

greatly increase the liability to produce over-oxidised metal as compared with the open hearth process, especially as it seems the custom to decarburise completely, and to produce the required grade of steel by addition of Ferro-Manganese, Spiegel, Ferro-Silicon, &c. Converters to blow only 10 cwts. of metal can be used successfully, and generally speaking the process lends itself to the production of small castings. With a 2-ton converter large castings can, however, be made, as it is possible to keep the metal from one charge in the ladle while another charge is being blown, and in this way with two 2-ton converters, castings up to 10 tons can be made, or with a single 2-ton converter, 3 to 4 tons casting can be produced. The waste is said not to exceed 14 per cent., which is exceptionally little for such small heats, and is certainly surprising considering the large amount of surface oxidation. The process can be worked either as an acid or a basic one, but there would appear to be little advantage in using the latter, and many difficulties would arise in regard to linings and in dealing with the slag. The process is at work at Woolwich Arsenal, where there are three converters which are said to give extremely satisfactory results.

The Stock Converter.*—This is a combination of an oil-melting furnace and small side-blown converter. Materials are charged cold into the previously heated converter; oil fuel under a pressure of about 40 lbs. to the square inch is supplied through flexible tubing to small tubes about $\frac{1}{2}$ of an inch in diameter, let into the main blast tuyers, which are about 2 inches in diameter, and air for combustion, at a pressure of about $1\frac{1}{2}$ lbs., is admitted. When the charge is melted, which takes about $1\frac{1}{2}$ hours for a 3-ton charge, the converter is rotated to the blowing position, the oil shut off, and the bath of metal subjected to a blast of air on the surface for about 16 to 19 minutes, when the vessel is rotated into the teeming position and finishing metal added in the usual way. The waste gases formed during the melting of the charge pass through an economiser containing iron pipes through which the blast passes on its way to the converter, and in passing through which it is heated up to a temperature of 700° F. During the actual blow the waste gases are allowed to escape, as they contain so much solid matter that they would be injurious to the regenerative apparatus. Owing to the intense heat developed during melting and blowing with heated blast, the converter has to be lined with magnesite bricks, but low phosphoric iron is used and no attempt is made to dephosphorise. The advantages of this converter are that no impurities are taken up by the pig-iron during melting, as in case of coke melting in cupolas, and owing to the hot blast being used a very high temperature is obtained, insuring a very fluid metal, which makes the process particularly applicable for manufacture of steel castings. The vessel is mounted so that it can be rotated into the different positions for charging, blowing, and teeming.

Small Converters Considered generally.—Although these small converters still have some enthusiastic supporters, with the few exceptions where manufacturers find it necessary to make their steel in comparatively small quantities under their own supervision, these converters are used almost exclusively for steel castings, and even under such circumstances the general consensus of opinion seems to be that a small open hearth plant gives better all-round results. For castings, especially where small ones have to be made, and metal has to be kept extremely hot and fluid, these small tipping converters undoubtedly offer certain advantages over a Siemens furnace. Steel can be made in smaller quantities, the converter can be used as a ladle to distribute the steel in small ladles for different castings, and thus the metal be kept very hot until the whole heat has been cast. Frequent charges can be made during the day, instead of one charge as in the

* For further details, see paper by P. P. Dowden on "The Manufacture of Steel," read before the Institute of Marine Engineers, Feb. 17, 1913.

open hearth furnace. Less space is required in the moulding shop, for as soon as one set of castings is set, they can be removed and moulding recommenced, whereas for a Siemens furnace sufficient moulding space must be available to take an entire charge, probably of not less than 5 or 6 tons. At all events, whatever may be the future of small converter plants, it is in the direction of steel founding that they are most likely to develop, as they cannot hold their own against the large outputs of Siemens or Bessemer plants for ordinary steel manufacture, and are also handicapped by the large waste which occurs during conversion.

CHAPTER IV.

CHEMISTRY OF THE ACID BESSEMER PROCESS.

General Considerations.—The reactions taking place in the acid-lined Bessemer converter, under various working conditions, have been carefully studied by Snelus in this country, by Kupelwiesser and Ledebur on the Continent, and by F. Julian in America, while the thermo-chemistry of the subject has received special attention from Jordan, Akerman, Pourcel, and, later, from Professor Hartley.

To arrive at the chemical history of the Bessemer blow it is necessary to examine the bath of metal at repeated intervals, and note the changes produced; also to examine the products of oxidation, and to consider the thermal conditions existing at each period when samples are taken. The products of combustion are either gaseous or liquid, the former passing away with the Nitrogen at the mouth of the converter, and the latter fusing at the intense heat developed to form a more or less fluid slag, which, being lighter than the molten metal, floats upon its surface.

