line of passage from the cemented zone to the material of the "heart" of the piece, which has remained soft; a variation corresponding to the rapid decrease in the carbon content due to the special mode of action of the hydrocarbons used as cements. We shall see later that this harmful phenomenon does not show itself in the cemented zones obtained with mixed cements having carbon monoxide as base.

It is also to be seen clearly in the same figure that the depth of the cemented zones increases only to a very slight extent beyond a certain limit which, under the conditions under which the specimens here reproduced were cemented, is reached after five hours of cementation.

To conclude, the Machlet apparatus of the "American Gas Furnace Co." is excellent from all points of view and can be used with the greatest advantage whenever thin cemented zones are to be obtained in large numbers of objects of small dimensions of such a kind that they are not to undergo violent shocks after hardening. The high carbon content of the cemented zones obtained imparts to the cemented and hardened objects a maximum resistance to wear by friction.

The Machlet furnace, independent of the special carburizing gas generator described, can be used very advantageously to cement with the gaseous cements having carbon monoxide as base, on condition that the pieces to be cemented are of suitable form and dimensions. In this case there can be obtained with this furnace cemented zones with perfectly "gradual" variation in the concentration of the carbon, and therefore such as present, after hardening, maximum resistance to shock.

The second type of furnace for cementation with gaseous cements is entirely similar to that especially designed for cementation with "mixed" cement having carbon monoxide as base. Briefly, it has fixed, vertical, cylindrical muffles, heated with producer gas from a coke gas producer built in the body of the furnace itself. An efficient system of regenerators permits of heating a sufficiently large section of the muffles placed in this laboratory to a uniform and constant temperature, which can be exactly regulated, ranging between 800° and 1200° C.

Fig. 130 represents a vertical section of a two-muffle furnace of this type. The figure also shows the apparatus for charging and discharging the pieces to

