

(19) provided with bolts (20), are placed refractory bricks forming the wall, pierced by holes (21) designed to allow of pyrometric measurements inside the laboratory. When the door is placed in front of the opening (15), a system of levers and eccentrics, shown in Figs. 109 and 110, permits of tightly pressing it against the well-planed walls of the furnace (by means of a simple turn of the axle 25, controlled by a key), so as to obtain tight closing without recourse to luting with clay.

Pieces of elongated form and of large dimensions which are to be cemented (or annealed or tempered) at the ends are placed with the ends to be cemented in the crucibles (11), suspending them from above to a cross-piece not shown in the figure. Two long cylindrical pieces placed in this way are to be seen over the furnace, to the left, in Fig. 111, which shows the exterior of two coupled furnaces of the type just described.

The crucibles (11), after the pieces to be treated have been placed in them in the manner indicated, are filled with the solid cement (or with inert substance, such as refractory earth, if it is simply a question of annealing or

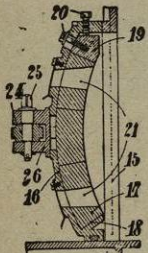


FIG. 109.

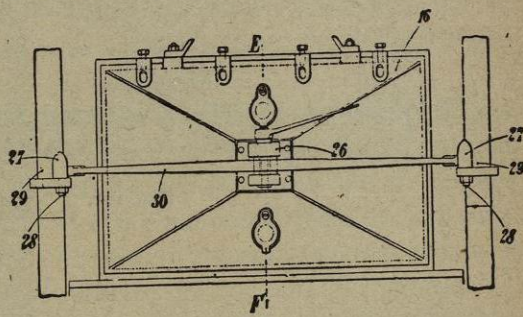


FIG. 110.

hardening), covered with pieces of sheet iron and then carefully luted with refractory earth.

The gas necessary for the heating of the furnace is furnished by a producer, which may be independent of or constructed in the mass of the furnace itself. A furnace of this type has been in operation for a long time in the works of the "Fives-Lille" Society at Fives, and gives very satisfactory results, especially since it permits of cementing and hardening the ends of long pieces such as connecting rods and locomotive shafts, avoiding the deformation which always occurs when such pieces are heated all over for a long time (for cementation or for quenching) in a horizontal position. When long pieces are not to be cemented, the same furnace can be used entirely as an ordinary furnace by merely doing away with the crucibles and utilizing the whole laboratory for the heating of cementation boxes.

This is the type of furnace at present adopted by most of the automobile factories. A good example of this is the equipment furnished by Stein for the Renault automobile factory at Billancourt. Fig. 112 shows the arrangement

