sure that the saving in melting cost as compared to melting in an electric furnace would balance the expense involved in eliminating carbon.

Moreover, up to the present time, as far as the author is aware, this procedure has not been brought to such a stage of development that it can be called a process which can be relied upon in practice. The greatest difficulty with it probably lies in the fact that to turn out producer gas consistently, with its composition as accurately controlled as is necessary for the success of this process, is an extremely difficult matter and one which is likely to give constant trouble in regular operation.

THE RAW MATERIALS

As the electric furnace is almost always run with basic lining, as a basic, and hence refining, process, the raw materials that can be used are not subject to the rigid specifications as to phosphorus and sulphur that must be adhered to in crucible, Bessemer and acid open-hearth practice. Phosphorus and sulphur are eliminated as completely as desired at each heat, hence we can remelt our own scrap up to any proportion without increase in impurities

The amount of sulphur and phosphorus that we can allow in our raw materials, therefore, depends chiefly upon the degree of purity necessary in our finished castings, and upon the time that we desire to spend in treating the steel. If a basic open-hearth furnace is used to supply the electric furnace, raw material averaging .3 to .5 per cent. phosphorus can be delivered to the electric furnace at say .05 to .1 per cent. very readily, and the refining completed in the electric furnace without too great expenditure of time. As far as possible, the dephosphorizing should be done in the open hearth. To effect the removal of a high percentage of phosphorus in the electric furnace is feasible, but may require the making and removal of several slags. Hence if we are operating an electric furnace alone, or one supplied with hot metal by an acid open-hearth furnace or a Bessemer converter, the extra expense in power and labor involved in the purification of very high phosphorus metal may be so great as to more than offset the saving made in the cost of raw materials. A safe middle course should be steered; one would not be justified in melting low phosphorus pig and scrap in a plant making only electric steel by the basic process, since Bessemer (.1 per cent. phosphorus), or basic (1.0 per cent. phosphorus), grades at a lower price can generally be refined at a cost less than the difference between the two grades of stock. But to use foundry iron and very high phosphorus scrap (averaging perhaps 1.5 per cent. phosphorus) would involve an expense in refining that would much more than offset the saving in cost of raw material. The possible ways of using the electric furnace in a steel foundry are shown in the following table.

THE POSSIBLE USES OF THE ELECTRIC FURNACE IN A STEEL FOUNDRY

Melt scrap	Impure—eliminate P and S. Pure—get hot and cast. Alloy steels—save alloys.
Melt pig and more or less scrap —eliminate C, Si and Mn	Impure—eliminate P and S. Pure—get hot and cast.
Treat hot metal	From cupola—eliminate C, Si, Mn, P and S. From acid Bessemer or open hearth—eliminate P and S. From basic open hearth—eliminate P and S.
Melt pig and scrap or treat cupola metal.	Eliminate C, P, and S, without loss of Mn and Si. (Greene's producer gas process.)

Two of these methods, the melting of pure scrap, and of pure scrap and pig, have already been discused.

In considering the refining of impure raw materials, too much emphasis can hardly be placed upon the fact that the true function of the electric furnace is the final refining of steel, and that melting and the elimination of carbon, silicon, manganese, and the bulk of the phosphorus and sulphur should whenever possible be carried out in furnaces of other types.

To melt and refine impure scrap in an electric furnace alone is a rather costly way to make steel; yet in many cases it will be the most advantageous practice to follow, especially if scrap and power be cheap, and coke or other mineral fuel costly. In a very small plant it may well be necessary to follow this practice, especially if the possible output and the money available to build the shop do not justify the installation of an open-hearth furnace, or small converter, to supply hot metal.

To melt pig iron and scrap, the pig forming a large proportion of the charge, and eliminate carbon, silicon and manganese (and phosphorus and sulphur if impure materials are used), in the same way as in an open-hearth furnace, should not be attempted, unless conditions demand it, on account of the necessarily high cost of the metal produced. It is difficult to imagine the existence of the conditions that would make such practice necessary, as they would be—cheap pig and power, scrap at a higher price than pig, and, if the output is of fair size, mineral fuel suitable for open-hearth or Bessemer work not available.

