

Assuming a equals .03
 b equals .015 } then X equals .059 per cent. }

(b) is taken as .015, on the assumption that a heat melted in 10 hours picks up .01 per cent. If (b) be .01, X equals .05 per cent.

B.—If the furnace melts its steel in 9 hours and holds it molten 6 and all the “pick up” takes place in the 6 hours. Further, if the same ratio of melting time and holding time applies to the additions, then $\frac{9}{15} \times 3$ or $\frac{9}{5}$ hours are spent in melting the additions and $\frac{6}{15} \times 3$ or $\frac{6}{5}$ hours in holding them fluid. Then a equals original per cent. of sulphur of steel, $\frac{b}{6}$ equals “pick up” per hour (all pick up occurring in the time the steel is held molten), and the “pick up” of the additions in $\frac{6}{5}$ hours is $\frac{b}{6} \times \frac{6}{5}$ equals $\frac{b}{5}$. The pick up of the 8 tons left in the furnace and held 3 hours is $\frac{b}{6} \times 3$ equals $\frac{b}{2}$.

Then we have,

$$X = \frac{8(X + \frac{b}{2}) + .84(X + \frac{b}{5}) + 1.26(a + \frac{b}{5})}{10}$$

Whence X equals $\left(\frac{6.3}{5.8}\right)a + \left(\frac{22.1}{5.8}\right)b$.

and if $\begin{cases} a \text{ equals } .03 \text{ per cent.} \\ b \text{ equals } .015 \text{ per cent. (on the same assumption as before),} \\ X \text{ equals } .089 \text{ per cent.} \end{cases}$

If (b) be taken as .01 per cent., X equals .071 per cent.

By figuring out a number of heats on assumption *B*, it can be shown that if we start with pig and scrap containing .03 per cent. of sulphur, and in the 2-ton additions use 60 per cent. of this new material and 40 per cent. of scrap from each preceding heat, the steel will contain over .05 per cent. of sulphur after four heats, and practically .07 per cent. sulphur after 32 heats have been made, if the “pick up” per heat be .01 per cent. Actually, of course, .071 per cent. sulphur is approached as a limit, never quite reached. If the furnace is emptied after 32 heats have been made, and recharged with 60 per cent. new material and 40 per cent. scrap of

.07 per cent. sulphur, it will take but one heat to pass .05 per cent., and 29 heats to reach .07 per cent. sulphur in the steel. Operated continuously, therefore, the furnace would produce steel of nearly .07 per cent. sulphur, on this assumption.

The exact amount of this increase in sulphur is not easy to predict, since the truth probably lies between the two extremes here taken. However, with a furnace that normally picks up .01 per cent., it is safe to predict an increase of at least .03 per cent., so that in order to produce steel of .05 per cent. we would have to use pig and scrap below .02 per cent., which would be out of the question. Therefore, with producer gas we cannot use the continuous process on an acid bottom, remelting our own scrap, for making steel very low in sulphur.

In some cases, for instance in a plant established in the Pacific coast states, pig iron may be very costly and scrap very cheap. The use of ferrosilicon or ferromanganese to contribute carbon, silicon and manganese to a bath of all scrap, following the expedient suggested for Bessemer practice, is not feasible in open-hearth work, as carbon is also essential. It is easy to show that if the ferroalloys were used in proportions sufficient to give the required carbon in the bath, the resulting manganese or silicon would be many times too high.

In order to be able to handle a bath of all scrap, it has been proposed by Mr. Lash to use gas coke or other material of that sort, charged on the bottom of the furnace under the scrap. As the latter melts it absorbs the carbon of the coke. The carbonaceous material being under a heavy mass of scrap, is protected from oxidation sufficiently to ensure the absorption by the bath of the greater part of the carbon. Though this process is, or has been, used with success, it has its drawbacks (as any method involving a preponderance of scrap must have), in that there is nothing to protect the iron from oxidation in melting. This is not an insuperable obstacle, as in acid practice a good deal of loss from this cause always occurs, but it should not be lost sight of in figuring on the use of the process.

