Because the absorption of sulphur from the coke is very considerable, a limit for sulphur in coke has to be made, and none should be used with over 1 per cent. of this impurity. It is just as well to draw the specifications to cover the content of ash at the same time, and refuse coke with ash over 10 or 12 per cent. Good foundry coke will conform to these figures, but the choice of a coke should be governed also by its texture and hardness. Too hard a coke that shatters badly in handling is in general not a good fuel for cupola melting; no specifications, of course, can be drawn for physical characteristics, and the best way to find out if a coke is suitable is to try a carload or so of it, always bearing in mind the natural conservatism of the average workman, who has an inveterate habit of getting used to one brand of coke, or one shape of scrap, and moving heaven and earth to prevent the purchase of any material other than what he has been using.

The proportion of purchased scrap that can be used is governed by the amount of heads, gates and "wastered" castings that the shop produces and has to melt up. Roughly from 30 to 50 per cent. of the metal in the ladle finds its way to scrap, so that at least 30 per cent. of the cupola charges has to be shop scrap. This remelting of scrap causes an increase of the phosphorus and sulphur content of the steel of successive heats, which, as Mr. Jameson has shown us, works up to a limit by progressively decreasing increments.

Taking his equations,[1] let us see what are the limits of phosphorus, sulphur and copper content that we shall attain in our steel, using a mixture of 30 per cent. of our own scrap, 10 per cent. of purchased plate scrap and 60 per cent. pig iron, of which two-thirds is iron containing .70 per cent. copper, one-third standard low phosphorus iron. Phosphorus and sulphur in purchased pig and scrap, .03 per cent. Converting loss, 12 per cent. (a good average for bottom-blown vessels). "Pick-up" of sulphur in melting, .01 per cent. Then, for the limits of phosphorus, sulphur and copper reached by our steel, using the formulæ,

$$X = \frac{(100-a)c}{100-(a+b)} \text{ and } X = \frac{(100-a)c+100d}{100-(a+b)}$$

Where X = per cent. of element in question after maximum is reached.

a = per cent. of scrap remelted = 30 per cent.

$100-a$ = per cent. of new material melted = 70 per cent.

b = converting loss = 12 per cent.

c = per cent. of element in question in pig and plate scrap = .03 per cent.

d = "pick up" (.01 for S).

[1] See Chapter XII

For Phosphorus[1]

$$X = \frac{70(.03)}{58} = .036 \text{ per cent.}$$

For Sulphur

$$X = \frac{70(.03)+100(.01)}{58} = .053 \text{ per cent.}$$

For Copper

$$\frac{40(.70)}{70} = .40 \text{ per cent. copper in new material}$$

$$X = \frac{70(.40)}{58} = .48 \text{ per cent.}$$

Since the ferromanganese used as recarburizer contains considerable amounts of phosphorus, generally averaging .30 per cent., it is necessary to take this factor into account in figuring out our X or maximum phosphorus that we will attain in our steel. To show clearly the influence of this factor in the problem, the following examples are appended, giving actual calculations made on several steels in which varying amounts of ferromanganese are used, depending on the amount of manganese desired in the finished product. From these figures it will be seen that the ferromanganese has a considerable effect on the phosphorus content of the steel. This effect, of course, increases with the amount of ferromanganese used per heat.

Ordinary Steel with 1.30 Per Cent. Manganese

80 lb. ferromanganese at .3 per cent. phosphorus }
22 lb. ferrosilicon at .1 per cent. phosphorus } physic
1400 lb. foundry scrap at X per cent. phosphorus }
4600 lb. new pig and scrap at .03 per cent. phosphorus } charged to cupola

5350 lb. steel produced

$$X = \frac{80(.3)+22(.1)+1400X+4600(.03)}{5350} = .042 \text{ per cent.}$$

Ordinary Steel with .60 Per Cent. Manganese

Using the same mixture, but only 40 lb. ferromanganese for physic.

