

309. THE EFFECT OF MOST VARIABLES ON THE SILICON-CONTENT IS THE OPPOSITE OF THAT ON THE SULPHUR-CONTENT. — Now looking back on Table 19 as a whole we notice that, with the exception of the direct chemical influence of the lime-content of the slag, the influence of each variable on the silicon-content is the opposite of its effect on the sulphur-content. In other words, those changes in the management of the furnace which tend to desulphurize and thus to make the iron grayer, simultaneously increase the silicon-content and thereby also tend to make the iron grayer.

From this fact arises the difficulty of making cast iron at once low in silicon and low in sulphur. Of the principles here tabulated only an increase in the lime-magnesia-content of the slag tends to decrease both the silicon and sulphur. In case we are called upon to make an iron low in both silicon and sulphur this then would be the principle on which we should chiefly rely.

310. RELATIVE PROMPTNESS OF DIFFERENT METHODS OF RAISING THE HEARTH TEMPERATURE. — We may recognize two kinds of considerations which may demand that the hearth temperature shall be raised. Thus, first, we may wish to change permanently or for a long period the condition of affairs, wishing to make an iron grayer than that which the furnace has normally been making, grayer either through containing more silicon or less sulphur or both, than the present product. Or, second, we may need to raise the temperature to meet a temporary and abnormal trouble, a temporary cooling due to the leaking of a tuyere or a bosh-plate, which is sending a stream of water into the hearth, and cooling it abnormally and indeed intolerably. To meet the latter state of affairs it is important that the remedy applied shall take effect promptly. Of the three means which we have been considering of raising the temperature of the hearth, *viz.*,

- (1) increase in blast temperature,
- (2) increase in fuel ratio (*i. e.*, lightening the burden), and
- (3) raising the melting-point of the slag,

the first one will give much the quickest relief. Our fuel, flux and ore are introduced only through the top of the furnace, and many hours must elapse between the time when we change the burden or the limestone ratio, and the time when the extra fuel or the extra lime will reach the hearth of the furnace. On the other hand, increasing the temperature of the blast immediately

throws an increased quantity of heat into the hearth. A difficulty in the way, however, often is that just at the time when we are in need of a hotter blast, the furnace gases on which we have to rely for heating that blast are from the same cause lean in carbonic oxide, *i. e.*, of low heating power. Hence the importance of so arranging matters that a deficit of gas can be met by firing our boilers with coal or other fuel, so that we may be free to turn into our hot blast stove a larger quantity of gas.

But though many hours must elapse between the time of increasing our fuel ratio and that in which this increase in fuel actually reaches the hearth so as to generate there an increased quantity of heat; nevertheless, this increase in fuel ratio gives relief much more quickly than might be expected, for the reason that the fuel is in large angular lumps which mechanically open up the charge in the upper part of the furnace, thus lessening the frictional resistance to the upward travel of the gas, and thus hastening the operation as a whole. In particular, since the blast can enter at the bottom of the furnace only so fast as the gases escape from its top, this opening action of our extra fuel has the same effect as an increase in the blast pressure, and permits us to blow in more air per second with the consequence that we burn more fuel per second, and hence generate more heat per second, while the abstraction of heat by conduction through the furnace walls remains substantially constant. In short, it increases the heat development per second without corresponding increase of the heat removal.

CHAPTER XIII. — METALLURGICAL GAS FURNACES

311. GAS-FIRING AND DIRECT-FIRING. — In a sense all reverberatory furnaces are gas furnaces, because they are heated by a flame, and a flame is only burning gas; so that in every case they are heated by burning gas.

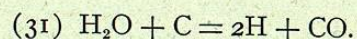
312. BY DIRECT-FIRING is meant burning coal or other solid fuel in a fire-box close to the working chamber of the reverberatory furnace, and in a layer so thin that enough free atmospheric oxygen passes through some of the wider crevices between the lumps of fuel, both to burn the carbonic oxide generated by the incomplete

combustion of the fuel by the limited quantity of air which passes through other and narrower crevices, and also to burn the hydrocarbons, if any, distilled from the fuel. Thus both the combustible gas and the air for burning it escape simultaneously and side by side from the surface of the fuel; the flame begins at the very surface of the fuel.

