

In America, according to Campbell,\* the scrap, instead of being charged cold with the pig-iron, is occasionally heated in a separate furnace while the pig is melting, and is then charged hot into the molten bath of metal, but so far as the author is aware this practice is not followed anywhere in this country, and is exceptional in America; and it is more than doubtful if it presents any advantages. In cases where very light scrap has to be used, as it is often impossible to charge the whole of the scrap before melting, it is best then to bundle it and charge from time to time into the molten bath, but with heavy scrap it is nearly always possible to charge it with the pig.

**Reactions in the Acid Siemens Process.**—In the acid process neither the Sulphur nor Phosphorus is to the least extent eliminated, and both, therefore, increase relatively in the finished steel as compared with the percentages in the original charge, and hence the first essential in selecting pig and scrap for the process is that they should be low both in Sulphur and Phosphorus; in no case should either constituent exceed 0.050 per cent. for high-class steel. The percentage of Silicon allowable in the pig-iron will vary with the special conditions of working, such as the amount of scrap available, as it is only necessary to have just enough Silicon in the charge to form, together with the Silica derived from the ore, furnace bottom, &c., sufficient slag to cover the metal. It is obvious, therefore, that if 30 per cent. of scrap is to be charged, a higher Silicon pig can be used than when only 10 per cent. of scrap is charged; and if no scrap at all is available, a pig-iron very low in Silicon should be used.

The following may be taken as typical pig-irons, suitable for manufacture of high-class acid open hearth steel under English conditions of working:—

	1	2	3	4
Carbon, . . . . .	3.500	3.210	3.640	3.600
Silicon, . . . . .	1.890	2.350	2.520	2.100
Sulphur, . . . . .	0.030	0.040	0.025	0.030
Phosphorus, . . . . .	0.035	0.038	0.030	0.032
Manganese, . . . . .	0.700	0.680	0.900	0.880

Both the Sulphur and Phosphorus will frequently, in Hematite pig-iron, run up to 0.050, or even 0.060, but in this case it should only be used to mix in small proportions with better grade iron, as otherwise the Phosphorus and the Sulphur will exceed 0.06 per cent. in the finished steel. It is often desirable to get pig-iron lower in Silicon than 1.8 per cent., but in this country it is very difficult to do so, without getting an iron too high in Sulphur. Small quantities of low Silicon and Sulphur pig-iron may occasionally be obtained, but not regular supplies, so that higher Silicon iron than is necessary has generally to be used to avoid the production of high Sulphur steel.† Low Sulphur and low Silicon iron might be obtained by using a high manganiferous pig-iron, but Manganese is very objectionable, as it rapidly cuts away the Silica lining of the furnace, and tends to make the slag too thin. Many engineers now decline to accept for structural purposes steel in which either Phosphorus or Sulphur exceeds .06 per cent., and consequently it is very important to start with pure materials. In other cases, where an exceptionally high-class material is required, the Phosphorus and Sulphur have to be below 0.04 per cent., and in such cases it is impossible

\* *Trans. Amer. Inst. Mining Engineers*, vol. xx., p. 399.

† Several West of England iron works have recently altered their blast furnaces to produce iron similar to that obtainable in America, and are now regularly supplying low Silicon and low Sulphur pig.

to fulfil the conditions without using a large proportion of Swedish pig-iron, or very best selected English Hematite, exceptionally low both in Sulphur and Phosphorus. It is, however, unusual to use Swedish pig-iron in this country for manufacture of *dead soft* steel, the high-class West of England Hematites being equal to all ordinary requirements. Swedish is, nevertheless, used to a considerable extent for higher Carbon steel when special purity is required, and in such cases the Silicon in the pig is frequently less than 1 per cent., showing that the process does not necessitate such high Silicon pig-iron as is usually employed in England. The difficulty of obtaining supplies of pig-iron low both in Silicon and Sulphur is the real reason why such silicious irons are used.

In working charges with 20 to 25 per cent. of scrap, pig-iron with 1.75 to 2.5 per cent. of Silicon is found to give very good results, although more silicious pig can be used without interfering with the quality of the product, but it is very wasteful, and requires great care in working.

One disadvantage of using a very silicious pig-iron is that a very silicious slag is formed, which is inclined to be infusible, and to interfere with the working of the furnace, and fluidity has to be obtained by additions of Oxide of Iron to combine with this Silica, with the result that a larger percentage of iron is lost in the slag.

On the other hand, it is important not to go to the other extreme, as if a large excess of scrap with low Silicon pig is used, the bath will be desiliconised, and practically decarburised when melted, will be thick and sluggish, will rapidly oxidise, and besides scarifying the furnace bottom, there will be a great tendency for the steel to be red short.

The following may be taken as a typical charge for soft steel:—

#### PLATE CHARGE SHOWING YIELD AND SLAG.

Original Charge—		Tons.	Cwts.	Qrs.	Lbs.	
Pig-Iron, . . . . .		16	5	0	0	
Scrap, . . . . .		4	0	0	0	
80 per cent. Ferro, . . . . .		0	3	0	22	} added at end of heat in the ladle.
Total charge, . . . . .		20	8	0	22	
Yield of ingots at cogging mill, 19 tons 1 cwt. 3 qrs. =						94.07 per cent.