One exception to these statements is the use of the furnace to melt down alloy steel scrap without loss of the contained alloys. The problem in this case is one purely of costs; if the scrap can be melted at a profit over the cost of the steel as made by other methods that remelt the scrap but lose the alloys, the method should be used. In many cases, however, it will not be found economical to do so.

Under ordinary conditions, if it is not deemed advisable to install an open-hearth furnace or a converter to supply the electric furnace with hot metal, it may in some cases pay to melt the scrap in a cupola and eliminate the carbon absorbed from the coke, and the phosphorus and sulphur, in the electric furnace. As far as the author is informed, this method has never been put in practice. In an electric furnace of the usual type the elimination of the carbon will be a slow and rather costly procedure; but by using a furnace without doors in the back, with the bottom carried well up the back wall, the hot metal practice used in tilting open-hearth furnaces could be followed. By melting down and heating up a little plate scrap in the furnace, and forming with iron ore a slag very rich in iron oxide, and then pouring in melted scrap (and possibly some pig iron) from the cupola, a lively reaction could be maintained, which would boil out the carbon very rapidly. By tilting the furnace back the slag could be kept from boiling out the doors, and during the violent part of the boil it is probable that current would not be needed. It is probable that the elimination of the carbon from the bath would take less time and consume less power than the operation of melting the cold scrap in the electric furnace itself, so that a saving could be made over that method.

For large tonnages an open-hearth furnace should be used to supply the hot metal for refining. Preferably it should be a basic furnace, in order to eliminate the bulk of the phosphorus and sulphur in the open-hearth rather than in the electric furnace; but acid metal of course can be treated, and need not be of very low phosphorus and sulphur.

Smaller shops may well find it advantageous to install small Bessemer vessels to supply hot metal for the electric furnace. In this case all the phosphorus and sulphur would have to be eliminated in the electric furnace, yet by using basic raw materials the cost of production can be brought low enough to compare very favorably with that of Bessemer steel made from low phosphorus pig.

Open-hearth Electric.—In discussing the arrangement of a shop using open-hearth and electric furnaces, the combined open-hearth and electric furnace, recently patented by Mr. Walker, must be considered. As one of its applications is the melting of alloy steel scrap, the following paragraphs compare the usefulness of this combined furnace and of simple electric furnaces for this purpose; and of the combined furnace and of ordinary open-hearth furnaces in conjunction with electric furnaces, for refining hot metal.

This design consists of a tilting open-hearth furnace with the gas and air uptakes and ports mounted on wheels in such a way that they can be pushed back from the hearth of the furnace, allowing brick-lined sliding doors to be lowered into position to cover the open ends of the furnace. Through water-cooled openings in the roof of the furnace, graphite electrodes are introduced in the usual manner.

The disadvantage of this furnace is that it is difficult to make it both a good open-hearth and a good electric furnace. One of the disadvantages of the furnace as an open-hearth is that while the gas is shut off and the ends slid back, the gas and air uptakes, end blocks and checkers cool off very greatly, so that much fuel has to be burned to get them hot again. The disadvantage as an electric furnace is said to be that the exigencies of open hearth design make it difficult to build the furnace in such a manner that it shall give good electrical efficiency.

One application of this furnace would be to melt and partially refine pig iron and scrap, eliminating carbon, silicon and manganese and part of the phosphorus and sulphur, using gas (of course other fuel could be used); and then, shutting off the fuel and closing the ends, to lower the electrodes into position and complete the refining of the steel. The saving would consist in carrying out the two operations in one furnace, avoiding the chilling of the metal in transferring from one furnace to another and the extra installation cost of two furnaces. Unless the efficiency of the installation both as an open-hearth and as an electric furnace can be brought nearly to the efficiency of the separate furnaces, the advantage gained in cost of installation will be more than offset by the increased consumption of fuel and electric power, compared to separate furnaces.

The second application of the furnace is in melting scrap containing costly alloys that are oxidized and lost in melting by other methods. The procedure in this case would be to bring the charge to incipient fusion with mineral fuel, and then finish the melting and superheating with electricity. In this way a great part of the necessary heat will be obtained from cheap fuel, and the smallest possible amount obtained from electric power. Since it would obviously be impossible to carry out the same process in two furnaces, owing to the impracticability of transferring the semi-solid charge, this application is unique.