$$X = \frac{40(.3)+22(.1)+1400X+4600(.03)}{5300} = .039 \text{ per cent.}$$

Figuring Cupola Charges.—To illustrate the methods of figuring cupola charges for Bessemer work, a few typical examples are here

[1] Sometimes phosphorus as well as sulphur may be picked up from the coke in the cupola. When this is the case, the second formula should, of course, be used for this calculation.

introduced. In this connection it is as well to state definitely that "mixing" has to be done wholly by analysis, and for that reason the use of several "brands" or makes of pig iron is not at all necessary. It will be found advantageous, nevertheless, to use at least four lots of pig iron for mixtures, because it is quite out of the question to obtain pig of uniform silicon content, and in order to keep the composition of the successive heats as nearly constant as possible from day to day, without constant figuring of new charges, several lots of iron must be used. Generally two lots will give out nearly together, and then two more can be selected and used, whose average silicon content is the same as the average of the two replaced. With four lots of pig and two kinds of scrap, composition can be kept fairly even for weeks by judicious selection, without the necessity of refiguring mixtures.

Desired { Si 2.10 per cent.
Mn low

Kind	Si, per cent.	Mn, per cent.	Cu, per cent.	Wght.	Si, lb.	Mn, lb.
Pig 1 Std. low P............	3.00	.30	0	1000	30.0	
Pig 2 Std. low P............	2.20	.30	0	800	17.6	
Pig 3 Cornwall low P......	3.30	.30	.60	1400	46.2	12.6
Pig 4 Cornwall low P......	2.50	.30	.50	1000	25.0	
Foundry scrap.............	.40	.60	.65	1800	7.2	10.8
				6000	126.0	23.4
					2.10%	.39%

Desired { Si 2.00 per cent.
Mn 1.50 per cent.

Kind	Si, per cent.	Mn, per cent.	Cu, per cent.	Wght.	Si, lb.	Mn, lb.
Pig 1 Std. low P............	3.00	1.80	0	1000	30.0	18.0
Pig 2 Std. low P............	2.20	2.20	0	1100	24.2	24.2
Pig 3 Std. low P............	3.30	1.60	0	900	29.7	14.4
Pig 4 Std. low P............	2.50	1.90	0	1200	30.0	22.8
Foundry scrap.............	.40	.60	.65	1800	7.2	10.8
				6000	121.1	90.2
					2.02%	1.50%

Desired { Si 1.80 per cent.
Mn low

Kind	Si, per cent.	Mn, per cent.	Cu, per cent.	Wght.	Si, lb.	Mn, lb.
Pig 1 Std. low P............	2.00	.30	......	700	14.0	2.1
Pig 2 Std. low P............	2.50	1.50	......	800	20.0	12.0
Pig 3 Lebanon low P......	2.90	.30	.60	1000	29.0	3.0
Pig 4 Lebanon low P......	3.40	.30	.50	1100	37.4	3.3
Foundry scrap.............	.40	.60	.65	1800	7.2	10.8
Plate scrap.................	.10	.60	......	600	0.6	3.6
				6000	108.2	34.8
					1.80%	.58%

This work is so much a matter of arithmetical juggling that it is not worth while to give more than these few examples. Low phosphorus plate scrap can be used in greater or less amounts to balance variations in silicon in the pig iron. If there is a shortage of foundry scrap, plate scrap should be worked in to take its place and save pig iron, the most costly raw material used. If much scrap is to be melted (it is generally best to melt at least 40 per cent.), the pig irons bought have to be correspondingly high in silicon; and the man in charge of this work has to keep close watch of his stocks of raw material in order to specify the silicon content of his pig iron to suit his future requirements. The use of 10 per cent. ferrosilicon and steel scrap to take the place of part of the pig iron is perfectly possible, though it will be hard to make the scrap and ferrosilicon melt at a sufficiently even rate in the cupola to give heats of the uniform composition so essential for good blowing. Even in melting pig iron and scrap, the unevenness of composition of successive heats, due to the more easily fusible materials of the charges melting first and running ahead of the other stock, sometimes gives the blower trouble. A large proportion of plate scrap can be melted in the cupola charge, and the shortage of silicon made up by adding 50 per cent. ferrosilicon melted separately. Generally there is no financial advantage in using these materials, as it is cheaper to use pig iron. As mentioned in the introductory chapters, in places where pig iron is costly and scrap cheap, the use of these materials in large percentages may be advantageous.