	Metal and Scrap Used.		Finished Steel.	Slag Analyses.	
	Pig-Iron.	Scrap.			
Carbon, . . . . .	3.58	0.18	0.180	Silica, SiO <sub>2</sub> , . . . . .	57.00
Silicon, . . . . .	2.42	0.038	0.028	Ferrous Oxide, FeO, . . . . .	25.12
Sulphur, . . . . .	0.028	0.047	0.051	Alumina, Al <sub>2</sub> O <sub>3</sub> , . . . . .	3.32
Phosphorus, . . . . .	0.04	0.044	0.048	Oxide of Manganese, MnO, . . . . .	7.62
Manganese, . . . . .	1.22	0.51	0.48	Lime, CaO, . . . . .	5.50
...	...	...	...	Magnesia, MgO, . . . . .	1.08
...	...	...	...	Phosphoric Acid, P <sub>2</sub> O <sub>5</sub> , . . . . .	.063
...	...	...	...	Sulphuric Acid, SO <sub>3</sub> , . . . . .	Trace.
...	...	...	...	Alkalies (not estimate), . . . . .	...
					99.703

Weight of slags, 2 tons 16 cwt. 2 qrs.

The yield on this charge is rather low. It should not be less than 95 per cent. on an average, and in some cases a yield of 97 per cent. is obtained.



**Elimination of Impurities.**—The elimination of the impurities in the charge takes place in two stages—

- (1) During melting, by the oxidising action of the flame.
- (2) After melting, by the action of Oxides of Iron formed during the melting period or added to the melted charge.

The percentage of impurities oxidised during melting will vary considerably with the composition of the pig-iron, the relative proportions of scrap and pig-iron, and the mechanical condition of the scrap—whether light or heavy—and also, of course, with the working condition of the furnace. Taking a furnace in good working order, with a charge of 25 per cent. scrap, the percentage of Silicon oxidised during melting will usually vary from 33 to about 50 per cent., and the Carbon removed will be about 30 per cent.; the Manganese is almost entirely oxidised during the melting. The Silica and Manganese Oxide, with some of the Oxide of Iron formed, unite with the sand adhering to the pigs and some of the furnace bottom to form a fluid slag, which is essentially a double Silicate of Iron and Manganese.

The following analyses of samples from different charges worked at the Consett Steel Company, and kindly furnished by Mr J. P. Walton, illustrate the removal of Silicon and Carbon during melting, and other analyses in the possession of the author confirm these results, although in many cases the percentage of Carbon removed in a given time is higher.

TABLE XXVI.—OXIDATION OF CARBON AND SILICON IN THE OPEN HEARTH PROCESS DURING THE MELTING OF THE CHARGE.

Number of Charge.	Charge consisted of		Composition of Pig-Iron.		Calculated Average Composition of Charge. Pig-Iron as per Analysis. Steel Scrap averaged C = .20, Si = .03.		Melted Charge before Addition of Ore.	
	Pig-Iron.	Steel Scrap.	C.	Si.	C.	Si.	C.	Si.
B 173, .	Tons. Cwts. 23 0	Tons. Cwts. 4 15	4.19	1.874	3.507	1.558	2.70	.750
C 400, .	23 0	4 15	4.24	1.563	3.549	1.300	2.75	1.070
A 274, .	23 9	4 15	4.20	1.740	3.660	1.390	2.78	1.134
B 171, .	23 6	4 15	4.20	1.740	3.620	1.380	2.91	.957
E 282, .	21 9	6 10	4.20	1.740	3.210	1.300	2.64	.630
F 258, .	23 0	4 15	4.20	1.740	3.569	1.400	2.86	.817

The following analyses of samples taken during the working of a boiler plate charge have kindly been supplied by Mr. Campion :—

	Original Charge, Average Composition.	Charge Melted.	1 hour later.	Boiling 20 mins.	Boiling 1 hour 20 mins.	Boiling 2 hours 20 mins.	Ready.	Finished Plates, Boiler Quality, for Flanging.
Total Carbon,	3.360	3.24	2.69	2.150	1.510	.570	.170	.170
Silicon, .	1.990	1.33	.50	.046	.041	.028	.028	.032
Sulphur, . .	.031	...	...	...	...	...	...	.046
Phosphorus, .	.044	...	...	...	...	...	...	.048
Manganese, .	.630	...	...	...	...	...	...	.490

In America, where iron containing much less Silicon—frequently only 1 per cent.—and larger proportions of scrap are used, practically the

whole of the Silicon and a large percentage of Carbon are removed during melting, as is shown by the following Table, given by Campbell,\* which embodies the average of nineteen consecutive heats under Group I., melted with producer gas, and the average of six heats under Group II., melted with oil vapour :—

TABLE XXVII.—ELIMINATION OF IMPURITIES IN AN OPEN HEARTH CHARGE.

Nature of Sample.	Group I.	Group II.	
Pig-iron, pounds, . . . . .	11,700	20,700	
Steel scrap, pounds . . . . .	45,550	36,800	
Composition of original charge, per cent. (estimated),	{ Si . . . . .	0.40	0.65
	{ Mn . . . . .	0.90	0.85
	{ C . . . . .	1.00	1.50
Metal when melted, per cent., . . . . .	{ Si . . . . .	.02	.05
	{ Mn . . . . .	.09	.06
	{ C . . . . .	.54	.64
Slag after melting, per cent., . . . . .	{ SiO <sub>2</sub> . . . . .	50.24	49.46
	{ MnO . . . . .	21.67	13.16
	{ FeO . . . . .	23.91	33.27

In cases where very light readily oxidisable scrap is charged, a considerable amount of Oxide of Iron may be formed and react locally on a part of the charge, and practically decarburise it before the rest is melted, although such a slag, taken as a whole, may not contain sufficient Oxide to make it an active working slag.