Three Stages Involved.—The reactions taking place in the acid Bessemer blow are usually divided into three stages or periods—1st, the slag-forming period; 2nd, the boil; and 3rd, the finishing period. During the first period the greater portion of the Manganese and Silicon are oxidised, and unite with some Oxide of Iron simultaneously produced to form a double Silicate of Iron and Manganese slag; and under normal conditions of working the Carbon is not appreciably attacked until a considerable portion of the Silicon has been removed, such proportions as are oxidised passing away mostly as Carbon Dioxide (CO₂). This period is marked by an irregular violet-coloured flame at the mouth of the converter, which gradually becomes more steady in character and changes to a yellow colour as the temperature of the bath increases. After about five or six minutes from the commencement of the blow, the Carbon begins to oxidise rapidly, and, the bath being very fluid owing to the high temperature produced by the combustion of a relatively large proportion of Silicon, the second period, known as the boil, commences. During this period the oxidation of the Silicon and Manganese continues, and the greater part of the Carbon is also removed, mostly in the form of Carbon Monoxide (CO), as the percentage of CO₂ formed in the early part of the blow rapidly decreases, while the CO increases, as will be seen from the curves in fig. 79. It is the formation and escape of this gas which causes the violent agitation of the bath, and is attended with a very large flame issuing from the mouth of the converter, and with the ejection of considerable quantities of metal and slag, and a further increase in the temperature, and consequently in the fluidity of the metal. Some Hydrogen is found in the gases issuing from mouth of converter during this part of the blow, derived from the dissociation of water vapour in the blast.

During the last period the small amount of Silicon left and the remainder of the Carbon are oxidised, the latter to Carbon Monoxide, the temperature being too high to admit of the production of Carbon Dioxide in the presence of iron. Some iron is also oxidised, as will be seen from the analyses of slag in Tables viii. and xii., where it will be noticed that the oxide rapidly increases between the end of the boil and the addition of Spiegel; although in cases where low Silicon pig-iron is used, and consequently a comparatively low temperature prevails, as in American practice, this is not very marked, and is in fact hardly perceptible at times. At the end of the boil the flame at the mouth of the converter rapidly contracts, and the final disappearance

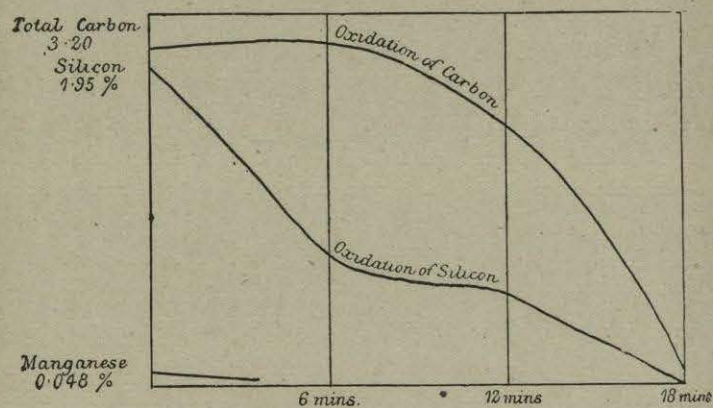


Fig. 78.—Curves showing removal of Carbon, Silicon, and Manganese in Acid Bessemer Process. (From analysis by Snelus.)

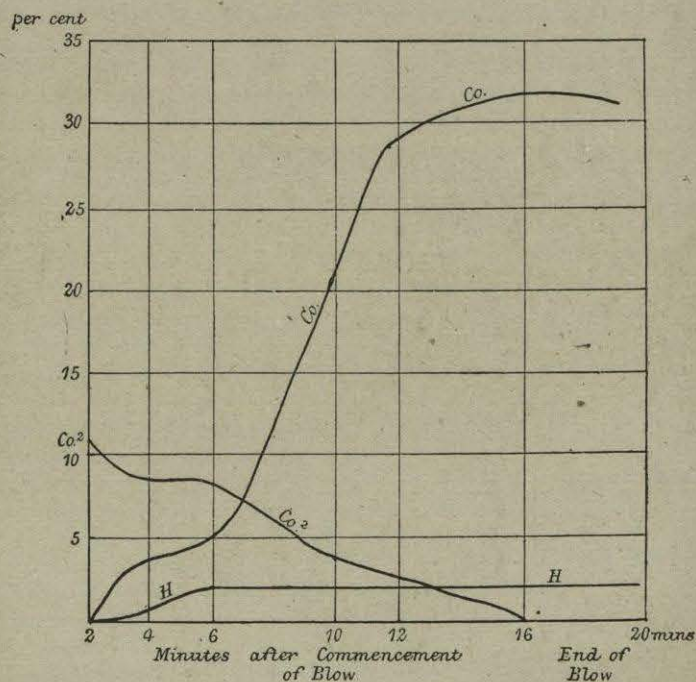


Fig. 79.—Curves showing composition of gases evolved from Acid Bessemer Converter at different stages of the Blow.

of the Carbon is marked by the "drop of the flame," which indicates that the conversion is complete; the blast is then shut off, and the vessel immediately turned down.

The following analyses of gases, and curves deduced therefrom, illustrate the reactions taking place during the blow:—

TABLE VII.—ANALYSES BY SNEBUS OF GASES FROM BESSEMER CONVERTER.

