

rods, etc., should be ample. Ladles may be dried and heated up with hard coal or coke fires, or oil or natural gas burners. The choice will be largely a matter of the relative cost of the fuel. In bottom-blown shops several extra bottoms are kept on hand, and one or two are always ready, lined up and dried out in a flask oven located conveniently to the melting shop. Storage space for tuyères, ladle nozzles and stoppers, sleeve brick for stopper rods, etc., should be conveniently located.

In order to keep the vessel at a low level, a pit is often placed in front of it, in which to set the ladle when it is being filled. The same thing is sometimes done in the case of physic furnaces. There are several drawbacks to such a lay-out. One is that if a ladle burns through and the steel goes into the pit, it is quite a job to get the resulting skull out, especially if the pit is deep and provided with concrete walls. Another is that such an arrangement makes it inconvenient to approach the vessel to fill shanks, or to pour in recarburizer from a small ladle. Moreover, men have a way of falling into such pits.

On the other hand, the pit can sometimes be made deep enough to hold the accumulated slag from a day's work, so that the job of removing slag between heats is dispensed with, and the whole cleaned out at once when the vessel is idle. In bottom-blown shops running to capacity, there is so much slag to take care of that it would not be advisable to make the pit deep enough for this purpose.

If, however, a shallow depression is provided in front of the vessel, the job of shoveling out the slag is easier, and especially when a car running on a small track is used in place of wheelbarrows to carry away slag, it is rather easier to remove it after each heat than to shovel a day's accumulation out of a deep pit.

Storage Yard.—The storage yard and raw material handling generally force themselves unpleasantly upon the attention of the management as soon as the shop begins to turn out a large tonnage. Too often it is then found that the whole shop has been so located that changes in methods of storing and handling material are difficult to make, when a little forethought in the beginning would have taken care of the whole matter. Means are generally provided to dump coke for the cupolas, and coal for the boilers (and pot furnaces), from trestles, and to get them to the places where they are wanted without too much expense. It is in the handling of pig iron, scrap and alloys that the trouble generally comes. A small shop as a rule cannot afford to use an overhead crane or a locomotive crane

with a magnet for unloading raw material, and depends upon hand labor for this work. This is quite right and proper, but the error is too frequently made of failing to foresee that eventually crane handling must take the place of hand labor and to make provision for the time when this is to take place. However the yard be arranged, everything that can be dumped from cars into bins or piles, such as coal, coke, ferromanganese (in quantity), etc., should eventually be so handled; and pig iron and scrap should be unloaded with a magnet, either with an overhead crane or with a locomotive crane.

Though the materials for the cupola charges, as well as coke, generally have to be loaded on cupola charging cars by hand, nevertheless the number of times they are handled should be the smallest possible. In certain shops some of the pig iron is picked up seven times by hand before it goes down the cupola, owing to inadequate and badly arranged storage space, which necessitates piling the pig iron, and sometimes moving piles about, instead of allowing it to lie in heaps as unloaded from the cars. Though generally the cars or lots of pig iron are kept separate, to facilitate control of cupola "mixtures," nevertheless the greatest economy will result from providing ample space to allow of leaving the lots in heaps, from which the iron is picked up and loaded on charging cars. Whether these cars, and the coke and limestone, be brought to the cupola charging platform by elevator, by overhead crane or by rope tramway, the practice of hand charging of the cupolas, when many heats are made, is to be condemned as a waste of money. In place of the old-fashioned practice of storing coke and limestone (sometimes also pig and scrap) in heaps on the cupola charging floor, weighing them there and charging into the cupola by hand, which involves several rehandlings, some system should be adopted by which weighed lots of coke, limestone and metal are sent to a single man at the top, who dumps them into the cupola by mechanical means. The objection to this method has always been that the material is not evenly charged; but by using two or three charging doors in the cupola, and properly piling the materials on the cars, there is no doubt that as good work can be done in this respect as is generally done by a charging gang. In a well-arranged shop pig iron and scrap are handled only three times—once off the cars, once on to the charging cars, once down the cupola.