The cost of power in this method of working, however (and also in working the furnace to refine metal melted and partially refined with fuel), will be greatly affected by the following considerations. If the furnace is supplied by a line that is taking care of other installations and therefore furnishes a great quantity of power at a correspondingly low unit cost, current will be paid for only as used, and the full saving from the use of fuel will be realized. On the other hand, should the furnace be supplied with power by its own generator, which would consequently lie idle during the period when the furnace was burning fuel, the cost of the generating plant would run on at almost its full figure during this idle time, because the operating force would have to continue on duty, and in a steam plant, fuel would be burned to keep up the steam in the boilers. As the overhead and other expenses would run on all the time, the cost of power in this intermittent operation of the generators would be greatly increased. In many cases this extra cost of power would offset, or more than offset, the saving from the use of fuel in one of these furnaces, as compared with melting in an ordinary electric furnace.

There is only one way to avoid this dilemma, which is to install two or three furnaces to operate on one power line. If the amount of time on fuel and on electric current were about equal, two furnaces on one line would keep the power plant constantly busy. If two-thirds of the time per furnace were on fuel and one-third on power, three furnaces would be necessary, and so on. On the other hand, should the time per furnace on power be greater than the time on fuel, the furnace would have to be allowed to lie idle part of the time, or a power plant be installed capable of supplying more than one furnace simultaneously. Thus, to take an extreme case, if the time on fuel were two hours and on current six hours, one power plant capable of running one furnace would operate as follows:

Furnace A	Furnace B
On fuel 12 m. to 2 p. m.	On fuel 6 p. m. to 8 p. m.
On power 2 p. m. to 8 p. m.	On power 8 p. m. to 2 a. m.
On fuel 12 m. to 2 a. m.	On fuel 6 a. m. to. 8 a. m.
On power 2 a. m. to 8 a. m.	On power 8 a. m. to 2 p. m.
On fuel 12 m. to 2 p. m.	On fuel 6 p. m. to 8 p. m.
On power 2 p. m. to 8 p. m.	On power 8 p. m. to 2 a. m.

Thus each furnace would make but two heats in 24 hours, and though the power plant would be kept constantly busy, each furnace would lie idle (burning some fuel to keep it hot), eight hours per day, in two periods of four hours each. This would run up the fuel bill, though obtaining current at a minimum cost.

Another way of distributing power over several furnaces, under the same conditions as above, two hours fuel, six hours current, would be to use three furnaces and a power plant capable of taking care of two of them at once. The schedule would be as follows:

Furnace A	Furnace B	Furnace C
On fuel 12 m. to 2 p. m.	f. 3 p. m. to 5 p. m.	f. 6 p. m. to 8 p. m.
On power 2 p. m. to 8 p. m.	p. 5 p. m. to 11 p. m.	p. 8 p. m. to 2 a. m.
On fuel 9 p. m. to 11 p. m.	f. 12 m. to 2 a. m.	f. 3 a. m. to 5 a. m.
On power 11 p. m. to 5 a. m.	p. 2 a. m. to 8 a. m.	p. 5 a. m. to 11 a. m.
On fuel 6 a. m. to 8 a. m.	f. 9 a. m. to 11 a. m.	f. 12 m. to 2 p. m.
On power 8 a. m. to 2 p. m.	p. 11 a. m. to 5 p. m.	p. 2 p. m. to 8 p. m.

Each furnace would thus make three heats every 26 hours, with an idle hour between heats, keeping the power constantly busy, and allowing the furnaces to lie idle only one hour at a time.

In order to use one set of transformers to serve two or three furnaces, it would be necessary to put switches in the heavy busbars that carry the low-voltage current to the furnaces. In order to switch such high amperage currents successfully, very expensive oil switches would be needed.

In case expensive alloy steel scrap is to be melted, and power to be supplied by a separate plant, it might in some cases pay to install two or three small fuel electric furnaces operating in the manner just described, rather than one plain electric furnace, but in this connection allowance will always have to be made not only for the inferior electrical efficiency of the very small units (the efficiency is very low in sizes below 2 or 3 tons), but also for the very poor efficiency of the furnaces while burning fuel. Even when power is available that can be paid for only as used, so that the multiplication of furnaces is not necessary, it is doubtful if the fuel electric furnace holds out any hope of making a saving over the plain electric furnace.