	Minutes from commencement of operation.					
	2	4	6	10	12	14
Carbon Dioxide, . . .	10.71	8.59	8.20	3.58	2.30	1.34
Oxygen,	0.92	...	0	0	0	0
Carbon Monoxide, . . .	0	3.96	4.52	19.59	29.30	31.11
Hydrogen,	{ 88.37*	{ 0.88	{ 2.00	{ 2.00	{ 2.16	{ 2.00
Nitrogen,		{ 86.57	{ 85.28	{ 74.83	{ 66.24	{ 65.55
Carburets of Hydrogen, . . .	...	...	...	...	0	...
	100.00	100.00	100.00	100.00	100.00	100.00

A certain amount of both iron and Manganese is volatilised during the second and final stages of the blow, but especially during the latter, when the metallic vapours are carried out into the air where with the Carbon Monoxide they are burnt.

Production of Fume.—The following analysis of fume is by Schöffel, and Prof. Hartley † considers that its composition suggests the volatilisation of Silica, or some Silicate or Silicon:—

FeO, 16.29; MnO, 48.23; SiO₂, 34.86.

The percentage of iron in the fume increases towards the end of the blow, since, for the complete removal of metalloids, a certain amount of overblowing or oxidation of the iron is necessary; and it seems probable that some of this oxide produced is carried away by the blast mechanically, rather than that the large proportion found in the fume has been volatilised. If blowing is continued so that the brown fumes become extremely dense, there is no corresponding increase in temperature to account for increased volatilisation. That Manganese is comparatively volatile has been distinctly proved, and there seems considerable probability that this element is volatilised to a small extent.

The Carbon, although responsible for the development of a certain amount of heat, plays a comparatively unimportant part in this respect, owing to the greater amount of the Carbon being oxidised only to CO—or, if oxidised to CO₂, being again reduced to CO—and also to the fact that all the products of its combustion, being gaseous, escape with the air, carrying away a considerable amount of heat. Silicon is the great heat producer; it plays an important part in rapidly forming a slag, and a certain amount of this element is necessary in all pig iron required for the Bessemer process. Manganese, within certain limits, is a very useful constituent, especially when the Silicon is low, as it raises the temperature of the bath, forms a fluid slag, protects the metal from

* Hydrogen not determined separately.

† "Cantor Lecture," March, 1898, by Prof. Hartley.

over-oxidation, and, lastly, tends to remove the Sulphur from the molten metal. Sulphur and Phosphorus are not oxidised, or, if oxidised, are immediately reduced again in the presence of a siliceous slag, and pass back into the metal. During the Bessemer blow of a 10-ton charge of metal having the following composition—Carbon, 3.50; Silicon, 2.00; Manganese, 1.00—7 cwts. of Carbon, 4 cwts. of Silicon, and 2 cwts. of Manganese are burnt, and as Silicon is a much greater heat producer than Carbon the intense temperature developed in the Bessemer converter is readily accounted for.

Mass Action in the Converter.—The influence of mass on chemical action has a most important bearing on the reactions which take place in the Bessemer converter. It cannot be supposed that traces of impurities are seized by the Oxygen out of the large mass of metal and oxidised directly, but it is generally admitted that the oxidation is an indirect reaction, Magnetic Oxide being first formed near the twyers, and reduced by the impurities in the bath to FeO and Fe as it passes upwards. The Oxide formed at the twyers thus acts as a carrier of Oxygen to the impurities in the bath, and the oxidation and reduction of iron goes on until all impurities are practically removed, when, if the blow is not at once stopped, the bath of metal rapidly becomes "burnt"—*i.e.*, surcharged with Oxide of Iron.

Thus the great affinity of Carbon, Silicon, and Manganese for Oxygen enables them to act as reducing agents to the Oxide of Iron formed, and, while being themselves oxidised and removed, they prevent, as long as they are present in the bath, any over-oxidation of the iron.

Silicon being the most readily oxidisable element in the metal, its reducing action is so great that, until it has been largely removed, the oxidation of the Carbon does not, under ordinary conditions of temperature, commence, as will be seen from the curves and analyses on pp. 87, 88, *et seq.* So great is the affinity of Silicon for Oxygen, that it is capable of decomposing to a large extent any Carbon Monoxide produced, giving rise to the formation of Carbide of Iron, and so preventing the oxidation of the Carbon during the early stages of the blow.

The Function of the Slag.—The action of the slag in the Bessemer converter is a somewhat disputed question—Akerman holding strongly the view that it plays a most important part in the oxidation of the impurities, as it does in other refinery processes. This view, he considers, is supported by the changes in the slag during the operation, as in nearly all cases the percentage of Ferrous Oxide is considerably reduced during the boil, showing that it must have acted as an oxidising agent to the impurities in the metal. As, however, was pointed out by Campbell,* in discussing this point, the amount of available Oxygen calculated on the weight of the Ferrous Oxide present is too small to have very much influence, unless we assume that it acts as a carrier of Oxygen to the bath. That the slag has some oxidising effect, there can be little doubt, as in the Basic Bessemer process it is possible to add from 10 to 15 cwts. of Oxide of Iron to a 7-ton charge without appreciably increasing the percentage of iron in the finished slag; but it is certain that the slag does not play anything like the important part it does in the Siemens furnace. In the latter all the Oxygen of the air has to pass through the slag first, when once the bath is melted, before it reaches the metal, whereas, in the Bessemer process, the Oxygen has to pass through the metal before it reaches the slag. The probability is that when a very oxidising slag is formed in the early part of the blow during the boil, the metal and slag being more or less intimately mixed, the latter gives up part of its Oxygen until a state of approximate equilibrium is established.