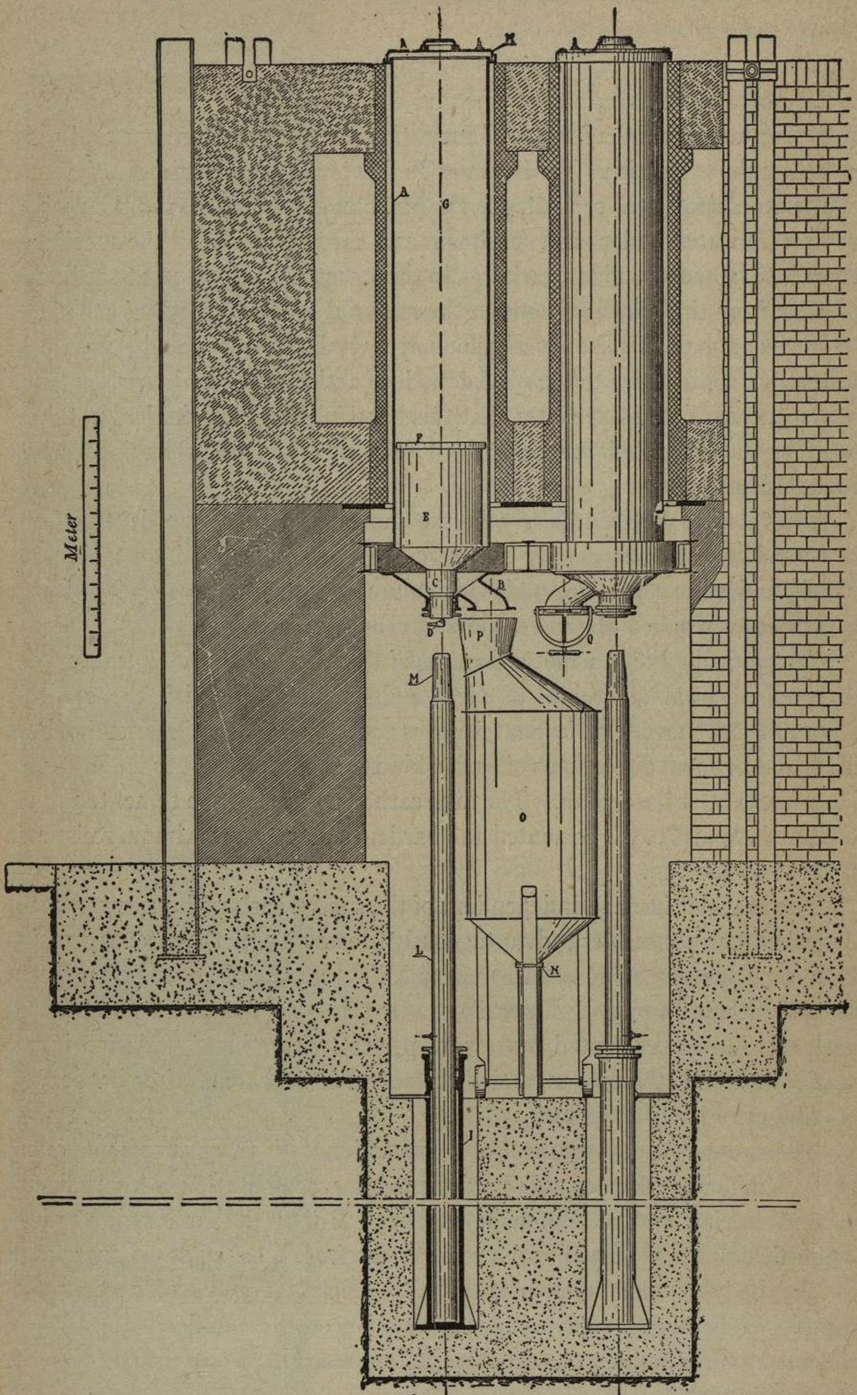

Fig. 130.

be cemented—the same as are used for cementation with "mixed" cement. Fig. 131 shows the outside of one of these same furnaces constructed by

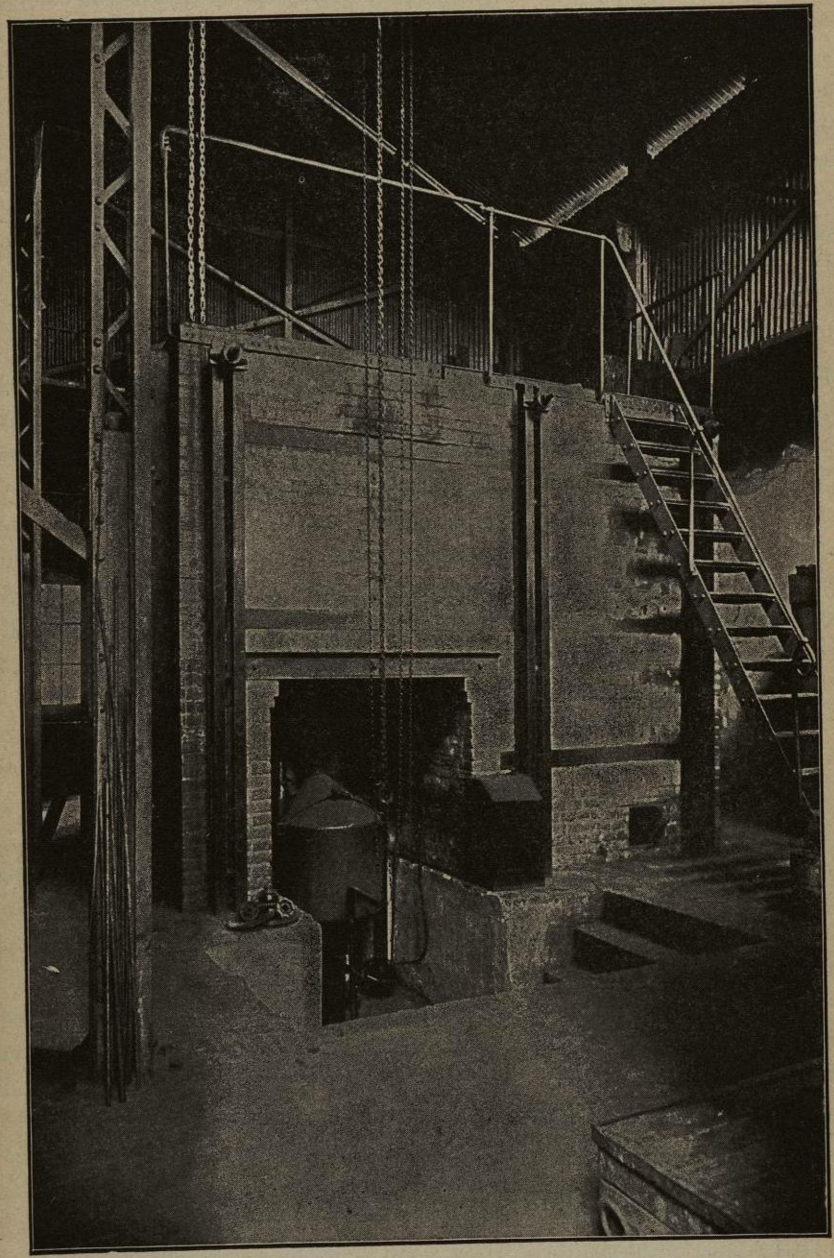

Fig. 131.

"Ch. M. Stein" of Paris in the Sampierdarena Machine Shops of the "Società Anonima Italiana Giov. Ansaldo e Co.," owner of patents on the apparatus and the processes of cementation for which they are especially constructed.