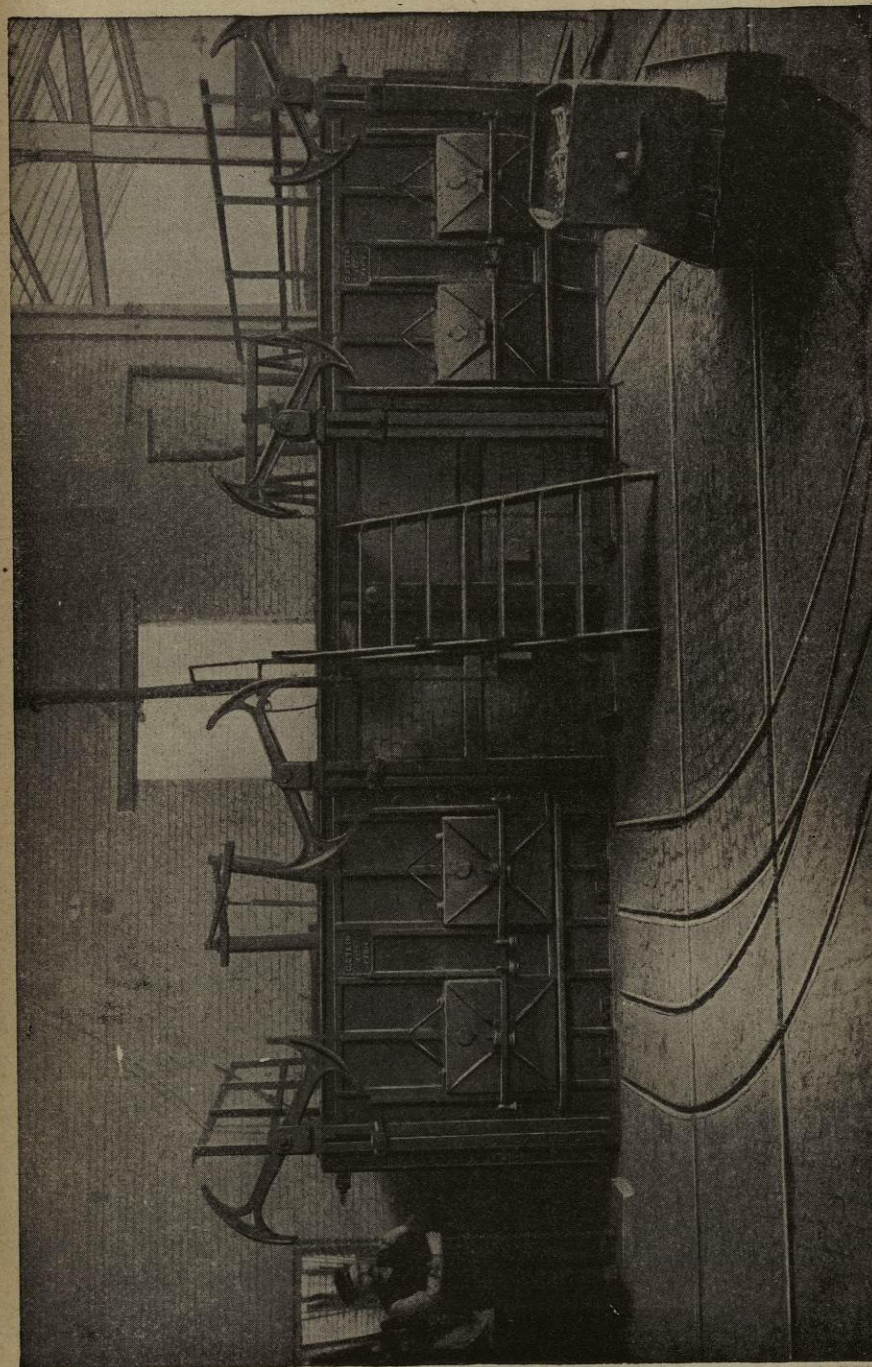


FIG. 111.





FIG. 112.

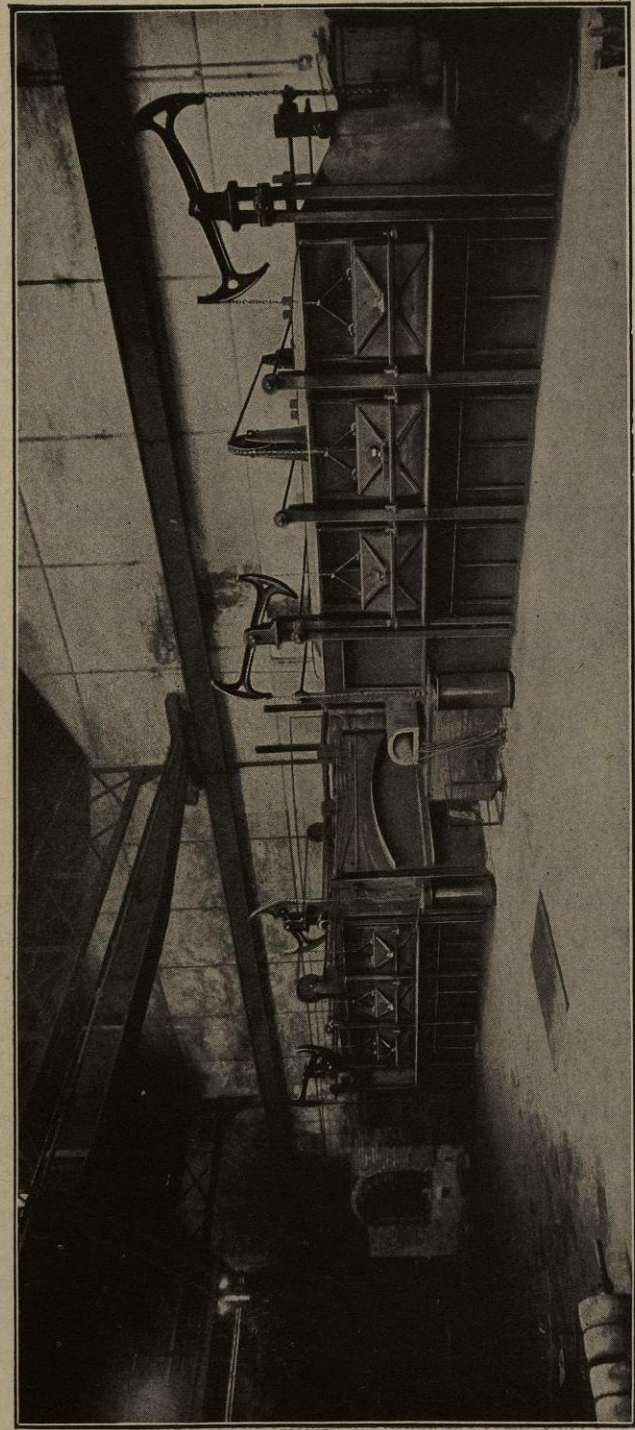


FIG. 113.