The composition of the charge of the furnace should be regulated, as far as possible, when making mild steel, to ensure the removal of as much of the Silicon and Manganese as possible during melting, and leave about 2.0 to 2.5 per cent. of Carbon in the bath of metal, which will be sufficient to ensure a vigorous reaction between the ore additions and the metal, and complete the removal of the Silicon. Much more Carbon than this unduly prolongs the process without any apparent compensating advantage, and with much less than this the metal does not come vigorously on the boil, and is what is termed sluggish in the furnace, with the result that it will probably be over-oxidised before it is ready to tap. This applies only to English practice, where we may assume that, as a rule, about 0.8 per cent. of Silicon will remain in the metal after melting. In cases like those given by Campbell, where the whole of the Silicon is removed during melting, from .5 to .7 per cent. Carbon left in the molten metal will be sufficient to work the heat down with, although the higher limit is preferable, or even 1.0 per cent.

**Composition of Slag.**—The oxidation of the metal after melting depends upon the composition of the slag and the temperature of the furnace, and both these factors are of the greatest importance.

In a most exhaustive paper by Campbell,† which has already been referred to, and which forms the most complete contribution to the metallurgy of the Siemens process ever published, he traces the chemical history and variations in composition of the slag in a large number of charges working both with producer and with oil gas; and from the results, given

\* Campbell, *Structural Steel*, p. 124.

† *Trans. Amer. Inst. Mining Engineers*, vol. xxii., 1893.



in the following table, it will be seen that the variation in Silica and Oxides of Iron in the slag, directly *after melting*, and just before tapping, is comparatively little. In the case of A, the figures are the average of nineteen heats, and in B, average of six heats:—

TABLE XXVIII.—VARIATIONS IN COMPOSITION OF SLAGS.

	Silica.		Oxide of Manganese, MnO.		Oxide of Iron, FeO.		Oxide of Iron and Manganese, FeO and MnO.	
	After Melting.	Before Tapping.	After Melting.	Before Tapping.	After Melting.	Before Tapping.	After Melting.	Before Tapping.
A. 19 heats producer gas,	50.24	49.40	21.67	16.50	23.91	29.79	45.58	46.29
B. 6 heats oil gas, . . .	49.46	49.36	13.16	11.30	33.27	34.11	46.43	45.41

The above results show that the Silica was practically the same in the slag just after melting as immediately before tapping, that the Oxide of Mn gradually decreased, that the FeO varied somewhat, but that the sum of the two Oxides, MnO and FeO, was practically constant.

For a good working slag what is required is sufficient Oxides of Iron and Manganese, to completely combine with the Silica present, so that any ore added is free to oxidise the remaining impurities in the metallic bath. When additions of ore are made from time to time to a slag in this condition, the percentage of iron in the slag is hardly affected at all, all the Oxide of Iron added being almost immediately reduced by the impurities in the metal, the iron passing into the bath.

Table xxix., taken from Campbell's paper, gives the analyses of the slag after various additions of ore have been made, and it is surprising how little the composition of this slag is altered. It is true that the amount of FeO is increased by nearly 2.5 per cent. after the addition of 1,500 lbs. of ore. But as Campbell points out, the stable condition of the slag is not determined by the percentage of FeO alone, but by the sum of the Oxides, FeO and MnO, and provided they are present in sufficient quantity to satisfy the Silica, a state of equilibrium is established, and no more Oxide passes into the slag, but it is free to act upon the bath of metal. From time to time some Silica is taken up from the hearth of the furnace, and small quantities of Oxide will be required to combine with this, and also any silicious matter introduced with the ore; but with these exceptions the Iron Oxide *added* should be practically reduced, unless a large excess of ore is added towards the end of the operation.

TABLE XXIX.—SHOWING HOW COMPOSITION OF SLAG IS AFFECTED BY ADDITIONS OF DIFFERENT QUANTITIES OF ORE.

	Before Addition of Ore.	After 500 lbs. of Ore Added.	After 1,000 lbs. of Ore Added.	After 1,500 lbs. of Ore Added.
Silica, per cent., . . . . .	51.90	51.98	52.77	52.75
Oxide of Manganese, MnO, per cent., . . . . .	18.50	17.51	16.29	14.93
Oxide of Iron, FeO, per cent., . . . . .	26.04	26.53	26.92	28.45
FeO and MnO, per cent., . . . . .	44.54	44.04	43.21	43.38

In a paper\* read before the Iron and Steel Institute by Messrs. A. McWilliam and W. H. Hatfield on the elimination of Silicon in the open hearth furnaces, the authors give the results of two experimental heats in which the composition of the slag in relation to Silica and Oxides of Iron was varied during the working of the charge, so that the effect of such variation on the removal of impurities might be seen. In Tables xxx. and xxxi. are given analyses of the metal and slag from samples taken at frequent intervals.