* *Trans. American Inst. Mining Engineers*, vol. xxii., pp. 668-9.

That is to say, for a particular set of conditions depending upon the composition of the slag, the composition of the metal bath, the temperature of the metal, &c., &c., the slag is capable of retaining only a certain amount of Oxide, and Oxide of Iron will pass into or be reduced from the slag, as the conditions vary during the blow.

Composition of Pig-iron.—The pig-iron used for acid Bessemer steel manufacture may vary within very considerable limits—

1. Low Silicon (under 1.0 per cent.) and high Manganese (from 2.4 per cent.), as in most Swedish works.
2. Low Silicon (under 1.00 per cent.) and low Manganese (under 0.5 per cent.), as in many American works.
3. High Silicon (from 2 to 2.5 per cent.) and low Manganese (.75 per cent. and less), as in most English works.
4. Occasionally high Silicon (2 per cent. and over) and high Manganese (2 per cent.).

Under suitable conditions good steel can be made from all these classes of iron, but whatever the percentage of Silicon or Manganese, the Phosphorus and Sulphur must both be below .06 per cent., as neither of these constituents is removed during the blow.

Low Silicon and High Manganese Pig-Iron.—The use of this class of iron is almost exclusively confined to Sweden, as the native ores containing Manganese produce a pig-iron which is low in Silicon, often contains 3.5 to 4.5 per cent. of Manganese, and is exceptionally free from Sulphur and Phosphorus. To the low Silicon and high Manganese is largely due the fine quality of the finished product, as they jointly develop just enough heat to enable the metal to be cast. The Manganese also plays an important part in preventing oxidation of the metallic bath, for even if blown quite down, the Manganese is rarely completely removed, as will be seen from the analyses and curves given. The practice in Sweden is not to blow until the Carbon is completely removed, and then to recarburise by additions of Ferro-Manganese, Spiegel, &c., but to stop the blow at the point when the required degree of decarburisation has been reached. The Manganese in the pig-iron not only protects the bath of metal from direct oxidation, but has a distinct tendency to remove Sulphur from the metal, and has the most important indirect effect of producing a very fluid slag which is at the same time far less oxidising than a rich iron slag. Akerman* is of opinion that the great fluidity of the slag in Swedish Bessemer practice plays a most important part in removing Oxide of Iron from the metal, as the more liquid the slag, the more completely it is brought into intimate contact with the metal, and the more readily does it remove and absorb Oxide of Iron, which would otherwise remain in the bath of metal. On the other hand, Manganese rapidly attacks the lining of the converters, and increases the waste. The Carbon is generally somewhat higher in these Manganiferous irons than in ordinary hematites, but this is no disadvantage, except that it slightly increases the waste, and prolongs the operation. The large amount of Carbon and Manganese present supplements the heat given out by the Silicon, and without the high percentage of these elements it would probably be impossible, considering the small charges worked, to cast the metal satisfactorily, as conditions do not lend themselves to the rapid work which is so essential a feature of American practice when working low Silicon pig. The following are analyses of samples taken with slags corresponding, during a Swedish Bessemer blow, and figs. 80 and 81 show graphically the rate of removal of impurities:—

* *Trans. American Inst. Mining Engineers*, vol. xxii., p. 282.

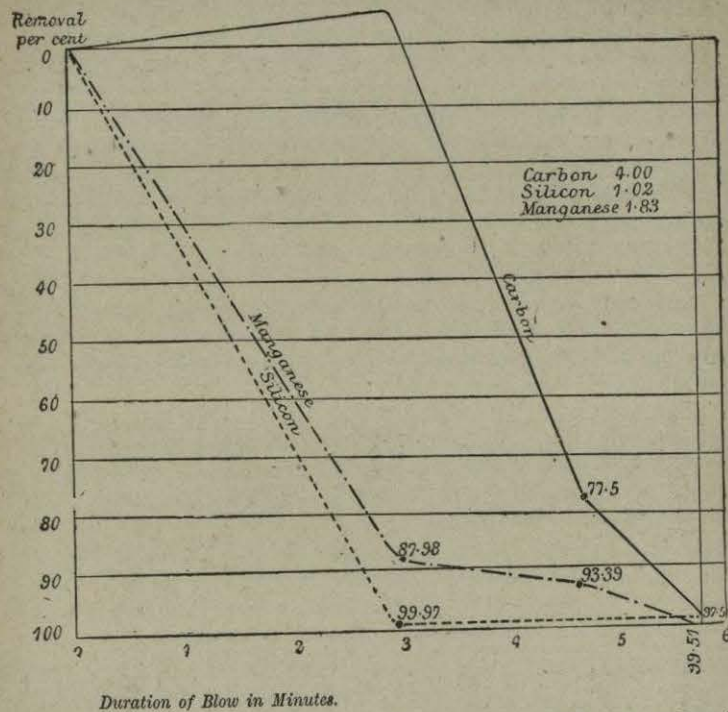


Fig. 80.—Elimination of Carbon, Silicon, and Manganese, Acid Bessemer; Low Silicon, Medium Manganese, Swedish practice. In this case not only is there no decrease in Carbon during first 3½ minutes, but a relative increase.