313. BY GAS-FIRING is meant chiefly burning the fuel in a layer so thick that all of the oxygen of the air which passes through it combines with the fuel, and that nearly all of it forms carbonic oxide with the carbon of that fuel; so that from the surface of the fuel escapes a stream of combustible gas, chiefly the carbonic oxide thus formed and hydrocarbons from the distillation of the fuel, diluted with the atmospheric nitrogen. The stream of gas is in turn burnt by air specially admitted for this purpose. Thus in direct-firing, it is flame proper which escapes from the surface of the fuel, while in gas-firing it is not flame but combustible gas to be later converted into flame.

In short, in direct-firing the fuel bed is so thin that it delivers flame direct from its surface; in gas-firing it is so thick that it delivers there a stream simply of combustible gas. This is the essential distinction.

314. KINDS OF GAS USED IN METALLURGY.—Gas made in the way just described is called "producer gas," or sometimes "air gas," to distinguish it from natural gas, from distilled gas made by the destructive distillation of bituminous coal, and from "water gas," made by passing steam over incandescent fuel, by the reaction



While in a few favored places like Pittsburgh natural gas can be had, the gas used in metallurgical processes is nearly always producer gas modified by the presence of some water gas; *i. e.*, some steam is mixed with the air used for making the producer gas itself. (See § 326, p. 429.) Under usual conditions this gas is probably far the cheapest per unit of calorific power. It is, however, so bulky, *i. e.*, so greatly diluted with atmospheric nitrogen, that the expense of installing pipes large enough to distribute it for domestic use would in general be prohibitory. In metallurgical establishments the distance through which the gas has to be carried is so short that its diluted condition is not a serious matter.

As nearly all of the gas used for heating iron and for melting steel is this modified producer gas, so when gas-firing for these purposes is spoken of, it is generally understood to be producer-gas firing; and in the following discussion it is this gas which is referred to. For heating the blast and raising steam for the iron blast-furnace, and also of late for burning in gas engines, the waste gases of that furnace are used; but not for heating or melting steel.

The description of direct-firing above given is that of the extreme type. In many cases, while much free oxygen passes through the fuel uncombined, and is thus in a position to burn the carbonic oxide and hydrocarbons which it then meets, yet there is not enough of it to burn the whole of these, and more or less additional air, often preheated, is admitted above the fuel to complete the combustion. This case is intermediate between the typical direct-firing and gas-firing. We need not here consider where the dividing line should be drawn.

315. PURPOSE OF GASIFICATION.—Gas furnaces, chiefly of the Siemens type (§ 276), are used for the open-hearth steel-making process (indeed, all open-hearth steel furnaces are of this type), and to a very great extent for reheating steel, and for melting steel by the crucible process. In other branches of metallurgy they are used relatively little. Let us ask why they are so much used in these steel processes, and why not in other metallurgical processes. The difference is not to be put down to the stupidity or ignorance of non-ferrous metallurgists, but, as in most such cases, is due to fundamental differences in conditions.

The gas furnaces which we are now considering are reverberatory furnaces, and our question really is as to the relative merits of gas-fired reverberatories like that shown in Figs. 98 and 99, and "direct-fired" ones, such as that shown in Fig. 116.

Every reverberatory furnace may for our present purpose be regarded as a system for heating a charge of metal or other substance by means of a flame passing by it, usually passing over it; a flame is burning gas; and the system may be divided into three parts, (1) the preparatory part in which the fuel is converted into gas, and the air is preheated, *etc.*; (2) the working chamber or laboratory in which the charge of metal, *etc.*, is heated, melted, *etc.*; and (3) the chimney through which the products of the combustion of the flame are carried away. Comparing gas and

direct-fired systems, while the dimensions of the chimney do not differ very strikingly, yet there is an enormous difference in the ratio of the volume of the preparatory part to the working chamber. This is readily seen on comparing the Siemens furnace shown in Figs. 98 to 101 with that of any direct-fired furnace, such as a common puddling furnace (Fig. 116). In the Siemens system the flame-preparing part as here shown is about thrice as large as the working chamber; including the gas-producing plant it is perhaps four times as large as the working chamber; while in the direct-fired furnace it is often not more than half as large as the working chamber. Thus, in order to use the Siemens system, the preparatory part of the apparatus has to be increased in size four-fold or even more, and the cost of installing the system, as well as the cost of repairs, is thus very greatly increased.