of one of these furnaces. The equipment (Fig. 113) comprises two furnaces, each having an available hearth surface of  $2.50 \times 3$  meters; the gas is supplied by a battery of independent producers using gas works coke, and reaches the furnace through underground flues. The two furnaces can be operated separately, but like all furnaces of this type, they must operate continuously. They can easily be placed under reduced operation by means of manipulating a few dampers; when these are adjusted they can be left completely alone as long as thirty-six hours.

The temperature of the laboratory can easily be regulated so as to keep it constantly within a variation of about  $10^\circ \text{C}$ .; the differences in temperature between different points in the laboratory do not exceed  $10^\circ \text{C}$ . when the temperature lies between  $800^\circ$  and  $1100^\circ \text{C}$ .

The perfect closing of the doors is insured by a lever and eccentrics such as already described for the furnace with vertical crucibles, and there is no need of luting.

The pressure of the gases in the furnace is a little higher than the external atmospheric pressure, and it is easy to obtain at will an oxidizing or reducing atmosphere.

The uniformity of temperature of the furnace is due essentially to the fact that the heating of the boxes placed in it is effected solely by the heat radiated by the arch heated by the flames, and by the heat transmitted through the hearth, under which these flames circulate.

We will add some considerations on the solid cements which practice has shown to be best adapted to obtaining particular results in case-hardening. Without stopping to discuss the innumerable cementation powders proposed by many inventors and protected by numerous patents, we will describe the preparation, use and effects of those solid cements which long experience has shown to be most effective and best adapted to furnishing definite results.

Many manufacturers, some of undoubted standing, put on the market cementation powders already prepared, the composition of which they keep secret and of the efficacy of which they give most marvellous guarantees. It is strange that purchasers can still be found to-day disposed to pay high prices for such mysterious powders, when with a little trouble they could acquire the fundamental knowledge of the laws governing cementation and thus prepare for themselves, at much smaller cost, perfectly satisfactory carburizing mixtures and work out the methods for any designed purpose.

In general, the manufacturers of cementation powders limit themselves to classifying their products in two general groups: the "rapid cements" and the "slow cements." The consumer who has only these indications can not solve the innumerable delicate practical problems in cementation which present themselves every day, especially considering the wide introduction and

use of special steels, such as nickel, chromium, chromium-nickel, tungsten, vanadium steels, etc.

There are only some *types* of *simple* cements, at present well known, whose efficacy is a *maximum* from all points of view, and the addition of other ingredients to these typical cements *in no wise increases their efficacy*. Such additions rob them of their principal merit—purity, which guarantees the purity of the product, and simplicity, which determines with precision their mode of acting and the conditions best suited for obtaining a definite result.

These last considerations hold especially for gaseous cements and mixed cements, but they have a real practical value also in the case of solid cements.

The simplest among the solid cements is more or less finely divided carbon. Of the carbons of different varieties usually employed for the preparation of solid cements, the purest is wood charcoal. However, simple powdered wood charcoal used for short cementations to produce thin cemented zones (from 0.5 mm. to 1 mm. thick) presents the disadvantage of furnishing too low and irregular carbon content. This phenomenon was explained fully on p. 184, where it was shown that the carburizing activity of pure wood charcoal, almost entirely free from volatile organic substances, is due only to the carbon monoxide formed by the action of the oxygen of the air occluded in the carbon. But low carbon content in the cemented zones results when carbon monoxide acting in the presence of carbon is diluted with nitrogen, as has been already explained. The strong irregularities of these zones are due to the fact that in the mass of the carbon the most finely powdered parts accumulate against some sections of the surface of the steel to be cemented, rendering the access of the carburizing gases difficult. The same low carbon content of the cemented zones which are obtained with wood charcoal, while it constitutes a disadvantage for thin cemented zones, may be advantageous in deeper cementations, in which the cements of more "intense" action have the serious defect of furnishing cemented zones in which the maximum carbon content is too high. This is the reason why many manufacturers of armor plates have abandoned the use of hydrocarbons or of the more rapid solid cements (for example, the mixtures of carbon and of barium carbonate) to return to the use of simple pure wood charcoal, which, although requiring a much longer time to furnish cementation of a given depth, guarantees against the reaching of too high carbon contents in the cemented zones.