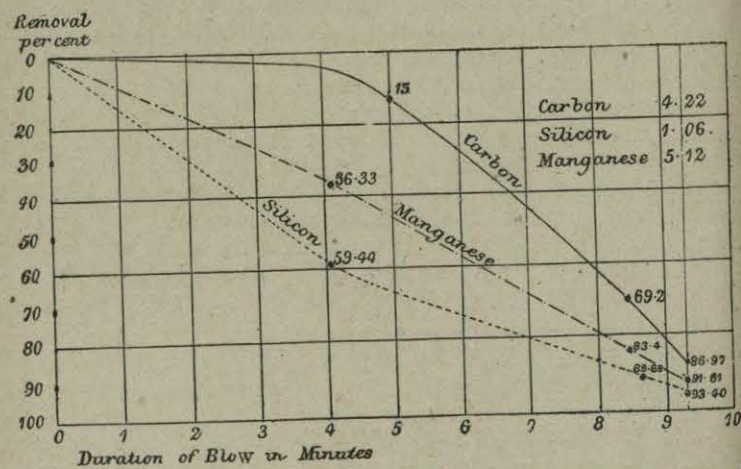


Fig. 81.—Elimination of Carbon, Silicon, and Manganese, Acid Bessemer. Swedish practice, Low Silicon, very High Manganese.

TABLE VIII.

	No. 1. MEDIUM MANGANESE.			No. 2. VERY HIGH MANGANESE.				
	Furnace Metal.	3 m.	4 m. 45 s.	5 m. 45 s.	Furnace Metal.	4 m. 15 s.	8 m. 35 s.	9 m. 20 s.
Carbon,	4.00	4.30	.90	.10	4.22	4.20	1.30	.55
Silicon,	1.02	.03	.03	.03	1.06	.43	.12	.07
Manganese, . . .	1.83	.22	.12	.09	5.12	3.26	.85	.43
SLAG.								
Oxide of Iron, . .	...	14.20	18.52	31.19	...	4.20	6.24	9.45
Oxide of Manganese, .	...	26.31	31.01	25.43	...	46.38	52.26	48.92
Magnesia, . . . .	...	.22	.14	.11	...	.54	.29	.46
Lime, . . . . .	...	.62	.38	.32	...	1.26	.70	1.00
Alumina, . . . .	...	2.86	2.70	2.24	...	3.08	2.49	2.94
Silica, . . . . .	...	55.26	47.20	40.50	...	45.87	39.07	37.63

In blowing metal with 2.5 per cent. and upwards of Manganese, sufficient is usually left in the bath at the end of the blow to make further addition of this metal quite unnecessary; and many thousands of tons of steel have been made in Sweden without either any Ferro-Manganese or other finishing metal being added, the finished product being entirely free from red shortness. Probably the low percentage of Sulphur in the pig-iron used largely enables these excellent results to be obtained, and it is more than doubtful if, with Sulphur equal to that in ordinary English hematite, the same freedom from red shortness could be insured without Manganese additions.

The percentage of Sulphur originally present in Swedish pig-iron is so low that the influence of Manganese in further reducing this is not easily noticed; but both in acid and in basic practice, whether Bessemer or Open Hearth, a Manganiferous slag always tends to reduce the Sulphur in the finished metal.

TABLE IX.—ANALYSES OF GASES BY M. TAMM FROM TWO BLOWS AT WESTANFORS WORKS, SWEDEN.

First Series.	Minutes from Commencement of Operation.			
	3 to 4.	9 to 10.	21 to 24.	26 to 27.
Carbon Dioxide,	9.127	5.998	4.856	1.853
Oxygen,	4.762	1.699	0.967	0.550
Carbon Monoxide,	0	17.555	19.322	14.311
Hydrogen,	0	0.908	1.120	1.699
Nitrogen,	86.111	78.840	73.735	81.587
Second Series.	2 to 3.	8 to 10.	12 to 15.	17 to 19.
Carbon Dioxide,	6.608	6.608	4.144	2.995
Oxygen,	7.256	1.206	0.989	1.318
Carbon Monoxide,	0	15.570	25.580	25.606
Hydrogen,	0	1.112	1.040	1.120
Nitrogen,	86.136	76.400	68.256	62.061

The foregoing table gives the analyses of gases taken at different periods during a Swedish blow; and it will be seen that free Oxygen is present during the entire operation, although gradually decreasing towards the end of the blow. This differs from the results obtained by Snelus, as will be seen by referring to the table on p. 81, he finding no free Oxygen after the first few minutes. This difference in the composition of the gases may have been due to the depth of metal blown being very small compared to the pressure of the blast. In other respects, the analyses confirm results obtained under dissimilar conditions, Carbon Monoxide increasing, and the Carbon Dioxide decreasing as the blow proceeds, the percentage of Hydrogen depending upon the amount of water vapour in the air.