For the melting and refining of impure pig and scrap it is open to question whether the combined furnace can compete with a tilting open-hearth operated continuously and supplying an electric furnace with partially refined metal. To take a hypothetical case, let us assume that a 10-ton tilting open-hearth furnace, run continuously, will supply 2 tons of metal every three hours (equivalent to a heat of 10 tons in 15 hours) to a 2-ton electric furnace, which will thus turn out eight heats per day, or 16 tons. If we can get 2 tons in two hours, our capacity will be 24 tons. Our plant will consist of

1 ten-ton tilting open-hearth furnace.
1 two-ton electric furnace.
1 generator for same.
1 set transformers.

To produce the same tonnage in open-hearth electric furnace, we will assume that the furnace will produce a heat in ten hours (including making bottom), or eight hours on fuel and two hours on power. To secure even current distribution from a separate generating plant, we shall need five furnaces, scheduled as follows:

A	B	C	D	E
Fuel 12 m. to 8 p. m.	2 to 10 p. m.	4 p. m. to 12 m.	6 p. m. to 2 a.m.	8 p. m. to 4 a.m.
Power 8 p. m. to 10 p. m.	10 p. m. to 12m.	12 m. to 2 a. m.	2 a. m. to 4 a. m.	4 a. m. to 6 a. m.
Fuel 10 p. m. to 6 a. m.	12 m. to 8 a. m.	2 a.m. to 10 a.m.	4 a. m. to 12 m.	6 a. m. to 2 p. m.
Power 6 a. m. to 8 a. m.	8 a.m. to 10 a.m.	10 a. m. to 12m.	12 m. to 2 p. m.	2 p. m. to 4 p.m.
Fuel 8 a. m. to 4 p. m.				
Power 4 p. m. to 6 p. m.	etc.			

This is the equivalent of $2\frac{2}{5}$ heats per furnace per day, or twelve heats per day for the battery. For a tonnage of 16 to 24 tons, each furnace would be of $1\frac{1}{3}$ to 2 tons capacity.

Our plant will consist of

5 one and one-third to two-ton open-hearth electric furnaces.
1 generator for same.
1 set transformers for same.
5 sets oil switches.

We see that we have to balance the cost of five open-hearth electric furnaces and five sets of switches against that of one tilting open-hearth furnace and one plain electric furnace. The advantage would probably be with the tilting open-hearth installation. Moreover, the labor costs on such an installation, and the repairs and upkeep per ton of metal, would undoubtedly be in favor of the more compact installation—to say nothing of the question of space, and of the difficulty of running several furnaces on a time schedule that must be adhered to quite closely.

Should power be available that could be paid for as used, the multiplication of furnaces would not be necessary. Assuming in that case the same rate of operation, eight hours on fuel and two on power, producing therefore $2\frac{2}{5}$ heats per day, our single open-hearth electric furnace would be of 16 to 24 (call it 20), divided by $2\frac{2}{5}=8\frac{1}{3}$ tons. This furnace could no doubt be built for considerably less than the 10-ton tilting open-hearth, and 2-ton electric furnace with transformers. Our plants in each case would consist of

Open-hearth electric	Tilting open-hearth and electric
1 eight to ten-ton open-hearth electric furnace.	1 ten-ton tilting open-hearth furnace.
	1 two-ton electric furnace.
1 set transformers 1200 to 1500 kw.	1 set transformers 300 kw.

The advantage in installation costs should be slightly in favor of the open-hearth electric installation. The power costs (though not the total fuel cost), would be less for the open-hearth electric furnace, figuring as follows:

Assuming that 150 kw. per ton will be required in each furnace, the fact that an 8-ton electric furnace should have a higher electrical efficiency than a 2-ton, being offset by the probably inferior efficiency of the open-hearth electric furnace, the latter will use 1200 kw., for $2\frac{2}{5}\times2=4\frac{4}{5}$ hours per day ($2\frac{2}{5}$ heats at two hours each), or 5760 kw.-hr. for 20 tons=288 kw.-hr. per ton. The 2-ton electric furnace would use 150 kw. per ton for 24 hours, or 7200 kw.-hr. for 20 tons=360 kw.-hr. per ton. Should the efficiency of the open-hearth electric furnace be better, this advantage would be more marked. This will, however, be offset by the higher fuel cost per ton in the fuel electric than in the open-hearth furnace, so that probably the total fuel plus current expense will be greater in the former than in the open-hearth and electric furnace combination.