Handling the Cupola.—A word as to the handling of the cupola in Bessemer foundry practice will not be amiss. No one who has not assisted in turning out a long day's run, heat after heat, in a Bessemer

foundry, quite realizes the prime importance of hot cupola metal, tapped exactly when it is wanted. The efforts of the metallurgist and blower are set at naught, the advantages of carefully adjusted composition of the vessel charge are lost, and heat after heat of cold steel turned out, when the cupola gets behind and throws down cold metal. To assure the production of hot steel, heats should be tapped from the cupola smoking hot, and not held more than 5 or 10 minutes in the receiving ladle. Small cupola charges with properly proportioned coke are advisable, and every effort should be made to keep the cupola running uniformly.

Blowing—Bottom-blown Vessel.—The usual procedure in bottom-blown Bessemer shops is to charge heats of pig and scrap that will tap out of the cupola at about 1.60 to 1.80 per cent. silicon, and about .50 to .80 per cent. manganese, or even less. In blowing such a heat, the first period or silicon flame lasts from three to even six minutes, and after some four minutes blowing the resistance to the passage of the blast considerably increases and the blast pressure rises, probably owing to the very pasty slag formed. At this stage of the blowing there is practically no flame at the mouth of the vessel, because the oxygen of the blast is all used in the combustion of silicon and manganese, which form slag, and only the inert nitrogen of the air issues from the vessel.

For a bath of given composition, this period of the blow will be the shorter, and the carbon flame will appear the sooner, the hotter the steel is allowed to grow—because as the temperature rises a point is reached where carbon is oxidized in preference to silicon and manganese. Therefore, if the bath is allowed to grow hot undisturbed, carbon will begin to burn before silicon and manganese are completely eliminated, whereas if the temperature is held down by additions of cold scrap or washed metal, silicon and manganese will be nearly all gone before carbon starts to burn.

When the silicon is nearly eliminated the carbon flame begins to appear, and soon the full long flame, of an intense white color, plays from the vessel, and showers of sparks are thrown out. By the intensity of the light of this flame the blower judges the temperature of the metal, and takes steps to make the blow hotter or colder, according to the methods that are used in the shop. About 8 to 12 minutes after the vessel is turned up, the flame shortens in or “drops” (quite rapidly in the case of a low-manganese mixture), which means that the carbon is practically eliminated, and to prevent the oxidation of iron that begins when the carbon gets low, and

increases rapidly as the carbon drops to the final amount of about .08 to .10 per cent., the vessel should be turned down at once, and the blast shut off.

The recarburizers are now added. If used solid, they are preferably thrown into the vessel and a proper time allowed for them to melt, though they may be thrown into the steel as it runs from the vessel. When melted additions are used, they are sometimes poured into the vessel, though often they are poured into the large ladle and the blown metal then run in from the vessel.

The engineer of the blowing engine keeps the pressure up to the full amount of about 25 lb., unless he gets the signal from the blower to slack off. When the vessel is turned down, either at the end of the blow or because anything goes wrong, the engineer at once slows his engine, and stops it when the vessel reaches the horizontal, to avoid blowing out slag and steel. It is for this reason that the engine must be placed where the engineer can see the vessel.

Before taking up the various methods in use for heating or cooling the bath, a few words must be said about the supposed dangers of allowing the metal to become too hot, either before or during the carbon flame period. The nature of the process is such that there must inevitably be great oxidation of iron at all stages of the blow, since at the mouths of the tuyères the oxygen is in such great excess that not enough silicon, manganese and carbon are at hand to satisfy this oxygen, and some iron must be burned to FeO. But most of this FeO is at once reduced to iron again by carbon, silicon or manganese, as long as there is any considerable amount of these elements present, though some of it unites with the SiO₂ and MnO formed and the SiO₂ of the lining, and is lost in the slag. During the first period of the blow nothing comes through the bath (and the rapidly increasing mass of slag) except the inert nitrogen of the air, and probably a little oxygen that has passed through the bath uncombined. When the carbon begins to burn, CO is formed in the metal by the union of carbon and oxygen, escapes in bubbles, and rises rapidly, carried upward by its own heat and by the rush of nitrogen being blown through the vessel. Upon reaching the outside air this CO begins to burn to CO₂, with a flame that will be hotter or colder, more or less luminous, according to the temperature of the metal in the converter; because the hotter the metal, the hotter the gas that is forced through it and the hotter the CO formed in it. The flame itself, of course, is formed *at the mouth* of the vessel, exactly

as a flame is formed when we apply a match to a mass of combustible gas escaping from a pipe.