Low Silicon and Low Manganese Pig-Iron.—That the temperature of the Bessemer charge principally depends upon the Silicon in the pig-iron, was first pointed out by Prof. Jordan,* of the Ecole Centrale in Paris, in 1869, and then by Prof. R. Akerman in 1872;† and for many years the pig-iron for Bessemer work has been selected by its content of Silicon, either high or low, to meet the special conditions of work, whether a hot or cold metal is required. The larger the quantity of metal blown, and the greater the rapidity with which the blows follow one after the other, the less Silicon will be required to keep up the heat of the bath; consistent with maintaining the metal fluid, the lower the Silicon the better, as there will be less waste, and quite as good, if not a better product.

In America, the practice in many works is to use metal very low in Silicon, from .8 to 1.2, which enables very rapid work to be done, the entire blow not lasting more than eight or nine minutes; the heat developed by such pig-iron is barely sufficient to keep the steel fluid for casting, and it is only by most rapid working—one heat following another practically without any interval, so that converters, ladles, &c., &c., are all kept extremely hot—that it is possible to avoid "skulling" in the ladle.

The advantages of low Silicon are:—(1) That a better yield is obtained, due, not only to the smaller amount of Silicon actually removed, but also to the smaller quantity of iron fluxed away in the form of Ferrous Silicate, as, especially in the absence of Manganese, iron is the most readily available base, and combines with the Silica to form a Silicate with consequent loss of metal.

(2) The larger the amount of Silicon in the metal, the larger obviously will be the amount of Oxygen required, and, consequently, the duration of the blow will be longer, and the wear and tear on the converter lining, especially on the bottoms, will be greater. On the other hand, with metal very low in Silicon, there is always considerable risk of not developing sufficient heat, and of the metal setting either in the converter or in the ladle. The general effect of Manganese in the Bessemer converter has already been referred to in the last paragraph, and its absence means that considerable additions of either Ferro or Spiegeleisen must be made at the end of the blow to remove all traces of red shortness caused by over-blowing. Indirectly, Manganese is a very important factor in Bessemer work, especially when low Silicon pig is used, as low Manganese and low Silicon in the pig generally indicate high Sulphur, and high Sulphur means red shortness in the finished product. In this country, at all events, it has not been found possible to produce regularly, on a commercial scale, pig-iron with 1 per cent. of Silicon or less, 0.5 per cent. of Manganese, and under 0.10 per cent. of Sulphur, although in America a pig-iron low both in Silicon and in Sulphur is made regularly in

* Bulletin de la Société des Ingénieurs Civils.
† Iron and Steel Inst. Journ., 1872, vol. ii.

certain districts—a result probably due largely to a very low Sulphur coke being available.

TABLE X.—AMERICAN PRACTICE.

	INITIAL CHARGE.			TIME OF ACTUAL BLOWING.						
	Molten Metal.	Steel Scrap estimated.	Average Composition of Charge.	2 Min.	M. S. 3. 20	M. S. 6. 3	M. S. 8. 6	M. S. 9. 10	Speigel-eisen Added.	After Adding Speigel-eisen.
Carbon, - - -	3.10	0.36	2.98	2.94	2.71	1.72	0.53	0.04	4.64	0.45
Silicon, - - -	0.98	0.08	0.94	0.63	0.33	0.03	0.03	0.02	0.035	0.038
Manganese, - -	0.40	0.97	0.43	0.09	0.04	0.03	0.01	0.01	14.90	1.15
Phosphorus, - -	0.101	0.10	...	0.104	0.106	0.106	0.107	0.108	0.139	0.109
Sulphur, - - -	0.06	0.08	0.06	0.06	0.06	0.06	0.06	0.06	...	0.059
SLAG.										
Silica, - - - -	...	...	...	42.20	50.26	62.54	63.56	...	...	62.20
Alumina, - - -	...	...	...	5.63	5.13	4.06	3.01	...	...	2.76
Ferrous Oxide, -	...	...	...	40.29	34.24	21.26	21.39	...	...	17.44
Ferric Oxide, -	...	...	...	4.31	0.96	1.93	2.63	...	...	2.90
Mangan. Oxide, -	...	...	...	6.54	7.90	8.79	8.88	...	...	13.72
Lime, - - - -	...	...	...	1.22	0.91	0.88	0.90	...	...	.87
Magnesia, - - -	...	...	...	0.36	0.34	0.34	0.36	...	...	.29
Phosphorus, - -	...	...	...	0.008	0.008	0.010	0.014	...	...	0.10
Sulphur, - - -	...	...	...	0.009	0.009	0.014	0.008	...	...	0.11
Appearance of flame, - - -	...	...	...	Silicon flame.	Brightening.	Moderate Carbon flame.	Full Carbon flame.	Flame drops.	Blown 10 secs. after drop.	...
Cubic feet of air, -	...	...	...	34,502	30,628	53,481	45,365	26,430	1,868	...
Cubic feet of air per minute, -	...	...	...	17,251	22,971	19,691	21,810	25,685	11,208	...