The silicon and manganese in the metal run from the cupola will be somewhat lower than in the metal charged, on account of oxidation in melting, some 20 per cent. of the silicon being so lost. Of the

two, the manganese suffers the greater loss, when it is present in considerable amounts. The exact composition of the metal tapped will vary somewhat from heat to heat.

When a given charge is used, the silicon and even more the manganese content of the metal run from the cupola tend to fall off, toward the end of the day's run. This can be taken care of by changing the mixture used for the later heats, but one should be careful not to go too far in this direction, since the cupola metal toward the last of the run is often hotter than that tapped earlier, so that in these heats less manganese and silicon are needed for the production of hot steel.

Figuring Recarburizers.—The figuring of additions to the steel is so simple a matter that a very few words must suffice to illustrate it. The materials available for this purpose are:

Material	Source of
1. Cupola metal	C (Si) (Mn)
2. 80 per cent. ferromanganese	C Mn
3. 20 per cent. spiegel	C Mn
4. 50 to 60 per cent. ferrosilicon	Si
5. 10 to 12 per cent. ferrosilicon	C Si
6. Silico-spiegel	C Si Mn
7. Pig iron	C (Si) (Mn)
8. Hard coal, coke, etc.	C
9. Carborundum	C Si
10. Nickel	Ni
11. Ferrochromes	(C) Cr

The choice among the many materials that can be used depends largely upon three considerations, as follows:

1. Are additions to be melted or solid?
2. If melted, by what method?
3. Is the steel to be of high or of low carbon content?

If solid additions are to be used, naturally the choice falls upon materials as high in the desired elements as can be obtained, unless too high a melting point results from great purity. Eighty per cent. ferromanganese, 60 per cent. ferrosilicon, etc., are then used, and extra carbon, if needed, obtained from additions of coke or of cupola metal.

If much hard steel, or steel high in various alloys, is to be made, the recarburizer generally has to be melted. As far as possible, metal from the main cupolas should be taken to make up recarburizer for hard steel heats, since it saves the melting of large separate lots of recarburizer.

The melting furnaces that are used are generally of a sort suited to intermittent operation, because a Bessemer plant is seldom run continuously. The furnaces that can be used are:

(1) Small cupola.
(2) Air furnace, or oil-fired furnace of some kind.
(3) Crucible furnace, generally oil or coal fired.
(4) Electric furnace.

The choice is governed by

(1) Nature of material to be melted.
(2) Amount of material to be melted.
(3) Cost of melting.
(4) Continuous or intermittent operation.

The cupola is suited to melting low percentage ferro alloys, and melts large quantities cheaply. Ferros such as 80 per cent. ferromanganese and 50 per cent. ferrosilicon lose too much by oxidation when melted in cupolas, and are generally handled in crucibles or a small electric furnace. The air furnace or some type of non-crucible oil melting furnace may be used in some cases as a substitute for the cupola, for instance, in places where coke is costly. The electric furnace can be substituted for the crucible furnace under some circumstances; it will in some cases give cheaper melting.

Whenever possible, the recarburizers should be used molten, as there is no doubt that they purify the steel far better when so added. When the additions are but a small fraction of the weight of the heat, especially if the steel is hot enough to melt them readily, and time is allowed for them to melt and act on the steel, quite good work can be done with solid recarburizers. But molten metal would do better.

Summarizing this question, the methods used in adding recarburizers are as follows:

1. Adding solid in ladle—least effective.
2. Adding solid in vessel—better.
3. Adding liquid in ladle—better yet.
4. Adding liquid in vessel—best.