As the process proceeds, there are fewer and fewer carbon, silicon and manganese molecules to meet the molecules of FeO formed near the tuyères, rob them of their oxygen and return the iron to the bath. Hence, the formation of FeO increases rapidly toward the last of the blow, and when the vessel is turned down there is a great deal of it in the metal, besides the far larger part that has found its way into the slag when it met slag particles brought in contact with it by the violent bubbling of the bath. Since the formation of large amounts of this FeO cannot be prevented, the only question to be considered in this connection is whether the attainment of extreme temperatures increases the formation of FeO, and its retention by the steel.

This question probably must be answered in the affirmative, since it is known that the solubility of FeO in iron increases with increasing purity of the iron, and with increasing temperature. It is theoretically possible, even, that such extreme temperatures can be reached at the first part of the blow that the iron will dissolve FeO and hold it so tenaciously that even the carbon, silicon and manganese will not reduce it. In practice this is probably never true to any appreciable extent; but in the later stages of the process there is little doubt that with great increase of temperature the power of iron to dissolve its own oxide becomes so great that the affinity of carbon for oxygen is insufficient to reduce the FeO as rapidly as at lower temperatures, and therefore more FeO is formed and held dissolved in the metal.

Moreover because the solubility of the FeO in iron rises with rising temperature, in very hot heats the reduction of this FeO by the manganese of the recarburizers is more difficult. If, therefore, from the exigencies of our business we have to make our metal extremely hot in order to pour very small castings, we face a difficulty due to the greater retention of FeO by our steel, which is then probably more prone to chill rapidly and form blow holes in the castings. If the reasoning we generally depend upon is correct, the remedy is plain. We know that the more FeO we wish to remove the more manganese we must add to the steel; therefore, if the steel tends to form and hold more FeO than normal because we are blowing very hot, we must, in order to attain our usual grade of purity, increase our manganese additions. By so doing, we kill two birds with one stone, since the part of the extra manganese that is used up in removing

more FeO promotes fluidity and sound setting by increasing purity; and the part that remains in the steel increases fluidity by lowering the melting point of the steel, and perhaps also by its direct influence on the fluidity at a given number of degrees above the melting point.

The experience of the author has been that if there is no chemical analysis specification upon the castings being made, it is advisable to blow steel for small castings as hot as it is possible to make it; and though no doubt more FeO is formed and held in solution in the steel than in colder heats, yet by increasing the manganese addition to say 1.30 or 1.40 per cent., the extra oxidation is more than counterbalanced by the extra elimination of FeO, and a steel made that will run better and show fewer blow holes than can be produced in the converter in any other way.

Cooling the Metal.—The means adopted to cool heats that are too hot are first, to blow steam through the bath with the air by means of a steam pipe (with valve under the blower's control), admitting steam to the wind box. Second, to use cold scrap, pig iron or washed metal, thrown into the vessel before turning up, when it is thought the heat will be too hot, or shoveled in during the blowing. Third, to allow the heat to stand after blowing. The use of steam is not advisable, for though information is not in existence to show positively that it injures the steel, yet the consensus of leading authorities is that the steel is better when no steam is used. Scrap does the steel no harm, as its only effect is to cool the metal because it is itself cold and therefore in warming up and melting it reduces the temperature of the bath. It is best to get it in before the heat is turned up. If one or two heats have blown very hot, and the next one also runs smoking hot from the cupola, and must be blown at once without cooling off in the receiving ladle, from 50 to 300 lb. of cold scrap in a 3-ton heat will reduce the temperature of the steel considerably. Of course good scrap should be used. Heads or short pieces of gates from the foundry are best, as they can be dropped into the vessel easily. Should the heat blow too hot in spite of the scrap added, or a heat unexpectedly blow very hot, scrap can be dropped into the vessel from a long suspended shovel provided for the purpose.

Because of its purity, washed metal is sometimes used for this purpose, but it is a great waste of money to use it, as it is no more efficient a "cold metal" than scrap. It is no colder than scrap, and therefore absorbs no more heat in warming up; and as its melting point is lower than that of scrap it probably is really less efficient as a

cooler, because it melts at a lower temperature and hence takes less heat from the bath in warming up and melting.