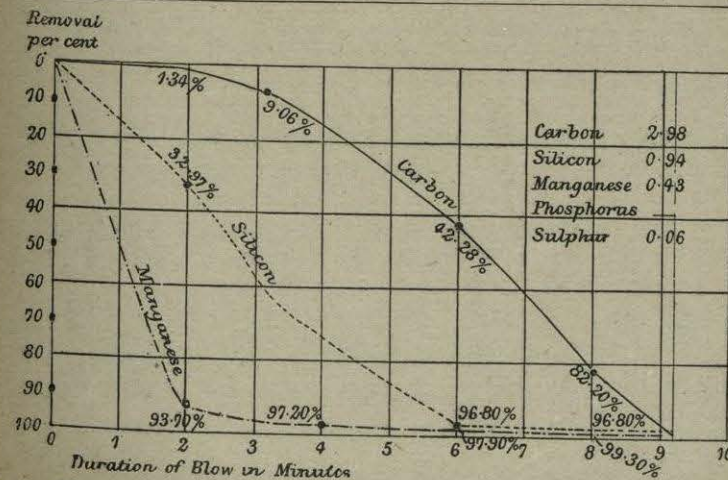


Fig. 82.—Elimination of Carbon, Silicon, and Manganese in Acid Bessemer. Low Silicon, and Low Manganese (American Practice).

In Table x. are given the analyses of a series of samples of metal and slag * taken during a low Silicon blow, and fig. 82 expresses graphically the rate of removal of the impurities. It will be noticed that neither Phosphorus nor Sulphur decreases; in fact there is a slight increase, and that the slag, after the addition of Spiegel, contains less Oxide of Iron and more Oxide of Manganese, which seems to point to the conclusion that some iron has been reduced from the slag by the Manganese of the Spiegel.

The increase of both Sulphur and Phosphorus is generally somewhat greater than that shown by these analyses, and it may generally be taken that such increase will be directly proportional to the waste or loss during blowing, and that these impurities will be concentrated in the steel to the extent of such loss.

High Silicon and Low Manganese Pig-Iron.—Pig-iron with about 2 per cent. of Silicon may be considered to represent fairly the iron used, and is found to give the best results, in English and Continental Bessemer practice. Pig-iron of this composition can be regularly and easily made low in Sulphur, and the heat developed is sufficient to avoid any risk of serious skulling. English plants are not adapted for the very rapid work customary in America, and consequently the metal used must be capable of developing more heat to allow for the loss by radiation from the vessels, &c., &c. Sometimes the Silicon is as high as 2.5 to 3.00 per cent., but if so, it is generally necessary to cool the blow by scrapping, and 2.0 to 2.25 per cent. of Silicon is what is preferred. The Manganese rarely exceeds 0.75 per cent., and Sulphur and Phosphorus should not be above .05 per cent., and frequently are as low as .035 per cent. Below are given analyses (Table xi.), by Snelus, of samples of metal taken from a Bessemer blow, and the curves (fig. 83) are deduced from these, and may be taken as fairly representative of the English practice, except that the Manganese in the pig-iron is exceptionally low. Temperature has a very marked influence on the removal of impurities, and as this temperature depends principally upon the Silicon present, the question of Silicon is very important. Provided the metal can be obtained hot enough to cast readily into ingot moulds, and free from Sulphur, the lower the Silicon in the pig-iron the better, as not only is the yield better, but the ingots will probably be sounder; if the Silicon is very high, there is considerable risk of its not being completely removed. Under ordinary conditions, the Silicon is oxidised from the commencement, and passes out rapidly at first before the Carbon is largely attacked, and then more gradually with the Carbon during the remainder of the blow, being almost completely removed before

TABLE XI.—ENGLISH PRACTICE—ANALYSES AT THE DOWLAIS WORKS.

	Molten Metal.	Time of Blowing.			After addition of Spiegel.
		6 min.	9 min.	13 min.	
Graphite,	2.09	—	...	...	...
Combined Carbon,	1.20	2.127	1.55	0.097	0.566
Silicon,	1.952	0.795	0.635	0.020	0.030
Sulphur,	0.014	Trace.	...	Trace.	...
Phosphorus,	0.048	0.051	0.064	0.067	0.055
Manganese,	0.086	Trace.	...	Trace.	0.309
Copper, . . . . .	...	...	...	...	0.039

* Howe, *Iron and Steel Inst. Journ.*, 1890, vol. ii., p. 102.

the drop of the flame. If, however, from any cause—either a very high percentage of Silicon or a very high initial temperature of the metal—the temperature of the bath exceeds a certain point, the Carbon is attacked in preference to the Silicon, with the result that the Carbon is removed before the Silicon. This was pointed out by Snelus as long ago as 1871, when he gave various instances of a considerable percentage of Silicon being found

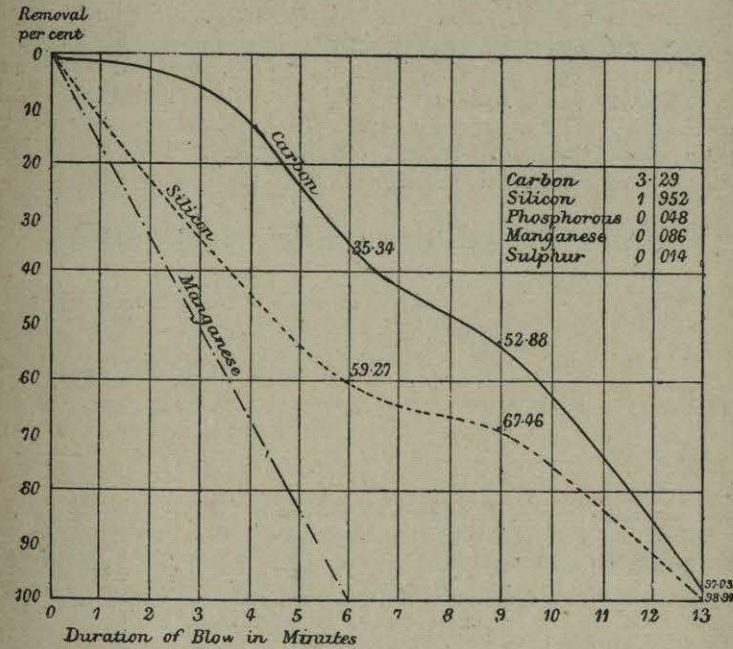


Fig. 83.