TABLE XXX.—DETAILS OF SPECIAL CHARGE No. 1.

Time.	Composition of Bath.			Additions.		Consistency of Slag.	Composition of Slag.		
	C.C.	Si.	Mn.	Materials.	Cwt.		FeO.	Fe <sub>2</sub> O <sub>3</sub> .	SiO <sub>2</sub> .
Hr. Min.	Per cent.	Per cent.	Per cent.				Per cent.	Per cent.	Per cent.
11 10	1.60	0.78	0.48	(Melted)	...	Thin	...	...	...
11 12	...	...	...	Ore	10	...	...	...	...
11 30	...	...	...	"	4	...	...	...	...
11 45	1.54	0.35	0.20	(Boil)	...	Thin	30.8	7.1	45.0
12 15	1.55	0.047	0.11	...	...	"	...	...	...
12 20	...	...	...	Ore	2	...	...	...	...
12 45	1.22	0.045	0.09	...	...	Thin	...	...	...
12 50	...	...	...	Ore	3	...	...	...	...
1 0	...	...	...	"	1½	...	...	...	...
1 15	0.94	0.028	0.042	"	...	Very thin	24.1	2.5	52.8
1 16	...	...	...	Ore	1	...	...	...	...
1 30	0.86	0.02	0.04	Lime	¾	...	...	...	...
2 0	0.73	0.022	...	...	...	Becoming thicker	...	...	...
2 30	0.65	0.034	0.056	...	...	Fairly thick	...	...	...
3 0	0.55	0.061	0.068	...	...	Thick	...	...	...
3 30	0.40	0.078	0.08	...	...	"	...	...	...
3 50	0.38	0.088	0.095	...	...	Thickest	20.8	1.1	56.8
3 55	...	...	...	Ore	1	...	...	...	...
4 5	...	...	...	"	¾	...	...	...	...
4 25	0.26	0.031	0.072	Lime	½	Becoming thinner	...	...	...
4 30	...	...	...	...	...	...	...	...	...
4 35	...	...	...	Ore	1	...	...	...	...
4 45	...	...	...	Lime	½	...	...	...	...
4 50	0.16	0.024	0.065	Ore	½	Fairly thin	...	...	...
4 55	...	...	...	...	...	...	...	...	...
5 13	0.14	0.025	0.065	Ore	¼	Fairly thin	21.9	0.57	53.4

Finished steel—Combined Carbon, 0.31; Si, 0.045; Mn, 0.58.

It will be seen that with a thin slag—that is to say, a slag relatively low in Silica—the oxidation of Silicon and Manganese was comparatively rapid, but with a thick or silicious slag not only were Silicon and Manganese not removed, but they were actually reduced from the slag and passed back into the metal. The authors maintain that the results are due to the variations in composition of the slag and not to its fluidity, as when it was thinned by other means than the addition of oxidising agents the impurities were not removed to the same extent.

\* *Iron and Steel Inst. Journ.*, 1902, vol. i., p. 53.



These results entirely support Mr. Campbell's conclusions that the activity of the slag as an oxidising agent depends upon the relation of the percentage of Silica to the Oxides present, and that it is the Oxide in excess of that required to satisfy the Silica in the slag which must be relied upon to do the work of oxidation. It is probable that the temperature has some influence on the removal of the Silicon, although this does not appear to be very great, at all events within the variations of temperature common in everyday practice.

TABLE XXXI.—DETAILS OF SPECIAL CHARGE No. 2.

Time.		Composition of Bath.			Additions.		Consistency of Slag.	Composition of Slag.		
		C.C.	Si.	Mn.	Materials.	Cwt.		FeO.	Fe <sub>2</sub> O <sub>3</sub> .	SiO <sub>2</sub> .
Hr.	Min.	Per cent.	Per cent.	Per cent.				Per cent.	Per cent.	Per cent.
9	45	1.60	0.80	0.64	(Melted) Ore	6	...	...	...	...
10	25	1.58	0.28	0.27	(Boil) "	4	Thin	22.1	2.5	48.6
10	52	1.47	0.026	0.064	"	...	Fairly thin	...	...	...
10	55	...	...	...	Ore	2	...	...	...	...
11	15	...	...	...	"	2	...	...	...	...
11	25	1.08	0.017	0.054	"	...	Thin	...	...	...
11	30	...	...	...	Ore	3	...	...	...	...
11	50	...	...	...	"	2	...	...	...	...
11	55	0.82	0.016	0.051	"	...	Thin	...	...	...
12	15	...	...	...	Ore	1	...	...	...	...
12	20	0.64	0.017	0.053	"	...	Thinnest	20.5	2.1	53.0
12	55	0.47	0.035	0.059	"	...	Becoming thicker	...	...	...
1	25	0.39	0.066	0.065	"	...	Fairly thick	...	...	...
2	0	0.33	0.058	0.071	"	...	Thickest	18.1	0.6	54.6
2	5	...	...	...	Ore	1½	...	...	...	...
2	30	0.24	0.032	0.056	"	1	Becoming thinner	...	...	...
2	45	...	...	...	"	½	...	...	...	...
3	0	0.19	0.032	0.055	"	...	Fairly thin	23.0	0.3	51.6

With careful work there is little risk of getting too high a temperature, although this is possible with a silicious iron, a rich gas, and a quick draught. We then get the same result as in the Bessemer converter—that the Carbon is oxidised preferentially to the Silicon, and we obtain a decarburised metal high in Silicon. The possibility of this is of course increased when working a very silicious iron, and hence it is important to regulate the temperature of the furnace according to the composition of the charge, and to obtain pig-iron as regular as possible, so that the furnacemen may not have to vary the conditions of working more than is absolutely necessary. The essential condition is to have sufficient heat to maintain a fluid bath of metal and slag, and to enable the metal to be tapped at such a temperature that it can be cast into the ingot moulds without "skulling" in the ladle.