If low carbon steel high in silicon and manganese is to be made, the choice must fall on high percentage silicon and manganese alloys because, as the following figures show, the low percentage alloys contain too much carbon per unit of silicon or manganese. For instance, a steel of silicon .40 per cent., manganese .80 per cent., using 20 per cent. spiegel and 10 per cent. ferrosilicon, would figure out as follows:

Kind	C, per cent.	Si, per cent.	Mn, per cent.	Wght.	C, lb.	Si, lb.	Mn, lb.
Spiegel...............	4.5	......	20	35.4	1.59	......	7.08
Ferrosilicon............	1.8	10	......	30.8	0.55	3.08	......
Blown metal..........	.10	.10	.10	934.0	.93	.93	.93
				1000.2	3.07	4.01	8.01
					.30%	.40%	.80%

These alloys thus contain too much carbon for our purposes, if we desire steel below .30 per cent. carbon.

Using 80 per cent. ferromanganese and 50 per cent. ferrosilicon, we figure as follows:

Kind	C, per cent.	Si, per cent.	Mn, per cent.	Wght.	C, lb.	Si, lb.	Mn, lb.
Ferromanganese.......	6	......	80	8.8	.528	......	7.04
Ferrosilicon............	.5	50	......	6.0	.030	3.0	......
Blown metal..........	.10	.10	.10	985.0	.985	.985	.985
				999.8	1.543	3.985	8.025
					.15%	.40%	.80%

To make steel of .20 per cent. carbon, the extra half pound of carbon needed can be added as coke, in which case we add 1 lb., allowing for a loss of 50 per cent.; or better we use cupola metal. If this contains 2 per cent. silicon, .50 per cent. manganese, 3.5 per cent. carbon, we have to cut our ferrosilicon and ferromanganese accordingly, thus,

Kind	Wght., lb.	C, lb.	Si, lb.	Mn, lb.
50 per cent. ferrosilicon.	5.5	.0275	2.75	....
80 per cent. ferromanganese...............	8.7	.5220	....	6.96
Cupola metal..........	12	.4200	.24	.06
Blown metal..........	975	.975	.975	.975
	1001.2	1.9445	3.965	7.995
		.19%	.40%	.80%

On the other hand, for steels above .34 per cent. carbon or so, the spiegel and ferrosilicon will not contain enough carbon for our purposes, and we must either melt pig iron with them, or use cupola metal to make up the deficiency as before. Whichever we do,

allowance must be made for the silicon and manganese in the pig iron or the cupola metal. Even in this case, however, it is not by any means necessary to use the low percentage alloys, melted in the cupola, as it may sometimes be cheaper to use the higher percentage ferros added solid, or even melted. For steel of .45 per cent. carbon, .40 per cent. silicon, .80 per cent. manganese, we have the following four methods open to us.

1. Using 20 per cent. spiegel, 10 per cent. ferrosilicon, and pig iron (carbon 3.5 per cent., silicon 1 per cent., manganese .50 per cent.).

Kind	Wght., lb.	C, lb.	Si, lb.	Mn, lb.
10 per cent. ferrosilicon..	27	.486	2.7	....
20 per cent. spiegel......	35	1.575	....	7.00
Pig....................	43	1.505	.43	.215
Blown metal..........	900	.900	.90	.900
	1005	4.466	4.03	8.115
		.45%	.40%	.81%

2. Using 20 per cent. spiegel, 10 per cent. ferrosilicon, and cupola metal (3.5 per cent. carbon, 2 per cent. silicon, .50 per cent. manganese).