Perhaps the best solution of this problem, in cases where pig iron is at a prohibitive price, would be to melt the scrap, or some of it, in a cupola, and thence run it into the open-hearth furnace. A great deal of carbon would be absorbed by the scrap in the cupola, probably from 2.50 to 3.50 per cent., and by pouring this cupola metal upon a partially melted charge of scrap in the open-hearth

furnace, a bath would be obtained high enough in carbon to be worked in the usual manner.

Because the cupola could not be run continuously, it would of course not melt as cheaply as in regular cupola practice. But the advantages secured should more than offset this drawback.

High Carbon and Alloy Steels.—The manufacture of high carbon and alloy steels in open-hearth furnaces presents some special features that should be considered.

For the production of high carbon steels, if the acid furnace is used, the method followed is to interrupt operations when the carbon of the bath is just below the content desired. This practice presents no special features, except that the bath must be of high carbon when melted, in order that it may be hot by the time it reaches the composition desired.

In the basic furnace, two methods are open to the steel maker. The first, of which one example is given in basic heat number 4 above, is to operate as in the acid furnace, tapping the heat when the carbon is just below the desired amount. To carry this method out successfully, the charge of the furnace should be comparatively low in phosphorus and sulphur, because, as we have already seen, it is not always easy to eliminate these impurities to the desired degree during the working of a bath that is kept high in carbon. The second method, which is more often used with charges high in phosphorus and sulphur, is to carry the carbon down below .10 per cent., in order to promote the elimination of the phosphorus and sulphur. This necessarily involves a very heavy addition of recarburizer, since to attempt to use coal or coke to bring heats of steel up from .08 per cent. to as high as .70 per cent. carbon, will almost inevitably result in the turning out of many heats of incorrect analysis. The ladle additions of ferromanganese and ferro-silicon will not contain nearly enough carbon to raise the carbon of the bath to the desired point, and we are thus forced to use pig-iron additions. For a 30-ton heat (say 66,000 lb.), of basic steel, containing say .10 per cent. carbon, to be brought to .80 per cent. carbon, .40 per cent. silicon, and .70 per cent. manganese, our additions will be about as follows:

	C, per cent.	Si, per cent.	Mn, per cent.
Ferromanganese at.....	6.00	.5	80.0
Pig at.....	4.00	2.0	.5
Bath at.....	.10	.05	.20

Item	Wght lb	C lb	Si lb	Mn lb
Pig.....	11,300	452	226	56.5
Ferromanganese.....	370	22.2	1.85	296
Bath.....	54,330	54.3	27.17	108.7
	66,000	528.5 .80%	255.02 .39%	461.2 .70%

Several considerations affecting the use of these heavy pig-iron additions present themselves immediately. To begin with, to add some 11,000 lb. of solid metal to a 54,000-lb. heat, will chill the bath to such a point that it will have to be heated up all over again, which can only be done by boiling out a large part of the carbon already added. It is essential, therefore, that the pig be added molten, and cupolas will be needed to melt it.

Moreover, if we add such quantities of molten basic pig, of the usual phosphorus content of at least .60 per cent., we shall raise the phosphorus of our steel to a prohibitive degree, as a little figuring will show:

54,000 lb. soft steel at .015 per cent. phosphorus, = 8.1 lb.
 11,000 lb. pig at .60 per cent. phosphorus, = 66.0 lb.

 74.1 lb.
 or .11 per cent. phosphorus.

Even if a special low phosphorus basic pig (phosphorus .30 per cent.) is used, the phosphorus of the steel will be too high.

54,000 lb. soft steel at .015 per cent. phosphorus, = 8.1 lb.
 11,000 lb. pig at .30 per cent. phosphorus, = 33.0 lb.

 41.1 lb.
 or .062 per cent. phosphorus.