**Sulphur in Producer Gas.**—In open hearth steel manufacture the Sulphur in the finished metal is often found to be higher than would be expected from the composition of pig and scrap used.

This may be due to Sulphur either absorbed from the gases, or introduced in the ore, and consequently care must be taken to see that good coal, low in Sulphur, is used in the gas producers, and non-

sulphurous ore in the furnace. It is the practice in some works to mix a little lime with the coal slack before it is used in the producers, and, provided it can be done without causing trouble with clinkering, it undoubtedly has a tendency to fix the Sulphur with the ash instead of allowing it to pass into the gases. The difficulty, however, is to add a sufficient quantity of lime to effect this without interfering with the regular working of the producer. In the opinion of many practical men, when, for any reason, the furnace is working sluggishly, and when the gas is said to be "cold," there is a much greater tendency for the bath to take up Sulphur than when working quickly, but the author is unable to offer any opinion as to whether this is due simply to a larger amount of gas being passed into the furnace to produce the required amount of heat, or to some other cause.

So far we have considered only the manufacture of dead soft or mild steel in the Siemens furnace, but as large quantities of steel are required of all degrees of carburisation, from .200 to 1.000 and even higher, it is necessary to discuss the manufacture of these different classes of steel.

**Axle, Tire, and Spring Steel, &c.**—The principal purposes for which high Carbon open hearth steel is used are for the manufacture of axles, tires, springs, guns, wire drawing, armour plates, steel castings, and to a small extent for tool steels.

Steel for axles varies in Carbon content from 0.25 to 0.35 per cent., and has a stress varying from 30 to 40 tons per square inch. Tire steel varies in Carbon content from 0.30 to 0.70 per cent., and has a stress varying from 35 to 58 tons per square inch. Spring steel, for railway purposes, varies from 0.50 to 1.2 per cent. Carbon, according to the particular purpose for which it is required. The majority of steel castings contain from .20 to .40 per cent. Carbon, although for special purposes they are made as high as 1.0 per cent. Carbon.

Broadly speaking, there are three important methods of making high Carbon steel in the Siemens furnace, viz. :—

1. To work the charge of pig-iron, or pig-iron and scrap, in the usual manner, but to tap out the metal as soon as it has reached the desired point of decarburisation.

2. To work the charge down dead soft, or nearly so, as for mild steel, and then recarburise in the furnace by the addition of pig-iron or spiegel, or by a mixture of both.

3. To work the charge dead soft, and recarburise outside the furnace by the Darby\* or other method of recarburisation.

In making axle steel, the practice more generally adopted is to tap out when the required degree of decarburisation has been reached, although for making the highest quality of material, many of the best makers prefer to work down and recarburise in the furnace. In the case of higher Carbon steel, such as tire steel, spring steel, and wire billets, with 0.50 per cent. of Carbon and over, it is usual to work down to about 0.20 to 0.30 per cent. of Carbon, and then bring back by charging pig-iron in the furnace.

In carrying out the manufacture by the second method, the charge of pig-iron and scrap is carefully worked down, so that when the bath contains about 0.3 per cent. Carbon the slag is thick and clean—i.e., practically exhausted, or free from active oxide. Samples of metal are then taken, and are generally tested for Carbon by colour, which only takes a few minutes. The metal samples should be solid, and free from blowholes or honeycomb structure, and if either the slag or the metal is not right, pig-iron must be added, a few pigs at a time, until both are satisfactory. Too much emphasis cannot be laid upon the importance of getting both slag and metal in the

\* See chap. viii., Basic Siemens, p. 189.



right condition before adding the metal for recarburising, as if any appreciable amount of Oxide of Iron remains in the slag the pig-iron added will react vigorously with the slag, considerable decarburisation will result, and the Carbon in the finished steel will be far lower than required. When the melter is satisfied both with his metal and his slag, he charges the pig required to give the necessary Carbon on the banks of the furnace, and allows it to melt down into the bath. It is then well rabbled or "rubbed up," the necessary additions of Silico-spiegel and Ferro-Manganese made, and the metal tapped. The Ferro-Manganese may be added either in the furnace immediately before tapping, or to the metal as it runs into the ladle. If steel with more than about 0.6 per cent. Mn is required, it is found that this becomes more evenly distributed if the Ferro is added in the furnace, in which case it is added in rather large lumps to guard against excessive oxidation. If added in the ladle, it should be in small pieces, not larger than hazel nuts.

The amount of pig-iron added for recarburising is calculated, so that when it has quite melted, the Carbon content of the bath shall be rather above that which is required, and it is then carefully worked down to the desired point. During the melting of the pig on the furnace banks, a certain amount of oxidation is of course taking place, and an allowance must, therefore, be made for this.