Kind	Wght., lb.	C, lb.	Si, lb.	Mn, lb.
10 per cent. ferrosilicon.	23	.414	2.3	....
20 per cent. spiegel......	35	1.575	....	7.00
Cupola metal..........	46	1.610	.92	.23
Blown metal..........	900	.900	.90	.90
	1004	4.499	4.12	8.13
		.45%	.41%	.81%

3. Using 50 per cent. ferrosilicon, 80 per cent. ferromanganese, and cupola metal.

Kind	Wght., lb.	C, lb.	Si, lb.	Mn, lb.
50 per cent. ferrosilicon.	3	.015	1.50	....
80 per cent. ferromanganese................	8.5	.510	....	6.80
Cupola metal..........	91	3.185	1.82	.455
Blown metal..........	900	.900	.90	.900
	1002.5	4.610	4.22	8.155
		.46%	.42%	.82%

4. Using 50 per cent. ferrosilicon, 80 per cent. ferromanganese and pig iron. This calculation will be very much like number 3.

As we have already set forth at some length in the introductory chapters, Bessemer metal is more overoxidized than open-hearth steel, and even when the deoxidizers are added molten in the converter, the removal of oxides is never complete. Nevertheless, if both ferromanganese (80 per cent.) and ferrosilicon (generally 50 per cent.) are added as deoxidizers, and especially if they are used molten, steel can be produced that is comparatively free from oxides and gases, and castings are poured that are quite free from blow holes, etc. The difficulty of deoxidizing the steel sufficiently to prevent blow holes increases greatly as the carbon content of the steel produced is reduced. Thus some shops that add enough ferromanganese, ferrosilicon and pig iron (or metal from the cupola), to produce steel of .50 per cent. carbon with the usual silicon and manganese, pour castings of this metal without great difficulty; but ask them to pour .20 per cent. or .15 per cent. carbon steel and they get into trouble with blow holes and misrun castings.

To examine this question a little more closely, we may take an example from practice. At one shop it was found that composition (A) (below) would run well, and gave castings with few blow holes; composition (B) soon became pasty in pouring, ran badly and gave castings with many blow holes; this trouble was corrected by substituting composition (C) for composition B.

	A	B	C
C....................	.40 per cent.	.20 per cent.	.20 per cent.
Si....................	.30 per cent.	.30 per cent.	.30 per cent.
Mn....................	.60 per cent.	.60 per cent.	1.30 per cent.

In explanation of this, it is suggested that steel B becomes sticky sooner than A or C, for the following reasons.

1. Carbon and manganese both lower the melting point of steel, therefore B's melting point is highest.

2. Carbon and manganese both increase the fluidity of molten steel, especially just before freezing. Steels low in carbon, silicon and manganese go through a longer period when they are sticky than those high in one or all of these elements. Therefore B soon became sticky.

3. The purer the iron, the more tenaciously it holds its oxides. Therefore B is probably less well cleansed of oxide than A, because it is more nearly pure iron, and therefore the same amount of silicon and manganese less thoroughly removes the oxide; and less well than C because the lower manganese less thoroughly removes the oxide.

4. The lower the temperature of the iron, the less tenaciously it holds its oxides, and the greater the tendency of carbon, silicon and manganese to reduce them. Therefore B is probably less well freed of oxide than A or C, because it freezes at a higher temperature.

5. Probably oxides both raise the melting point of the steel, and decrease its fluidity, hence B will be less fluid and have a higher melting point than A and C from this cause also. This follows from considerations 3 and 4.

The stickiness of steel of composition B rendered it a difficult matter to run such a steel into small sections. A 3-ton heat soon became too "mushy" to run into light work, and many of the castings poured of metal approaching the mushy state were full of blow holes.

There are many ways in which the greater abundance of blow holes in steel B than in A or C may be explained, the most probable being that owing to the higher melting point of B, less time is allowed for the escape of gases from this steel, which are therefore carried over in considerable quantity into the mushy stage just before freezing, when their escape is greatly hindered by the resistance of the mushy steel to their egress. It may be added that additions of aluminum, silicon-calcium and other deoxidizers improved the pouring qualities of steel B, but as the same additions were used for steels A and C, the relative ease of handling was not affected by these additions; and as steel C was found to be superior in physical properties to either A or B, it soon displaced them both in the foundry. It was as strong or stronger than A, and as tough or tougher than B, without being in any way too hard for common use. This foundry had for years had difficulty in pouring steel of as low as .20 per cent. carbon and had been deterred from trying composition C by the opinion, long commonly held, that more than 1 per cent. of manganese rendered the steel brittle. No doubt harder steels, containing from .45 per cent. of carbon up, such as are used for the manufacture of rails, are rendered brittle by such high percentages of manganese. At any rate, the rail mill men formerly held that 1 per cent. was about the maximum content of manganese that it was safe to add to their steel. But in the case of soft steels, much more manganese can be used not only with safety, but even with great benefit to the steel. This is perhaps because the functions of manganese and of carbon in steel are much alike, so that it is the sum of their percentages, or the sum of some multiple of the percentage of each, that cannot exceed a certain figure without producing a brittle steel.