Other forms of less pure carbon are preferable for case hardening. The presence in these of not wholly decomposed organic residues or of large proportions of ashes rich in alkali or alkaline earth carbonates, gives rise to the formation of gases (hydrocarbons, cyanides and carbon dioxide, respectively), whose action, in the presence of free carbon, produces an increase in the maximum carbon content in the cemented zones. Among these varieties of carbon most frequently used for surface cementation are bone charcoal, leather scraps, residues of incompletely carbonized hoofs or horns,



lamp black, etc. In any case, these substances must be pulverized and well dried before using.

Many manufacturers are accustomed to mix the different varieties of carbon, in definite proportions, which permits, in a certain way, of "graduating" (although only with a very rough approximation) the "intensity" of the carburizing action of the cement in such a way as to make it higher than the minimum value which it has for simple wood charcoal but lower than the excessive values which it reaches for the other varieties of carbon mentioned above.

It may be said that every manufacturer uses mixtures of special composition, which, moreover, all give good results, for each manufacturer has had to determine, by means of long-repeated trials, the special conditions under which the mixture used by him must be made to act.

Among these mixtures I shall cite, as examples, the following:

(A) Powdered oak charcoal.....	5 parts
Powdered leather charcoal.....	2 parts
Lamp black.....	3 parts
(B) Powdered beech charcoal.....	3 parts
Powdered horn charcoal.....	2 parts
Powdered animal charcoal.....	2 parts

Mixtures are frequently used of various kinds of carbon with organic substances (such as horn scrapings, flour, beer dregs, resin, glue, heavy mineral oils, etc.) or mineral salts (especially alkali and alkaline earth carbonates, alkalis, cyanides, ferrocyanides, common salt, etc.). It is easy to understand the action exercised by organic substances easily decomposed by the action of heat, or by those salts which evolve carbon dioxide at a high temperature, or by cyanogen or its derivatives (nitrogenous organic substances, alkali cyanides, ferrocyanides, etc.).<sup>1</sup> The effect of other substances which many manufacturers add to their cement is, on the contrary, not easily explainable; such, for example, are glass, siliceous sand, kitchen salt, etc.

It must be pointed out at once, however, that recent experiments show that the efficacy of these substances is small and sometimes null.

A simple mixture recommended by various authors and used by many manufacturers is:

(C) Wood charcoal.....	90 parts
Sodium chloride.....	10 parts

It seems that this cement, used in many machine shops, gives better results than simple wood charcoal. For this it is not easy to give a scientific

<sup>1</sup>We have already seen (p. xiii) that the use of cyanide compounds was proposed as early as the beginning of the nineteenth century by the American professor, A. K. Eaton.

reason. It is, however, certainly less efficacious than the cement of the following composition:

(D) Powdered wood charcoal.....	60 parts
Barium carbonate.....	40 parts

This is one of the best solid cements, both because we know well its mode of action, which I have already shown (see p. 184) is due to the simultaneous activity of the wood charcoal and of the carbon monoxide formed by the action of this carbon on the barium carbonate, and because for cementations of small depths it gives cemented zones markedly more homogeneous than those furnished by the other solid cements. In general, the maximum concentration of the carbon in the cemented zones obtained with carbon and barium carbonate at temperatures between 900° and 1100° C. varies from a minimum of about 0.7%, for the very thin zones obtained near 900°, to a maximum of about 1.3% for the zones thicker than 1 mm. obtained near 1100° C.

Another advantage of this cement lies in its property of being "regenerated" easily and spontaneously when it is left exposed in a thin layer to the air, after having used it in the usual manner. This process of "regeneration" is due to the fact that the barium oxide formed during the cementation, by the dissociation of the barium carbonate, absorbs carbon dioxide from the air, again forming barium carbonate.

After a certain number of alternating cementations and regenerations it is necessary to add some wood charcoal to the cement to replace that burned during the cementation and during the discharging of the boxes.

The preparation of this cement consists simply in finely grinding and intimately mixing the wood charcoal and barium carbonate.

The barium carbonate is found on the market sufficiently pure at about 50 centesimi (10 cents) per kilogram. If natural barium carbonate (*witherite*) is used, it is necessary to powder it carefully before adding it to the carbon; the finely divided precipitated barium carbonate, on the contrary, can be mixed directly with the granulated carbon and the one operation of grinding the carbon can be used for preparing the mixture.