Probably the simplest way to handle heats that have blown hotter than necessary is simply to allow them to stand in the vessel or ladle until their temperature has fallen to normal. As the metal cools, the iron retains its oxide less tenaciously, and the oxide is reduced by the carbon and manganese of the recarburizers; and the extra time allowed for this reaction tends to make it more complete.

Warming up the Metal.—A heat whose composition is already fixed may be warmed up in a number of ways. By shoveling 30 or 50 per cent. ferrosilicon into the vessel in lumps, or in pasteboard cans full of fines, silicon is added to the bath and the temperature greatly raised by the heat produced in oxidizing this extra silicon to SiO_2 . Generally, this material is added during the carbon flame period, when the blower is able to judge by the appearance of the flame, and the behavior of previous heats, whether or not his steel needs warming up.

The use of ferrosilicon for this purpose is mentioned in a patent on the use of manganese as a vessel addition, granted to R. A. Hadfield,¹ dated 1903; and is the subject of a later patent issued to A. Tropenas² in 1908. The Tropenas patent calls for the addition of the ferrosilicon when the carbon flame appears. Hadfield does not specify the exact stage when it should be added. In the Walrand process it was customary to add ferrosilicon quite early in the blow. This process, the invention of Walrand and Légenisel,³ which has been used more abroad than in America, is to blow nearly to the "drop of the flame" without additions of any kind; pour into the vessel a certain amount of molten ferro-silicon, containing generally 10 per cent. of silicon; turn up and blow until this silicon is eliminated; then turn down and proceed as usual. The iron is protected from oxidation during this "after blow" by the silicon, so that extra loss by oxidation is slight or non-existent, and very hot steel is produced.

Particulars of this method are given in two papers by Mr. G. J. Snelus, in the *Journal of the Iron and Steel Institute*.⁴ In the first article, it is stated that blowing small heats containing a high percentage of silicon, or adding ferrosilicon to the blow during the car-

¹U. S. Patent No. 743715, dated November 10, 1903.

²U. S. Patent No. 354694, dated February 25, 1908.

³U. S. Patent No. 503816, dated August 22, 1893, reissue No. 11570, dated 1895.

⁴Vol. 1, 1894, page 26, and Vol. 2, 1896, page 104.

bon flame period, had been tried prior to Walrand's invention and had proved a failure, because the gases evolved from the burning carbon carried away much of the heat produced by the combustion of the silicon. Mr. Snelus attributes the success of the Walrand method to the fact that the heat of oxidation of the silicon is rapidly evolved, and that there are no gases (except of course nitrogen), to carry away that heat.

In the second article the statement is made that in an English shop using this method, the vessel was turned down for the addition of ferrosilicon when the bath contained about 1.30 per cent. of carbon. The object of turning down before the complete elimination of carbon was to secure the presence of carbon during the after-blow to provide a flame, that there might be a "drop" to show when the added silicon was eliminated from the bath. In most of the shops using the method, the "drop" was determined by the vanishing of the carbon lines in the spectrum of the flame.

These methods are expensive, as they call for considerable amounts of ferrosilicon. Probably the simplest and cheapest way to accomplish the results desired is to turn the vessel slightly forward so that one or more of the tuyères are at or above the surface of the bath, and blow awhile in this position, slacking the blast to avoid blowing metal and slag all over the shop. By this means CO is burned to CO_2 , within the vessel, by the free oxygen from the exposed tuyère openings; and iron is oxidized to FeO and goes into the slag in considerably increased amounts, resulting in a further gain in temperature. Though this procedure results in decreased output, owing to greater loss of iron, yet it is cheaper to burn twenty dollar pig iron to get extra heat than to burn seventy dollar ferrosilicon (equivalent to \$140 silicon.)

Effect of Varying the Silicon and Manganese.—To increase the temperature of the steel by changing the composition of the metal charged to the vessel is the remedy for persistent cold blows, and is the method to be followed as far as possible. To add heat-producing elements is of course the only way to secure additional heat, and this can be done without extra cost by varying the silicon and manganese in the metal charged.