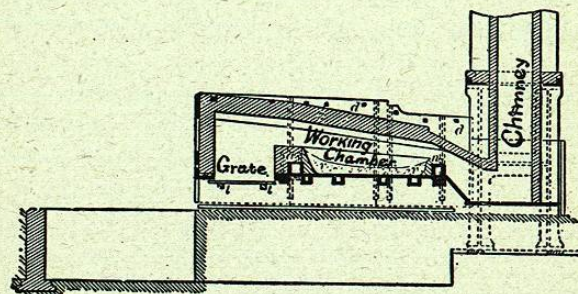


Fig. 116. Direct-fired Reverberatory (Puddling Furnace).

There are, indeed, other forms of gas furnace, of the recuperative system (Morgan furnace, Fig. 113, p. 377), in which the fuel-preparing part of the apparatus is much smaller and less costly than in the Siemens system. In the recuperative furnaces the heat is filtered out of the escaping products of combustion by passing them around a system of clay pipes or its equivalent, while through those pipes the air which is to burn the gas is passed, or *vice versa*.

To these recuperative furnaces the objection of excessive first cost applies less strongly than to the Siemens system; nevertheless it applies, and with force. It will suffice for our present discussion if we confine our attention to a comparison of the direct-firing system with the Siemens system; for while the recuperative system is less expensive to install than the Siemens, it is less economical of fuel under most conditions, and probably also more expensive to maintain.

That the great expense of installing and maintaining the Siemens furnace is endured implies that some corresponding great advantages have been proved. What are these?

316. THE ADVANTAGES OF GAS-FIRING as such are:

(1) *That the Temperature and Character of Flame* are under better control.

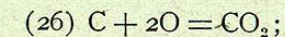
(2) *Fuel Economy*: that it permits recovery of the heat which, in direct-fired furnaces, is carried away by the products of combustion and lost. This recovery of course permits a corresponding economy of fuel.

(3) *Higher Attainable Temperature*. — This recovery of the heat of the products of combustion permits generating a much higher temperature than is possible with direct-firing, a temperature which is limited only by the danger of melting down the materials of which the furnace is made. Indeed, one of the chief cares of the open-hearth steel melter in using the Siemens' furnace is to avoid melting the furnace itself, although this is built of the most infusible fire-bricks to be had.

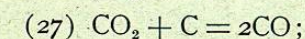
Let us consider these advantages in detail.

317. TEMPERATURE AND CHARACTER OF FLAME UNDER BETTER CONTROL.* — The combustion of bituminous coal may for the present purpose be regarded as composed of four parts.

(A) carbon burns at and near the grate-bars to carbonic acid,



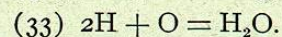
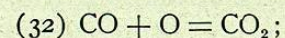
(B) the resulting carbonic acid is reduced to carbonic oxide by the carbon of the overlying fuel,



* *Oxidizing, neutral and reducing flames*. It is common to say that the flame of gas furnaces may at will be made either oxidizing, neutral or reducing: but "reducing" is a relative term. A flame which would be reducing toward copper might be highly oxidizing toward iron. In order that a flame shall generate the high temperature required in heating iron for rolling, and in melting steel, the combustion of the flame must be nearly complete, and this implies that most of the hydrogen, hydrocarbons and carbonic oxide shall be converted into steam and carbonic acid; and this in turn implies that the flame must necessarily be oxidizing towards iron, because both steam and carbonic acid oxidize hot iron rapidly. It is therefore misleading to talk about a heating or melting flame in iron metallurgy as "reducing." All we can say is that some flames are strongly oxidizing and some are only mildly oxidizing.