Using coke or coal in the ladle as a source of carbon is a practice to be avoided whenever possible. To sum up this subject, the composition of typical recarburizers and the methods of using them are given in the following table.

Material	C, %	Si, %	Mn, %	Ni, %	Cr, %	Used	In	Melted in
Cupola metal...	3–4	1–2	.5–3	......	......	Molten	Vessel or ladle	C
Ferromanganese.	6–7	.30	80	......	......	Molten, solid	Vessel or ladle	Cr–E
Spiegel.........	4–5	.30	20	......	......	Molten	Vessel or ladle	C–A
Ferrosilicon......	0.5	50		......	......	Molten, solid	Vessel or ladle	Cr–E
Ferrosilicon......	1.8	10		......	......	Molten	Vessel or ladle	C–A
Silico-spiegel....	1.9	10	20	......	......	Molten	Vessel or ladle	C–A
Pig iron.........	3–4	1–3.5	.30–3	......	......	Molten	Vessel or ladle	C–A
Hard coal, coke..	50					Solid	Ladle	......
Nickel..........	.50	......	......	99	......	Molten	Vessel or ladle	Cr–E
Ferrochrome....	7–8				70	Molten	Vessel or ladle	Cr–E
Ferrochrome....	.50–2				70	Molten	Vessel or ladle	Cr–E

C = cupola. Cr = crucible. E = Electric furnace. A = Air furnace.

ALLOY STEELS

The composition of Bessemer steel may be varied within wide limits with comparative ease, since the blown metal is practically pure iron, containing only about .10 per cent. of carbon, silicon and manganese, and therefore by properly proportioning the recarburizers, the chemical content may be made almost anything we please. In this connection, however, it should be remembered that if heavy additions are to be made to the steel, in order to secure high carbon content, or a high content in manganese, nickel, chrome, or other alloy, it is often essential to melt these additions. If this is not done, the steel will be so chilled that it will be impossible to pour it; indeed, in the case of some of the alloy steels now made in great quantities, to attempt to use solid additions would result in practically solidifying the steel in the ladles or vessel.

The limitations of the Bessemer process in the production of alloy steels are chiefly confined to chrome, tungsten and molybdenum steels. These alloys often have to be added molten, and ferrochromes are very hard to melt alone, ferrotungsten and ferromolybdenum even more so, while metallic tungsten and molybdenum cannot be melted alone. With sufficient amounts of ferromanganese or pig iron, ferrochromes can be melted, but if crucibles are used for melting, low carbon ferrochromes will absorb carbon from the graphite of the crucibles very rapidly, so that the production of low carbon chrome steels of high chrome content is not at

all easy. Tungsten and molybdenum steels of high alloy content and low carbon are almost impossible to produce by Bessemer methods.

In the manufacture of nickel-chrome steel, the Mayari pig irons can be used to great advantage, as almost all of the nickel remains in the metal after blowing. The chrome is reduced by oxidation losses from about 2 per cent. to some .50 to .70 per cent.

Similarly, if nickel and chrome, or nickel-chrome steels are manufactured in quantity, it will pay to keep the scrap from these heats separate and use it in the manufacture of the alloy steel, because much of the chrome and nearly all of the nickel can be counted upon to remain in the metal and reduce the consumption of nickel and ferrochrome proportionately.