The heat of combustion of silicon is much greater than that of manganese, while that of carbon (to CO) is inconsiderable. At first sight, therefore, it would seem a simple matter merely to increase the percentage of silicon in the vessel charge and thereby make the steel blow very much hotter. But with mixtures con-

taining some 2 per cent. silicon and .60 to 1.00 per cent. manganese, the first period of the blow is very long, sometimes 6 minutes, without any shortening of the carbon flame period, so that a blow requires from 12 to 14 minutes. The pressure of the blast during the silicon-burning period becomes very great and the engine works hard and slows down. The steel produced is not as hot as would be expected. This result agrees with the statement of Walrand and Légenisel that it is difficult to secure hot steel in the bottom-blown vessel by the use of mixtures containing high percentages of silicon.

By the use of mixtures containing rather less silicon than in the above case, and in addition considerable amounts of manganese (the manganese often considerably exceeding the silicon), very good results have been attained. The first period of the blow lasts but one or two minutes, the carbon flame comes up very soon after blowing begins, and the total time of a blow is from 8 to 10 minutes. The metal is much hotter than that obtained from the high silicon mixture.

Complete data are not at hand to calculate the total amount of heat contributed to the charge by each of the above mixtures. From a rough estimate, however, it seems that the high silicon charge contributes more total heat than the high manganese metal. The latter appears to require somewhat less air to burn the metalloids than the former, but not enough to account for the greatly diminished blowing time; and a smaller proportion of the total heat produced would appear to be carried away in the gases, but not enough to account for the hotter steel produced, if the gases in each case are assumed to be heated to the same temperature.

In blowing the high silicon mixture, evidently no carbon is oxidized till silicon and manganese are largely eliminated, while in the case of the high manganese mixture the temperature at which carbon is oxidized in preference to manganese is soon reached, so that the burning of carbon begins while considerable amounts of manganese (and probably some silicon) remain in the metal. This speeds up the blow, because when carbon is being burned to CO, the bubbling produced by the escaping gas causes the bath to froth up in the vessel and offer greatly decreased resistance to the passage of the blast. That this is so is shown by the lowering of the pressure of the blast in a high silicon heat when carbon begins to burn, with accompanying speeding up of the engine; and by the fact that with the high manganese mixtures the pressure remains low from the first.

Thus the amount of air passing through the bath per minute is in-

creased and the operation shortened. The difference in the two cases, in the amount of heat lost by radiation, and in heating the entering air and the departing nitrogen and CO, is difficult of calculation; but that the air passing in greater volume and at greater speed through the freely boiling high manganese bath has less opportunity to absorb heat from the metal, and hence carries away much less heat, volume for volume, is quite probable. Thus the loss of heat to the gases in the case of the high manganese charge is probably much less than that in the high silicon charge, partly because less air in all is blown through the metal, and partly because the escaping gases are not heated so hot.

At the same time radiation losses are decreased, since the total time of the blow is so much shortened, and the radiation per minute is probably constant; and thus the mixture which gives probably less total heat actually produces much hotter steel.

In addition to their effect upon the heat of the steel, these high manganese mixtures cause marked changes in the slag, because the great amount of MnO produced makes the slag extremely fluid and watery. This is in some respects desirable, because a fluid slag of low melting point doubtless separates more completely from the metal in the ladle than the very gummy slags made with low manganese mixtures. This is because the fluid slags more easily form large globules by the union of small droplets, and these large globules float out of the steel far more rapidly than very finely divided particles. Moreover, the highly manganiferous irons do not pick up so much sulphur in the cupola as lower manganese irons, and if the cupola metal is allowed to stand 10 or 15 minutes in the receiving ladle, some of the sulphur floats out as sulphide of manganese.

The disadvantage of the high manganese mixtures are: first, that a slag rich in MnO corrodes the linings, and especially the bottom of the vessel severely, and second, that the fluidity of the slag sometimes results in explosive "slopping" of the vessel. This is in part due to the reaction between FeO of the slag and carbon of the steel. The first difficulty is much more than offset by the advantages secured; the second sometimes becomes a great nuisance. The easiest way to stop slopping appears to be to throw a few pounds of 50 or 60 per cent. ferrosilicon into the vessel. This probably acts by temporarily reducing the proportion of MnO and FeO and increasing the SiO₂ in the slag, and thereby rendering it less fluid and active; and if only a sufficient amount of sand or ground bricks could be got into

the slag, it would probably have the same effect. The slopping, however, takes place during the carbon flame period when the volume of gas coming from the vessel is so great that only very heavy materials can be dropped in; even a brick will not fall through the ascending current of gases, and if it would the chances are it would not melt and go into the slag quickly enough to stop the slopping.