The amount of Carbon oxidised during the melting will vary with the percentage of Silicon in the pig-iron, the higher the Silicon the less the Carbon is oxidised, so that when using a Swedish pig with 1 per cent. of Silicon for recarburising (for steels where low Silicon is required) rather more must be added than when hematite pig containing 2.5 per cent. Silicon is used. In making .50 per cent. Carbon steel, it is usual to work the bath down to 0.20 per cent., and a charge of about 7 tons 2 cwts. of pig and scrap would require about 14 cwts. of Swedish pig, with 4.0 per cent. Carbon and 1.0 per cent. Silicon, charged on the banks, to give .49 to .51 per cent. Carbon in the ingot, provided the slag was right before the Swedish pig-iron was charged into the furnace. Theoretically this should give .54 per cent. Carbon, thus showing a loss of about .03 to .05 per cent. For .60 Carbon steel, working under the same conditions, about .3 cwt. more of pig-iron would be required. If grey hematite instead of Swedish pig is used to obtain the same result, rather less pig would be required. For .70 Carbon steel, the bath may be safely worked down to .30 before charging the recarburising pig-iron. A certain amount of Carbon will always be added by the Ferro-Manganese additions, and also by the Silico-spiegel, or Ferro-Silicon, when these are used, and allowance must be made for this.

Although it is the practice at some works to make tire steel from .50 to .70 per cent. Carbon by working down to the required point and tapping at once, this method of working for such high Carbon steels is not regarded as satisfactory by many steel makers.

It is extremely difficult to get a thick, quiet, inactive slag, with Carbon in the steel, at or above .50 per cent., and unless the slag is practically exhausted as regards free Oxide at the time of tapping, it will be impossible to insure steel of the required Carbon content.

In cases of high Carbon steel, where low Silicon is required, excellent results may be obtained by running finely-ground anthracite on to the stream of metal as it flows into the ladle; this should be all in when the ladle is about three-quarters full of metal, and then sufficient Aluminium should be added to give a good solid ingot. If no Aluminium is added, or too little, the ingots are liable to be honeycombed, and if too much is added, although the ingots will be solid, they will "pipe" badly. If anthracite were pure Carbon, and there

were no loss, 2.24 lbs. would give .100 Carbon when added to 1 ton of steel, but in actual practice about 3.12 lbs. are required, so that to raise the Carbon .01 in a 10-ton charge, 3.12 lbs. are necessary.

In the case of tire steel, when great hardness to resist wear on the tread is required, combined with soundness and absence of all brittleness, a certain amount of Silicon in the steel is beneficial, and this is added to the bath just before tapping in the form of Ferro-Silicon or Silico-spiegel. About  $\frac{1}{2}$  or  $\frac{1}{4}$  of the Silicon present in the Ferro-Silicon is oxidised, so that to obtain .15 to .18 in the steel, sufficient Silicon pig or Silico-spiegel must be added to give .22 per cent. of Silicon.

In all cases, whether hard or soft steel is being made, the casting temperature has an important influence on the quality of the steel produced, and is a question which has not received so much attention as it deserves. The point to aim at is to have *just sufficient* heat to teem the metal clear from the ladle, so that when the metal is once cast into the moulds it will set as rapidly as possible. The lower the casting temperature, in all probability the better the steel.

The following may be taken as a fairly typical charge for the manufacture of tire steels:—

	Tons.	Cwts.
Best selected pig-iron,	5	13
Scrap (selected),	5	0
Best grey pig-iron on banks after bath worked down,	1	0
Ferro (80 per cent.), 226 lbs.; Aluminium, 8.5 lbs., added in ladle.		
Silico-spiegel, 45 lbs., added to furnace just before tapping.		
Analysis of finished steel—Carbons, .54; Silicon, 0.224; Manganese, 0.65.		

When it is intended to catch the Carbon on the way down, and tap without "pigging back," a much greater proportion of pig-iron is used, so as to give a higher initial Carbon content in the bath, and, consequently, a longer period of boiling; not more than 25 per cent. scrap should be used if steel with 0.60 per cent. Carbon is required. With such a proportion of scrap very excellent results can be obtained, and some makers prefer this method to recarburising in the furnace.

The following is a typical charge:—

	Tons.	Cwts.
Best selected pig-iron,	9	10
Scrap,	2	10
80 per cent. Ferro equal to 1 per cent. of charge; 70 ozs. Aluminium, added in the ladle.		

This charge gave steel containing Carbon, 0.63 per cent.; Silicon, .170 per cent.; Manganese, 0.60 per cent.

In the manufacture of tires, the metal, instead of being cast in a mould of the usual shape, is cast in special circular moulds known as cheese moulds, shown in fig. 156.