THE BESSEMER CONVERTER SUPPLYING ELECTRIC FURNACES

The Bessemer converter can be used to supply the electric furnace with hot metal for refining. A possible arrangement for a plant of limited output is outlined and discussed in the following paragraphs. The equipment would consist of:

Two or three 1000-lb. side-blown vessels. One to be run at a time, turning out two heats per hour.

Three 1-ton electric furnaces, each capable of turning out a heat every three hours.

The vessel would blow enough metal in one hour to fill the first electric furnace, would fill the second furnace in the second hour, and the third furnace in the third hour. Thus each furnace would have two hours to refine its charge, before it would be needed again to take metal from the vessel. Working in this manner, we could produce some eight heats per 24 hours in each furnace, or 24 tons per day, 144 tons per week.

The costs of metal produced by this method, if basic raw materials be used, should be sufficiently low to be attractive to shops of small output.

They can be roughly estimated as follows:

Raw material per ton of steel, calculating 16 per cent. loss, and using 50 per cent. pig, 30 per cent. shop scrap, and 20 per cent. purchased scrap,

1 ton ÷ .84 = 1.19 tons, of which
.595 tons will be pig
.357 tons will be shop scrap
.238 tons will be purchased scrap

.595 tons basic pig at $15.00	$ 8.93
.357 tons shop scrap at $14.00	5.00
.238 tons high phosphorus scrap at $10.00	2.38
	$16.31

	Per ton of steel
Raw material	$16.31
Bessemer plant labor, $42 per day, or for 24 tons	1.75
Bessemer plant, other expense (see estimates in introductory chapter)	2.53
	$20.59

ELECTRIC FURNACE LABOR	Per week
2 melters at $150 per month	$ 69.23
4 helpers at $4.00 per day (2 on Sunday)	104.00
4 helpers at $2.50 per day	60.00
	$143.23 or for 144 tons, about $1.00 per ton

SUMMARY	Per ton of steel
Material delivered to electric furnace	$20.59
Electric furnace labor	$1.00
Other electric furnace expenses, (estimating 500 kw.-hr. per ton)	8.83
	$30.42

If the plant were run only single turn, blowing some 14 heats, or enough for seven electric furnace heats, the cost would be considerably higher. In this case two of the furnaces would be busy for six hours, producing two heats each, and the third for nine hours, producing three heats, giving us a total of 7 tons of steel. A rough estimate of costs is as follows:

	Per ton of steel
Raw material	$16.31
Bessemer plant labor $21 per day, or for 7 tons	3.00
Bessemer plant, other expenses	2.53
Electric plant labor, $71.62 per week, or for 42 tons	1.71
Electric plant, other expenses	8.83
	$32.38

Bessemer-electric.—The combined Bessemer converter and electric furnace has been patented. Its application would be to combine in one furnace the elimination of carbon, silicon and manganese by blowing, and dephosphorizing and desulphurizing by means of electric heating. The advantages of the process would be, first, avoiding loss of heat in transferring the metal from one furnace to another, and second, economy of installation.

Aside from the probability that the electrical efficiency of such an installation would be low, on account of the limitations imposed by the exigencies of Bessemer design, there would be several disadvantages of this furnace that must be considered.

In the first place, if dephosphorizing and desulphurizing is to be attempted, a basic lining will be needed in order to maintain a basic slag. In America, where only siliceous pigs are available for Bessemer blowing, such a lining will be too severely cut to permit its use. In this country, therefore, the furnace would have to be acid lined, and used as an acid electric furnace. In Europe where basic Bessemer pig is available, this difficulty would not appear.

In the second place, the production of this type of vessel would be low, probably a heat only every two and one-half or three hours, say four heats on a 12-hour turn, or 8 tons for a 2-ton vessel. Compared to the output of an ordinary 2-ton vessel, making some 20 tons on a turn, this is very low, and as we have shown, a half-ton vessel and three one-ton electric furnaces will make some 7 tons in one shift.