The easiest and cheapest way to deal with this slopping is to allow plenty of room in the top of the vessel to take care of the bubbling slag, and to slack down the air pressure by slowing the engine when the vessel gives signs of trouble. When the vessel is newly lined, extra space can be secured by cutting down the weight of the heats, and making up for it by blowing one or two more heats a day; and as soon as the lining is cut away by the slags, there will be room enough to blow full-sized heats. This method has been found to work very well in practice, and the author has seen as many as sixteen or eighteen heats of high manganese metal blown in one day without the use of any vessel additions whatever to prevent slopping, many of the heats being poured into very small castings.

Published details of German Bessemer practice suggest the use of vessel mixtures running very high in silicon, even up to 3 per cent., with manganese around 1 per cent. The possibilities of this method have not to the author's knowledge been investigated by the users of small bottom-blown vessels in America. The experience with high silicon irons already mentioned would appear to show that the blowing time would be very long with such mixtures, and the gain in heat not as great as could be desired.

Blowing—Side-blown Vessel.—The metal generally charged to the side-blown vessel contains from 1.75 to 2.00 per cent. silicon, and .30 to .50 per cent. manganese. The vessel is tipped forward and the molten pig iron charged in the proper amount. The weight of the charge varies somewhat from day to day, as the lining of the vessel cuts away or builds up, and is fixed by the fact that the level of the metal must be such that it is just even with the bottom edge of the tuyères, when the vessel is tilted forward at an angle of some 7 or 8 degrees. The converter is tipped back to this angle after charging by means of a hand wheel, until the metal reaches the tuyères. If too little metal has been charged, so that the vessel is not inclined forward enough when the metal is at the tuyère level, more is charged till the angle is about right. The blast should strike well out toward the middle of the converter, so that it is important to have this angle correct.

When the correct amount of metal has been charged, the vessel is tipped forward one or two degrees, and the blast is turned on, at a pressure preferably of about $3\frac{3}{4}$ or 4 lb. At first, only sparks come from the mouth of the vessel; and as the metalloids are eliminated from the bath and the volume of the metal decreased, the vessel is gradually turned toward the vertical, so that the blast shall continue to impinge upon the bath at the correct spot. After about 3 or 4 minutes blowing, a faint flame appears at the mouth of the vessel, which soon increases in size; on thus "getting a light," as it is called, the vessel may be tipped back a little, which will assist in bringing up the full flame, and the blast may be reduced a little.

The flame at this stage of the blow is short and rather thin, looking much like the ordinary Bessemer flame when it first appears. After some 5 to 15 minutes blowing (the vessel meanwhile being gradually turned nearer and nearer the vertical), the flame begins to lengthen out and grow brighter, and a "boil" takes place. This is accompanied by a flame much like a full ordinary Bessemer flame, and often by the throwing out of a good deal of slag and frequently of metal. In order to keep the charge in the vessel during a boil, the blast is slacked down as low as possible, without filling the tuyères. It is not possible to lower the blast below about $1\frac{1}{4}$ lb., without allowing the metal or slag to run into the wind box. The long flame of the boil seldom lasts much over a minute or possibly two, and the flame quickly goes back to its former dimensions. Frequently, there are several boils, at intervals of from 3 to 10 minutes, not all of which are well marked. As many as four or five may occur.

Should the volume of the metal become so low that the blast cannot be made to strike the bath at the proper point, so that the flame goes out, pig iron or ferrosilicon is charged cold, or the vessel is turned forward, the blast taken off, and more fluid metal charged to make the volume right.

It is important in blowing to keep tipping the vessel up so that the blast shall impinge upon the bath at the correct point, and the tuyères be the proper distance above the surface of the metal. If the tuyères get too high above the metal, the tubes of slag that form at the noses of the tuyères by the chilling of the slag will get so long as to interfere seriously with the blast, partially shutting it off and allowing it to strike at improper points. The result is frequently great oxidation of the metal, and violent slopping.