The construction of the furnace proper, or of those parts of it which act as heating apparatus, presents nothing essentially new, but consists of the ordinary parts for production of gas, combustion, regeneration of heat, regulation of temperature, etc., etc., and is designed with particular care so as to obtain maximum uniformity in temperature in the operating parts of the muffles. In a furnace of the dimensions shown these operating parts are the central portion of these muffles, about 1.20 mteers long. Moreover, efficient devices for the regeneration of heat make it easy to keep constant the temperature of the laboratory and of the muffles in it for a practically indefinite time, at any point within a wide interval of temperature. In the interior of the muffles the temperature can be kept constant between 800° and 1200° C. with a tolerance of 10°, and with differences between the various points of the useful zone not greater than 10° C.

It is proper to furnish some more details as to the structure of the accessory apparatus represented in Fig. 130, for while they lend themselves very well to cementations with gaseous cements, they have been studied especially for cementation with the mixed cements having carbon monoxide as base. The dimensions of the individual parts shown in the figure can easily be obtained from the metric scale given in the drawing. We call attention to the fact, however, that furnaces of this type are constructed of various dimensions, according to the special purposes for which they are intended.

In the interior of each of the muffles of refractory material is placed a cylindrical retort of soft steel *A*, whose external diameter is about 10 to 20 mm. smaller than the internal diameter of the muffle.

Seamless Mannesmann tubes, which can easily be found on the market up to a diameter of about 35 cm., serve well as retorts. For greater diameters, such as are shown in the furnace in the accompanying figure, autogenously soldered sheet-iron tubes are used.

The retort is supported by a base ring connected with a frame fixed in the wall of the furnace. The setting of the retort to the base ring and to the upper ring *H*, designed to receive the cover, is such as to permit of substituting one retort for another in a few minutes. To the base ring is also fixed a funnel of special shape *B*, of cast iron, closed at the bottom by a slide-valve *Q*.

The special form of this funnel, and especially the side neck and the slide-valve, are provided for the use of mixed cement. Through the wall of the funnel passes, through a tightly fitting stuffing box, the steel tube *C*, for the admission of the carburizing gas. This enters through the side tube *D* which is screwed, during the cementation, to the middle of the piece *C*. This is connected with the hollow cylinder *E*, of cast-steel, designed to support the pieces to be cemented on the disk of steel and refractory material *F*. The carbon monoxide, after having passed through a hole made along the

axis of the piece *C*, reaches a small distributor placed inside *E*, and then passes into the cementation chamber *G* through numerous holes made in the disk *F*. During the cementation, the cylinder *E* rests on a series of projections on the same base ring to which is fixed the funnel *B*, so that, during the cementation, this ring must support the whole weight of *E*, of the disk *F*, and of all the objects to be cemented which rest directly or indirectly on this disk *F*. The section in Fig. 130 shows the position of the varicus parts during the cementation.

The method of charging the retort varies markedly according to the dimensions and forms of the objects to be cemented, so that it is not possible to give general rules. We will therefore limit the directions to those which hold for some special examples.

Supposing that cylindrical gear wheels whose maximum diameter is only 100–150 mm. less than the internal diameter of the retort are to be cemented.

The tube *D* is first unscrewed; then, by means of the plunger *L*, controlled by the hydraulic cylinder *I*, the whole of the parts *C*, *E*, and *F*, into which the plunger fits in rising, with its truncated conical end *M*,[1] is raised. When the piston has reached its limit, and the upper surface of the disk *F* is only about 30 cm. below the cover of the retort, the cover *H* is removed and the wheels to be cemented are placed "in column" on the disk *F*, arranging them horizontally, one above the other. As the wheels are put in place, the plunger *L* and with it the pieces *C-E-F* are lowered and the charging is complete when the apparatus has reached its lowest position, indicated in the figure. In this position, the last wheel charged must be at least 30 cm. from the upper edge of the retort. In general, the objects to be cemented are charged already heated to about 800°–900° C., which realizes very great advantages, both as regards the quality of the product and economy and regularity of the operation. For the preliminary heating of the pieces to be cemented, use may be made of a small muffle furnace heated directly with coal, since the uniformity of temperature which can be obtained with such a furnace is more than sufficient for this special purpose. Sometimes, especially when it is not necessary to push the cementation furnace to its maximum production, one of the vertical muffles may be used for the preliminary heating of the objects to be cemented while in the other the cementation of the preceding charge is effected. In this case, a better utilization of the furnace is obtained by using each of the muffles alternately for the cementation and for the preliminary heating of the pieces.

Good results are also obtained, when the pieces to be cemented are not of too large dimensions, by using for the preliminary heating a series of apertures

[1] The plunger *L M* is cooled internally with a current of water so as to prevent its becoming too hot in case it should accidentally remain in the retort for too long a time.