(C) the hydrocarbons of the fuel are distilled;

(D) the carbonic oxide and the hydrocarbons from *B* and *C* burn to carbonic acid and steam; with these products is mixed the nitrogen which accompanied the atmospheric nitrogen of phases *A* and *D*.



If phase *A* alone occurred there would be no flame, because flame is burning gas. A burning solid gives no flame, unless distillation or combustion gives rise to a gas. The burning of that gas causes flame, and this flame may look as if it was the combustion of the solid; but really it is only the combustion of gas evolved from the solid.

In the present case, the gas which in burning gives flame is the carbonic oxide resulting from phases *A* and *B* jointly, and the hydrocarbons resulting from *C*; the burning of the flame itself, *i. e.*, the combustion of that gas, is phase *D*.

The carbonic oxide and hydrocarbons from *B* and *C* are deoxidizing; the carbonic acid and steam from *A* and *D* are oxidizing towards iron. Any free oxygen which accompanies them intensifies the oxidizing character of the flame; if the air admitted for *D* is insufficient to burn the whole of the carbonic oxide and the hydrocarbons, this deficiency weakens the oxidizing character of the flame. *A* and *D* thus strengthen while *B* and *C* weaken oxidation. Further, *A* and *D* are exothermic; *B* and *C* endothermic. Hence, if the character, *i. e.*, the strength of the oxidizing power of the flame, and also the temperature, are to be constant or indeed to be closely under control, the degree to which phases *B* and *C* on one hand, and *A* and *D* on the other take place must be constant or under control.

That this constancy and control are much greater in gas- than in direct-firing is readily seen.

For suppose the coal on a direct-firing grate has been freshly stoked so carefully and evenly that the quantity of oxygen which, passing through the wider interstices between the lumps of fuel reaches the upper surface free and uncombined, is just enough to burn completely the combustible gases which it there meets, (1) the carbonic oxide from phases *A* and *B* occurring in the narrower crevices in which the oxygen is more fully exposed to

the fuel, and (2) the hydrocarbons distilled from the freshly charged fuel.

Here we have as oxidizing factors (1) the supply of this free unscathed oxygen, and (2) the degree to which the carbonic acid from *A* escapes *B*; and as deoxidizing factors the supply of carbonic oxide from *B* and of hydrocarbons from *C*. The character of the flame depends on the balance between these two sets of factors, a balance which in direct-firing clearly must shift rapidly and widely. For as the air passes up through these passages it widens them all by burning away the fuel which bounds them, thus lessening the intimacy of contact of air and fuel, and thus increasing the proportion of free oxygen and of carbonic acid from *A* and lessening the supply of carbonic oxide from *B*. Moreover the air passes the faster through the initially larger passages and therefore widens these the faster, and thus further augments the proportion of the whole air which passes through them, and thus the proportion of free oxygen and carbonic acid; the initially smaller passages at the same time not only convert the carbonic acid to carbonic oxide less thoroughly because constantly widening, but they have a decreasing proportion of the air to operate upon, so that in both these ways the supply of carbonic oxide decreases.

At the same time the supply of hydrocarbons from *C* is probably diminishing rapidly, because the high temperature of the thin fire upon which the fresh coal is charged leads to a distillation of hydrocarbons so rapid as to restrict itself quickly through exhaustion of the supply.

Thus the balance shifts rapidly towards stronger oxidation, through increase in the proportion of free oxygen and carbonic acid, and simultaneous decrease in the supply of carbonic oxide and hydrocarbons.

Further the heat development must shift in like manner. It depends on the ratio between the supply of free oxygen and the supply of carbonic oxide and hydrocarbons. As this ratio changes so will the temperature generated. With a certain ratio of free oxygen to carbonic oxide and hydrocarbons the highest temperature will be generated; shift this in either direction, either by cutting off carbonic oxide and hydrocarbons so that free oxygen is in excess above this ratio, or vice versa, and the temperature sinks.