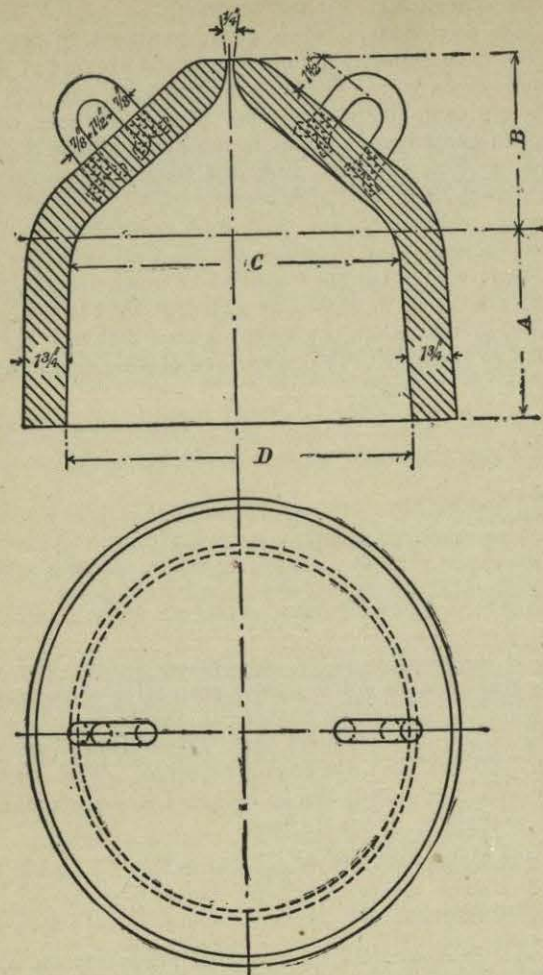
These are always cast in groups from the bottom, about four moulds being set on one bottom plate. In figs. 156 and 157 are shown plan of moulds and of bottom plate, with section of latter and git.

These ingots are flattened under the hammer, the centre punched out, and then finished in a special tire mill.

Washed metal\* is now being largely used to replace Swedish pig-iron in the manufacture of high-class steels for making axles, and sometimes as much as 70 to 90 per cent. is charged with pig or with part pig-iron and part scrap, although usually it does not exceed 30 per cent.

\* See chap. viii., Basic Siemens, pp.195-196.





A	B	C	D
5 <sup>1</sup> / <sub>6</sub> "	6 <sup>1</sup> / <sub>2</sub> "	13 <sup>3</sup> / <sub>8</sub> "	14"
5 <sup>3</sup> / <sub>4</sub> "	6 <sup>3</sup> / <sub>8</sub> "	11 <sup>3</sup> / <sub>4</sub> "	12"
6 <sup>1</sup> / <sub>6</sub> "	6 <sup>1</sup> / <sub>2</sub> "	13 <sup>3</sup> / <sub>8</sub> "	14"
9 <sup>1</sup> / <sub>2</sub> "	6 <sup>3</sup> / <sub>4</sub> "	19 <sup>1</sup> / <sub>8</sub> "	20"

Fig. 156.—Cheese Ingot Moulds for Casting Ingots for Tires.

The following charges are from actual works' practice:—

	1.	2.	3.	4.
Best selected pig,	Per cent. 6	Per cent. 5	Per cent. 15	Per cent. 6
Washed metal,	20	5	5	20
Best axle or tyre scrap,	74	90	80	70

When using such a large proportion of scrap as above, a portion of the pig-iron or washed metal would be reserved for charging on the banks to recarburise, as it would be difficult under these conditions to catch the bath at the right point.

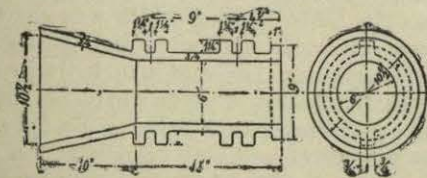
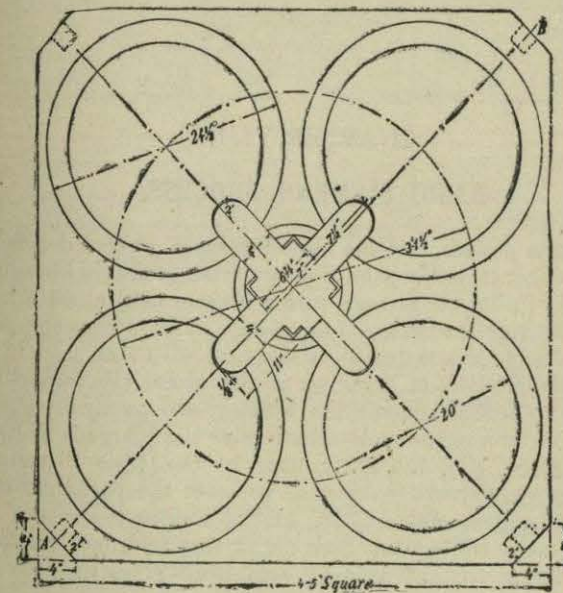
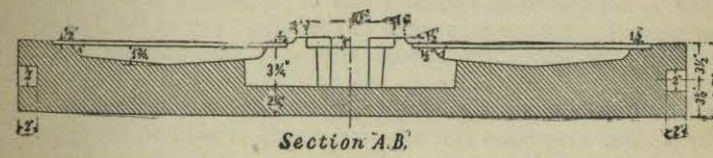


Fig. 157.—Bottom Plate for Casting Cheese Ingots for Tires. A group of 4 ingots is cast from one centre git.

Some engineers specify that a certain percentage of Swedish iron shall be used in the charge, and as the Sulphur and Phosphorus have generally



to be under 0.04 per cent., it is absolutely necessary to use either Swedish iron, washed metal, or one or two very special brands of English iron.