The Bessemer process is particularly well suited to the manufacture of manganese steel, for the following reasons.

First, Bessemer blown metal and ferromanganese, mixed together in such proportions as to give the manganese content desired, result in a steel of correct composition in carbon and silicon.

Second, manganese steel is poured largely into comparatively small castings; hence the very hot Bessemer metal, made in small heats at frequent intervals, is well suited to the pouring problems presented.

Third, the enormous dose of ferromanganese added to the blown metal deoxidizes it to an extent that is quite sufficient to make the quality of the steel as high as is needed.

The special problems presented in the manufacture of this steel are the melting of the ferromanganese, which is used in such great quantities that it cannot be added solid, and the working up of the scrap.

The ferromanganese is commonly melted by one of the processes suitable for high percentage alloys, as, for instance, the crucible furnace or the electric furnace. In spite of the cost of these methods of melting, they generally will do cheaper work than any others, as by their use heavy losses of manganese by oxidation in melting are avoided. Efforts are being made with varying success to substitute cheaper melting methods.

The scrap problem is a hard nut to crack, because in remelting and blowing this metal the manganese is necessarily all oxidized and lost. By using as much of the scrap as possible in the cupola charge, and by using it in place of spiegel for recarburizer in the manufacture of ordinary steel, the accumulation is greatly cut down.

What cannot be used is sold to the open-hearth shops, who do not save the manganese the metal contains. Electric furnace melting will save the manganese, but considerations of cost have so far prevented its adoption for this purpose.

Crucible or cupola melting of the scrap for use direct is not feasible, because of the great absorption of carbon that necessarily occurs in the process.

The Basic Bessemer Process.—We have seen that in the Bessemer process, as carried on in the United States, no phosphorus or sulphur is eliminated from the steel; in fact, owing to the loss of carbon, silicon, manganese and iron in blowing, without any loss of phosphorus and sulphur, the percentage of these impurities somewhat increases. In the case of sulphur, and to some extent phosphorus, an actual increase in the total weight of the impurity occurs, because some is absorbed from the fuel in the cupola. Because the lining of the vessel, and therefore the slag, is acid, *i.e.*, siliceous, any phosphorus oxidized to P_2O_5 is at once reduced by iron and carbon, with the formation of FeO,CO, and metallic phosphorus, since iron and carbon have a greater affinity for oxygen at these high temperatures than has phosphorus; and in the absence of any base such as lime (CaO) to hold the P_2O_5 in the slag as phosphate of lime, permanent oxidation of the phosphorus is impossible. Phosphate of iron, if formed, will at once be broken up by SiO_2, as SiO_2 has a greater affinity for FeO than has P_2O_5, at these temperatures. Thus no phosphorus can be eliminated in acid-lined vessels.

The basic Bessemer process was designed to overcome this difficulty, and give a rapid process of steel making that should at the same time be a dephosphorizing process. The first requisite being a basic slag, lime is added to the charge in the vessel before blowing begins. Since this lime would at once attack a lining of silica (SiO_2) or any acid material, eating into it until enough SiO_2 was dissolved out to unite with the CaO to form a siliceous slag, the lining of the basic Bessemer vessel has to be of either neutral or basic material. On account of its cheapness, a basic lining of burned dolomite (double carbonate of lime and magnesium) is used. Though in fact this lining is partly eaten away by each heat and contributes material to the basic slag, this contribution is not necessary, is indeed an evil, for if not thus cut into the linings would last much longer.