In gas-firing the conditions are under better control, as will now be explained. It is the necessary thinness of the bed of coal in direct-firing that causes the rapid shifting in the degree to which the carbonic acid from *A* is reduced to carbonic oxide by *B*, and thus in the carbonic oxide supply, as well as in the degree to which free oxygen passes unscathed through the fire, and thus in the free oxygen supply; it is this same thinness that makes the upper surface of the fire so hot that the hydrocarbons of the freshly charged fuel distill with a supply-exhausting rapidity. To prevent this shifting and to retard this distillation we have but to make the fuel-bed deep, as we do in gas-firing, so that no free oxygen can get through it, and that nearly all the carbonic acid from *A* is reduced to carbonic oxide by *B*; this gives us a nearly constant supply of both carbonic oxide and hydrocarbons. The gas is thus made in a special apparatus, the gas-producer, under constant and controllable conditions. The gas is next converted into flame by phase *D* in the working chamber itself, by admitting air there. By thus separating the gas-making and the gas-burning operations each is brought under control. We regulate the strength of the oxidizing conditions and the temperature by varying, by means of valves, the supply of gas and of air.

The Morgan furnace, Fig. 113, p. 377, would represent gas-firing with the sole aim of thus getting control over the temperature and character of the flame, if we were to strike out the very simple arrangements there shown for preheating the air used in phase *D* of the combustion for burning the gas from phases *B* and *C*.

318. FUEL ECONOMY. — In most reverberatory furnaces, and particularly in the open-hearth steel melting furnace, in which it is necessary that the temperature of the working chamber throughout its length should be above the melting-point of steel, say above 1600° C., it is necessary that the flame itself should throughout the length of the working chamber be at a very high temperature, and hence that the flame must escape from the working chamber at this very high temperature and therefore must carry out with it most of its sensible heat. In a direct-fired furnace most of the heat developed by the combustion of the fuel will thus be carried out of the furnace in the flame, during the latter part of the heating operation when the ingots which are heating have nearly reached the temperature of the flame, and

therefore have little further power of absorbing heat from it. Gas-firing affords a ready way of recovering this heat by preheating the air by either the regenerative (Siemens) or the recuperative system.

As an alternative a large part of this heat may indeed be recovered by passing the flame under steam boilers. The inconvenience of this method is very great, especially because the supply of steam from this source is likely to vary greatly. On this account it has in some cases been found that the cost of raising steam by the waste heat from heating furnaces is greater than by boilers independently fired. In short, it may cost more to recover heat in this way than it is worth, if fuel is very cheap.

As the purpose of these regenerative and recuperative arrangements is to recover the heat carried away from the working chamber by the products of combustion, so they become less important or even needless if this heat can be utilized directly in the heating chamber itself. In certain cases this can be done, as for instance in Morgan's continuous heating furnace, Fig. 113. In this by charging cold ingots one by one at short intervals at one end of the furnace, and pushing them along towards the hot end, and by passing the flame over them in the opposite direction, a very large proportion of the heat of the products of combustion is recovered directly in the working chamber itself, and they escape at so low a temperature that no great outlay for further recovery of their heat would be profitable. This illustrates the principle, perfectly obvious when enunciated, that large outlay for recovery of the heat of the products of combustion, *i. e.*, for regeneration or recuperation, can be profitable only when there is much heat in those products, *i. e.*, when they would otherwise escape from the working chamber at a very high temperature, or when they are in very great quantity. It is because in Mr. Morgan's furnace the charge itself recovers so much of the heat of the products of combustion, that he goes to such slight expense in so building his furnace that it shall itself recover a further fraction of that heat, by recuperation. In other words, because his charge itself cools the products of combustion so far, *i. e.*, leaves so little heat in them, only a relatively small and inexpensive recuperative installation is called for to recover that little heat.

Here we have the essential reason why gas-firing and regeneration have been applied chiefly to iron and steel metallurgy;