After one or more boils, followed by the subsidence of the flame

to its former size, the "final flame" appears. This is long, intensely white, and feathery at its upper edge, and is the only long flame the vessel gives that lasts more than about a minute. Frequently, slag or metal is thrown out during this stage of the process, but the experienced blower seldom fails to recognize the final flame. The "drop" is much like that of the regular Bessemer flame, and when it appears the vessel is turned down and the blast shut off. The total time of a blow will be from 14 to 25 or 30 minutes.

If the blower is uncertain whether or not he has had a final flame and drop, the vessel is turned down and the bath inspected. If the final flame has occurred and the carbon is eliminated, the metal and slag lie quiet and flat in the vessel without bubbling; whereas if there is still carbon in the metal, the slag boils fairly strongly.

It will be seen from the foregoing that the burning of silicon, manganese, and especially carbon, progresses slowly in the side-blown vessel, with one or more periods of sudden increase in the rate of elimination, accompanied by strong boiling of the slag and consequent slopping. Evidently as the blast rushes over the surface of the bath, silicon, manganese, carbon and iron are oxidized, and a slag formed which grows progressively richer and richer in FeO as the carbon, silicon and manganese are eliminated from the surface metal, leaving the iron unprotected and hence more free to oxidize. The circulation of the bath is not sufficient to reduce this FeO by the action of carbon, silicon and manganese to anything like the same extent as is possible in the bottom-blown vessel, where FeO is formed at the bottom of the bath and is largely reduced by the metalloids before it can swim to the surface and enter the slag.

As the oxidation of the metalloids progresses, a point is reached where the slag becomes very high in FeO available for reaction with carbon, and at the same time the fluidity of the slag reaches a maximum. Doubtless the action of the blast is largely confined to the upper layers of the metal, reducing its contents of carbon, silicon and manganese to a very low point, and oxidizing much of its iron to FeO, especially as the surface soon grows so hot and the carbon so low that the oxidation of iron is very rapid. Then the effect of the slag on the metal begins to be more violent, probably assisted by diffusion of carbon into the upper layer from below; the metal and slag begin to boil, the FeO oxidizing silicon, manganese and carbon from the metal rapidly, and soon the boiling becomes very violent. A long flame is thrown out because the CO is evolved so rapidly that it burns to CO₂ largely at the vessel's mouth. Upon the ex-

haustion of the available FeO of the slag this reaction subsides, and the bath, well mixed by the strong boil, is again subjected to slow oxidation, followed by renewed boilings when the slag reaches the proper composition.

If vessel mixtures are blown that contain from .75 per cent. to 1 per cent. of manganese with the usual silicon, the boiling and slopping are very violent and result in a great loss of metal. This is no doubt due to the fact that the MnO formed by the combustion of the manganese makes the slag very watery and promotes the reaction between the carbon of the bath and the FeO of the slag.

Ferrosilicon is thrown into the vessel to discourage boiling, as well as to provide extra heat. It probably acts on the slag in the same way as in the bottom-blown vessel, by increasing the SiO₂ and reducing the FeO, thereby rendering the slag less fluid, and postponing its reaction with the carbon of the bath.

So far as the author is aware, the addition of pig iron, washed metal, or scrap in order to cool the steel when it gets too hot is not often resorted to in side-blown practice. The same additions can be used as for a bottom-blown vessel when it is desired to keep the temperature down, as for instance, for a large casting; but as in bottom-blown practice it is probably the best and most economical practice to simply let a hot heat cool off, and if necessary increase the manganese additions to more thoroughly reduce FeO from the steel.

Recarburizing in the vessel is very common practice in side-blown foundries. This is owing partly perhaps to the inviting angle at which the vessel stands when "turned down," with its open throat conveniently disposed to throw or pour the recarburizers down into the metal, unlike the bottom-blown vessel which has to be turned into a horizontal position in order that the metal may clear the tuyères when the blast is shut off.

The size of heats and hence the amount of recarburizer varies from day to day, as has been already explained, according to the condition of the lining of the vessel. Generally it will be sufficiently accurate to estimate the increase or decrease in capacity each day and proportion the recarburizer to be added accordingly; but of course if greater accuracy is required, the first heat of the day can be weighed in the ladle and any error in the estimate corrected.