In order to keep the amount of lime needed to produce a basic slag, and hence also the volume of slag produced, at a minimum, pig

iron low in silicon is blown; in practice the silicon should not be over .50 per cent. Since this takes away the greater part of the heat-producing element utilized in ordinary Bessemer work to warm up the charge, some substitute has to be found, and that substitute is phosphorus, the very element the process is designed to remove. This apparent paradox is easily understood when the details of the process are considered. At the beginning of the blow, SiO_2 and MnO, as fast as formed from the oxidation of silicon and manganese, unite with the CaO (lime) to form a double silicate of lime and manganese (and of course iron); and since lime is in large excess, a highly basic slag, capable of holding phosphorus in solution as phosphate of lime, is formed from the start. When silicon, manganese and carbon are eliminated and the flame drops, the blowing is continued long enough to oxidize the phosphorus, which is not rapidly removed as long as carbon, silicon and manganese are present, since the affinity of those elements for oxygen at high temperatures is greater than that of phosphorus. The combustion of of this phosphorus to P_2O_5 produces a great deal of heat, and the iron is protected from oxidation by the phosphorus as long as any considerable amount of the latter is present, just as in the acid process the iron is protected by silicon, manganese and carbon. Upon completion of the necessary length of "after blow" to remove phosphorus, the vessel is turned down, and the steel handled as usual.

As phosphorus is the source of much of the heat necessary to maintain the carbonless iron fluid at the end of the blow, there must be a considerable amount of it in the pig iron used. Actually from 2.5 per cent. to 3 per cent. is needed to produce sufficient heat; and as the highly phosphoric slag produced is a valuable by-product, being sold for fertilizer, the amount of phosphorus in the pig is kept as high as it is possible to have it without too much prolonging the blow.

The removal of sulphur in the basic process is only partial and rather erratic, so that the pig iron required is not very high in this impurity.

In America, there are no iron ores so far opened up that will produce pig iron suitable for carrying on the basic Bessemer practice at a profit; no ores being mined that can be used for the manufacture of low silicon—high phosphorus pig at a sufficiently low cost. Some of the Alabama ores come the nearest to it, but the phosphorus in the pig iron smelted from them is not high enough for the

basic Bessemer process, nor is the silicon low enough. Indeed, these ores produce a pig difficult to work even in the basic open-hearth process, as the pig contains too much silicon, which is a handicap in basic open-hearth practice, for the same reason as in basic Bessemer; namely, because it requires a great deal of lime to slag the SiO_2 produced, and the heavy blanket of slag makes it difficult to work the heats. "Duplexing" has successfully handled these pigs; the silicon, manganese and carbon being removed in an acid Bessemer converter, and the carbonless steel then purified of phosphorus and sulphur in a basic open-hearth furnace.

As the basic Bessemer process has been several times attempted in this country, and uniformly proved a financial failure, we shall not again refer to it in these pages.

CHAPTER V

THE OPEN-HEARTH PROCESS

The open-hearth or Siemens-Martin process for making steel was developed in England about 1867 by Sir William Siemens, and independently in France by Martin. The process consists essentially of the melting down of steel scrap and some pig iron in a furnace of the bath type, oxidizing out the carbon, silicon and manganese of the metal by means of additions of iron ore, and adjusting the composition by proper additions.

In order to maintain in a fluid condition the nearly pure iron produced by the elimination of the metalloids from the bath, a high temperature has to be attained in the furnace, much higher than can be secured by the direct combustion of coal. To meet this essential condition, the regenerative principle was invented. By the use of checker chambers such as have been described in the chapter on the crucible furnace, producer gas, resulting from the partial combustion of coal in a gas producer, is fed very hot to the hearth of the furnace, meets sufficient preheated air for its combustion, and heats the furnace chamber and bath to a very high temperature. So intense a heat can be attained that when a furnace is "hot," the operator has to be constantly on his guard lest the brickwork be melted away.

Besides producer gas, other fuels can be used. Natural gas, when obtainable, is excellent for the purpose and does not have to be preheated, but is piped directly into the hearth, only the air passing through regenerators. Fuel oil is used in the same way. On the continent of Europe, coke-oven gas has been tried, and of late experiments are being made with powdered coal.

Whatever the fuel, and whatever the method of working, conditions in an open-hearth furnace are pretty much the same. The reasoning that has already been given in discussing basic Bessemer steel making shows us that a basic lining and a basic slag are necessary, if dephosphorizing of impure material is to be attempted. As in Bessemer work, therefore, we have to consider both acid and