On varying the proportions of the two components, the results which are obtained vary, working under definite conditions. It is difficult to establish rules predicting the direction and the importance of these variations, because the action of this cement<sup>1</sup> depends to a great extent on the rate at which the temperature rises in the various parts of the cementation boxes;

<sup>1</sup>In reality, this cement acts as a "mixed" solid-gaseous cement, but in the practical definition of a cement we must take into account essentially the substances which we can regulate directly and whose action we can govern; now, this is certainly not the case for the carbon dioxide which is evolved from the barium carbonate of this cement. We can regulate only the carbon and the barium carbonate.



in fact, this velocity determines the extent and the rapidity of the evolution of carbon dioxide in the various phases of the cementation.

The differences in the course of the cementation to which variations in the proportions of the carbon and barium carbonate may give rise are shown by some experimental results obtained by Guillet<sup>1</sup> by cementing for eight hours at 1000° C. with mixtures of wood charcoal and barium carbonate in varying proportions an ordinary dead soft steel with 0.05% of carbon, and then analyzing successive layers 0.25 mm. thick:

Compositon of the Cement		Concentration of the Carbon	
Wood charcoal,	Barium carbonate,	In 1st layer,	In 2nd layer,
parts	parts	percent.	percent.
80	20	1.14	0.75
60	40	1.32	1.19
40	60	0.94	0.77

Both this cement and those consisting of various qualities of carbon, pure or mixed with each other, or with sodium chloride present the disadvantage of low thermal conductivity, which, as already explained, aggravates the most important disadvantages of using solid cements in boxes. Some other cements, still with carbon as base but containing other salts or organic substances, do not possess this particular disadvantage of low heat conductivity, but are in other respects inferior to the carbon and barium carbonate cement.

(E) Coke saturated with heavy mineral oils.

This is a very "quick" cement, in the sense that it gives rise in a short interval of time (two to three hours) to thin cemented zones of very high carbon content, from 1.5 up to 1.8% according to the temperature. It is very rapidly "exhausted," however, and is not suited for prolonged cementations intended to give cemented zones deeper than a few tenths of a millimeter.

Moreover, even in the case of very thin cementations, such "quick" cements can be usefully employed only when the cemented and hardened pieces are intended to resist friction only, but not shocks; because in their zones of high carbon content and of sudden variations in the carbon concentration shocks would rapidly produce fracture and exfoliation, as explained in the first part of this volume.

Besides, this cement presents another serious disadvantage, of not behaving in a constant and uniform manner when the conditions under which cementation is effected are kept as constant as is attainable in practice. In other words, in using this cement it is not possible to regulate the conditions of the operation in such a way as to obtain well-defined predetermined results.

<sup>1</sup> *Mém. de la Société des Ingénieurs Civils de France*, 1904, p. 189.

Three other cements, recommended by Grenet and which have given good results in practical tests, are the following:

(F) Powdered wood charcoal.....	1.0 kg.
Salt.....	0.1 kg.
Sawdust.....	1.5 kg.
(G) Coal with 30% of volatile materials.....	0.5 kg.
Charred leather.....	0.5 kg.
Salt.....	0.1 kg.
Sawdust.....	1.5 kg.
(H) Charred leather.....	1.0 kg.
Yellow prussiate.....	0.2 kg.
Sawdust.....	1.0 kg.

The velocity of cementation increases gradually from the first to the third of these cements.

The efficacy of the sawdust, which renders the mass porous and easily penetrable by the gases, is easily explained by the increased activity of the gases.

There are also used as cements some pure carburizing salts or mixtures of various salts, such as potassium ferrocyanide, or the mixture of two parts of potassium ferrocyanide with one part of potassium bichromate. These are very "quick" cements, and are used almost exclusively for very thin cementations (about a tenth of a millimeter); in this case they are not used in boxes but by spreading as a varnish on the objects to be cemented. In cementations carried out in this way, the cement always undergoes more or less complete fusion, and then behaves like a liquid cement. With these processes I shall deal later, in speaking of liquid cements.

As I have already said, there are in use in machine shops numerous mixtures of the most varied and complex composition. The results of accurate and precise experiments do not justify, however, the use of such complex mixtures, which do not furnish results superior to those which are obtained with the less complicated cements, and, further, because of their complexity, do not furnish results which are constant or uniform and can be exactly predicted. The best and surest results are always obtained by using the simplest cements.

One of the most serious disadvantages of solid cements, simple or complex, lies in the impossibility of determining *a priori* with certainty the results which will be obtained by cementing under definite conditions a steel of definite composition.

This is due especially to the impossibility of knowing with precision the velocity with which, in the various cements and under the various conditions, the propagation of heat takes place through the charge from the outside to the interior of the charges contained in the cementation boxes. This is well known to every one who has had experience with surface cementation, and is