The weighing of melted recarburizer is to be recommended, though if it is melted in crucibles, weighing before melting is generally sufficiently accurate for small additions. Cupola metal can be

measured fairly accurately by volume instead of by weight, by using small ladles of known capacity to take off the desired amount. For heavy additions and rapid working, however, platform scales on which the entire addition is weighed in one ladle are essential.

A bottom-blown vessel easily turns out three heats per hour, so that from 18 to 25 heats can be blown per day, running single turn. This rate can be maintained every day in the week. A side-blown vessel takes so much longer to blow each heat that the production is only about two heats per hour, or 9 to 12 heats per day. On account of the necessity for repairing the lining, a single side-blown vessel can rarely produce more than 40 heats per week. Side-blown plants, however, generally use two or three vessels, so that a production of 12 heats per day, or 72 per week, can be regularly obtained.

These rates of production can be considerably increased, if the cupola capacity is available to provide metal. As a bottom-blown vessel seldom requires over 12 minutes to blow a heat, and a side-blown 20 to 25 minutes, it is of course possible by driving to turn out steel at a rate greatly exceeding that given, especially for a short time. Thus in bottom-blown shops, when three or four heats are required for a large casting, one heat is charged in the vessel and held until the next heat is tapped from the cupola into the receiving ladle. By the time heat one is blown, heat three is ready to tap from the cupola, again filling the ladle, and heat four is tapped from the cupola soon after blowing starts on heat three; thus four heats are turned out as fast as the vessel can take care of them. Since the third and fourth heats are charged into the vessel almost as soon as tapped, they are so hot when charged as to need less silicon than the first and second heats, especially as the steel for a large casting need not, generally must not, be too hot. The average blowing time is reduced by cutting the silicon and manganese in the later heats, and thus it is possible to blow four heats in about 40 to 45 minutes.

The methods of pouring Bessemer steel vary somewhat with the size of the castings that are being made, and with the preferences of the man in charge. In some shops the whole heat is poured into a large ladle, and castings poured directly from this, or from "shanks" filled from the large ladles. In others, the shanks are filled directly from the vessel. In the latter case recarburizing in the vessel must be the practice adopted, in the former it may be. Again some shops use a stopper and nozzle in the large ladles, some pour "over the lip." The discussion of the relative advantages of these methods properly

belongs in the chapter on moulding and pouring, and is given there in some detail.

THE RAW MATERIALS

The raw materials of the baby Bessemer process for steel foundries are:

1. Low phosphorus pig.
2. Low phosphorus scrap.
3. Ferromanganese, ferrosilicon, etc.
4. Heads, gates, and "wastered" castings.

The fuel is coke for the cupolas, oil, hard coal, etc., for physic furnaces other than cupolas, and coal or oil for the boilers of the blowing engine of the bottom-blown vessel.

The increase of phosphorus and sulphur, resulting from the remelting of scrap, is greater in the Bessemer process than in any other, both because the loss of iron in converting to steel is greater, and because a great deal of sulphur is "picked up" from the coke in the cupolas. In order to make steel within the limits of standard specifications, therefore, the greatest care must be taken in the selection of raw materials. In order to keep the phosphorus and sulphur content of the steel below .05 per cent., both pig iron and scrap must contain well under .03 per cent. of those impurities. There is a very limited supply of "low phosphorus" iron, and the price is necessarily very high, consequently the greatest possible amount of low phosphorus steel scrap should be worked into the cupola mixture. This scrap is generally used in the shape of plate trimmings, and in that form is cheaper than the standard "low phosphorus heavy melting scrap" sold for open-hearth use. For open-hearth furnaces this plate scrap is so light that a great loss is encountered in melting it, but it is well suited to cupola melting. Heavy steel scrap is very hard to melt in the cupola, and should be used sparingly, if at all.

The furnaces smelting the iron ores of Cornwall, Pa., produce a low phosphorus and sulphur pig iron, that contains from .40 per cent. to .90 per cent. or so of copper. For many years even slight amounts of copper in steel have been considered deleterious, and consequently this pig iron has been sold considerably cheaper than standard low phosphorus pig. The researches of late years have shown clearly what has long been known in some shops, viz., that copper below .50 per cent., or even .70 per cent., is not at all harmful to steel if the sulphur be kept low; and the use of this copper-bearing pig is greatly increasing.