Many steel makers prefer, in the case of *axle steels*, which usually contain from .25 to .35 per cent. of Carbon, to catch the metal when the required point of decarburisation has been reached, rather than work down to nearly soft steel and then recarburise by charging pig-iron on the banks. When making steel *below 0.4* Carbon, most excellent results can be obtained by this method of working, and the difficulties of getting slag and metal into the right condition are considerably less than in case of higher Carbon steel; but even for these lower Carbon steels it is necessary to use a larger percentage of pig-iron to ensure a fairly long boil than if it is intended to recarburise in the furnace, and not more than 50 per cent. of scrap should be used in the charge.

In the manufacture of special steels or alloys for armour plates and other purposes, the charge is worked in the same way as for ordinary high Carbon charge, and then the special alloy of Ferro-Chrome, Nickel, &c., added, special care being taken to see that the slag is as free as possible from oxides. The ingots of these steels are usually cast from the bottom, to ensure greater soundness and a better surface or skin on the ingot.

## CHAPTER VIII.

### BASIC SIEMENS PROCESS.

The basic Siemens process, like the basic Bessemer process, depends, for the removal of Phosphorus, entirely on the formation of stable Phosphates, and this is effected by lining the furnace with a basic or neutral material, and by lime additions during the working of the charge. The furnace employed, with the exception of some minor details, is identical with that used in the acid process, and the method of working is the same, the impurities being oxidised partly by the air during the melting, and partly by the addition of solid Oxides of Iron to the molten bath after the charge is melted.

**Early Practice.**—In the early days of the basic Siemens process several furnaces were specially designed to meet the particular difficulties encountered, to facilitate repairs, &c., and to reduce the cost of construction; but after many trials it has been found that a furnace constructed on modern lines similar to that used for acid work gives the best all-round results in actual practice.

**The Batho Furnace.**—Amongst the earliest forms of modified furnaces used for basic work was the Batho furnace, which was greatly improved in various ways by Messrs. Riley, Dick, Wailes, and Hilton. In its earlier form it was a round furnace, and the roof was built in an iron frame, forming a lid, and was suspended independently of the walls of the furnace from girders above, arrangements being made for raising the roof bodily when the furnace required re-lining or repairs. A sketch showing the general arrangement of a modified form of the furnace of this type is given in figs. 158 and 159. The chief points urged in favour of these furnaces were, that the regenerators, being on each side of the body of the furnace, were quite independent of the latter and contained in separate iron casings so that in the event of a breakout there was no risk of the metal

getting into the regenerators; that it was impossible for a leakage of gas to take place between the gas and air regenerators, leading to the destruction of the brickwork; and that, the regenerators not being underneath the staging, the latter was much cooler for the men to work on. One modification of the furnace was to make the body elliptical (as shown in the sketch) instead of cylindrical, but with all these furnaces the difficulty of getting the gas and air ports to withstand contraction and expansion was so great that it has been found better to return to the rectangular furnace, with a solid square block for the ports, which is capable of resisting the great strain put upon it by contraction and expansion. The modern type of furnace (as shown in

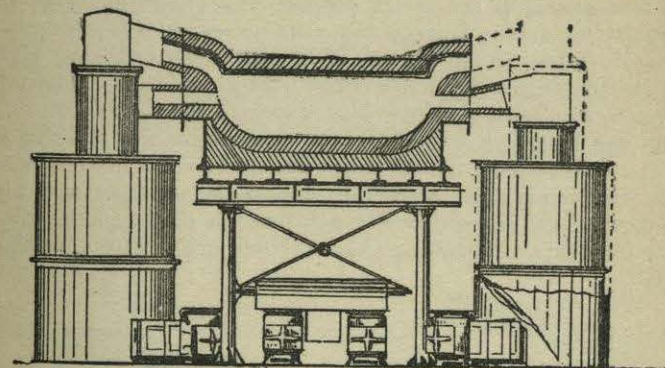


Fig. 158.

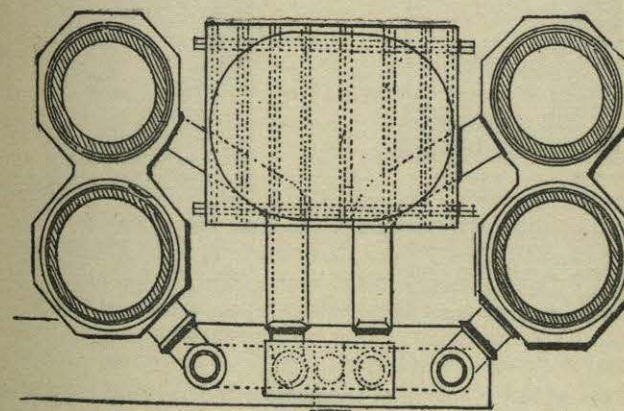


Fig. 159.—Sketches illustrating general arrangement of a Batho Furnace. Sectional plan and elevation.

(figs. 127-130) practically has all the advantages claimed for the Batho furnace. The body of the furnace is independent of the regenerator arches; the regenerators are away from the bottom of the furnace, and there is practically no risk of air and gas burning, due to leakage of gas and air between the regenerators. It may be, therefore, taken as established by experience that the best form of furnace for basic Siemens work is that of the ordinary Siemens type, as far as general design is concerned, and it will differ only in the internal lining of the hearth or crucible, and the method of supporting the roof and other details. Owing to the very friable nature of basic material, it is not possible to build the entire working body of this; it would,