Therefore, we are forced to use Bessemer or low phosphorus pig as recarburizer, in this method of working. The resulting content of phosphorus in the steel will be as follows:

54,000 lb. soft steel at .015 per cent. phosphorus..... 8.1 lb.
 11,000 lb. Bessemer pig at .10 per cent. phosphorus... 11.0 lb.

 19.1 lb.
 or .029 per cent. phosphorus.

54,000 lb. soft steel at .015 per cent. phosphorus..... 8.1 lb.
 11,000 lb. low phosphorus pig at .03 per cent. phosphorus..... 3.3 lb.

 11.4 lb.
 or .017 per cent. phosphorus.

Of the alloy steels, nickel steel can be readily produced in an open-hearth furnace, either acid or basic. The nickel is added in the form of plaquettes charged with the heat or thrown into the bath, and there is almost no loss in melting. In the manufacture of very high percentage nickel steel, a difficulty arises in making the additions without unduly chilling the bath. In either acid or basic furnaces, nickel steel scrap can be remelted with but slight loss of nickel, but to melt a bath containing over 5 per cent. of nickel is undesirable, because the estimation of the carbon content of steel so high in nickel, by either color carbon or fracture determinations, is impossible. The bath should be melted down, therefore, at from 4 to 5 per cent. of nickel, and the rest added in successive lots of plaquettes, which should preferably be preheated. To get the nickel all in and melted requires several hours, and in the meantime the bath continues to lose carbon. In the acid furnace, to prevent this elimination of carbon as far as possible, the silicon is generally charged before the nickel additions are begun. Owing to this loss of carbon while adding the nickel, the additions are commonly started when the heat is a little *above* the desired carbon content. Very close control of the carbon can be attained only by analysis of the samples by direct combustion in oxygen, since no other method of analysis can be used for the rapid determination of carbon in these heats.

Other alloys, such as chrome, tungsten, etc., are oxidized almost completely in remelting the scrap. Chrome in the basic furnace, starting at 1 per cent., will generally go down to .10 per cent. by the time the heat is ready to tap. Moreover, the chromic acid resulting from the oxidation of the chrome produces a very pasty slag, which, especially in the basic furnace, makes trouble by "building up" on the bottom to a serious extent. Plants remelting chrome steel scrap as a large part of their charge generally have to run one or two heats of carbon steel every little while to cut out these slag accretions.

Ferrochrome of 70 per cent. chrome should be added in the furnace and, at least in basic furnaces, a considerable proportion of the chrome is oxidized in melting. It has been found that the amount of chrome so entering the slag as oxide is greatest immediately after melting, and that by holding the heat from 20 minutes to $\frac{1}{2}$ hour after the ferrochrome is melted, quite a considerable amount of the lost chrome will be reduced by the carbon of the bath and restored to the steel. The French metallurgists assist this

action by spreading coke dust over the slag in the manner that has been described in the discussion of the French methods of deoxidizing acid slags.

Tungsten, molybdenum, etc., can be added to the bath as ferro alloys, or as metallic powder. In either case, it is generally best to put these expensive alloys in sheet metal cans which are then tossed into the bath. When so charging tungsten, it will sink to the bottom of the furnace, owing to its great weight, and generally nearly $\frac{1}{2}$ hour will be necessary to melt it. If the ferrochrome or ferromanganese have been put in the same cans with the tungsten and carried to the bottom of the furnace, the usual loss in adding these alloys to the furnace will not occur, and much smaller additions are made, nearly as small, in the case of manganese, as when adding the alloy in the ladle. Heavy additions of these alloys must be heated to avoid chilling the bath, and will present the same difficulties that are met with in making high percentage nickel steels.

Manganese steel can be made quite easily of open-hearth metal, as of Bessemer metal, and by practically the same methods. In order to avoid heavy losses the large additions of ferromanganese have to be melted and added in the ladle. The scrap produced can be remelted and its iron saved, but in ordinary practice the manganese contained in it is lost. The large heats that have to be disposed of, and the rather low temperature of the metal compared to Bessemer steel, make the process unsuited to the production of much of the work that the makers of manganese steel castings are called upon to turn out.