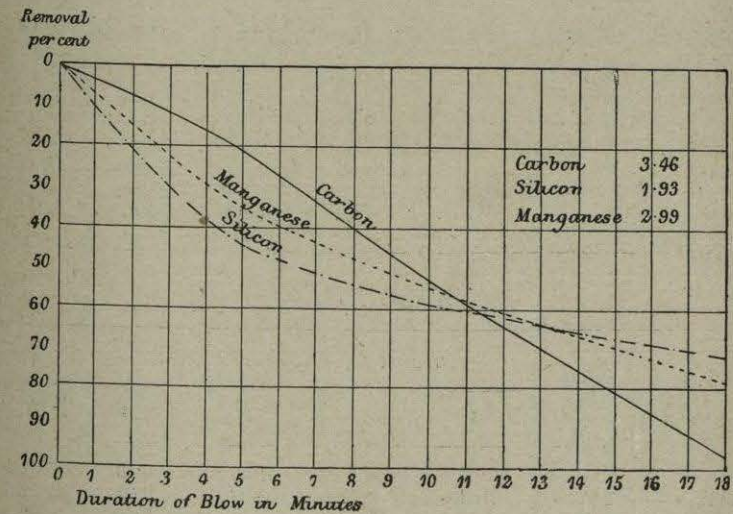


Fig. 84.—Elimination of Carbon, Silicon, and Manganese in Acid Bessemer, with fairly high Silicon, and high Manganese pig, showing practically complete removal of Carbon before Silicon and Manganese.

in finished low Carbon steel. One case came under the author's notice some years ago, in which a low Carbon steel with about .12 per cent. Carbon contained 0.90 per cent. of Silicon. According to Mr. Campbell, it was the practice in Germany at some works to make high Silicon steel for special purposes by blowing a silicious pig. This removal of Carbon before the Silicon is shown in diagram (fig. 84).

High Silicon and High Manganese Pig-Iron.—Pig-iron of this composition is not often employed, at all events in England, as such iron is not produced commercially in any large quantity; but below (Table xii.) are given analyses of samples by Kessler and Muller, and the curve (fig. 85), and Tables xiii. and xiv. give particulars of other similar charges. The high temperature developed by the Silicon would produce a very fluid slag of Silicate of Manganese, which would in all probability be very destructive to the linings of the converters.

TABLE XII.—KESSLER AND MULLER'S RESULTS.

	Pig Metal.	CONVERTER SAMPLES.—Times of Blowing.			
		1	2	3	4
		5 min.	10 min.	15 min. End of Blow.	After Addition of Spiegel.
Carbon, graphitic, -	3.180	...	...	...	...
" combined, -	0.750	2.465	0.949	0.087	0.234
Silicon, -	1.960	0.443	0.112	0.028	0.033
Phosphorus, -	0.040	0.040	0.045	0.045	0.044
Sulphur, -	0.018	Trace.	Trace.	Trace.	Trace.
Manganese, -	3.460	1.645	0.429	0.113	0.139
Copper, -	0.085	0.091	0.095	0.120	0.105

CORRESPONDING SLAGS FROM CONVERTER.				
Silica, -	46.78	51.75	46.75	47.27
Alumina, -	4.65	2.98	2.80	3.45
Ferrous Oxide, -	6.78	5.58	16.86	15.43
Manganese Protioxide, -	37.00	37.90	32.23	31.89
Lime, -	2.98	1.76	1.19	1.23
Magnesia, -	1.53	0.45	0.52	0.61
Alkalies, -	Traces.	Traces.	Traces.	Traces.
Sulphur, -	0.04	Traces.	Trace.	...
Phosphorus, -	0.03	0.02	0.01	0.01

TABLE XIII.*

	Initial Charge.	Time of Actual Blowing—Minutes.				After the Addition of Spiegeleisen.
		5	10	15	20	
Carbon, -	3.03	3.17	3.19	1.61	0.19	0.21
Silicon, -	2.41	1.26	0.27	0.03	0.01	0.16
Manganese, -	2.45	0.70	0.19	0.12	0.06	0.22

* Dinger's Polyt. Journ., Band ccv., p. 456.

TABLE XIV.

	Initial Charge.	Time of Actual Blowing—Minutes.			After Addition of Spiegeleisen.
		5	10	18	
Carbon, -	3.460	2.710	1.630	0.092	0.104
Silicon, -	1.930	1.070	0.790	0.532	0.346
Manganese, -	2.990	1.920	1.368	0.538	0.621

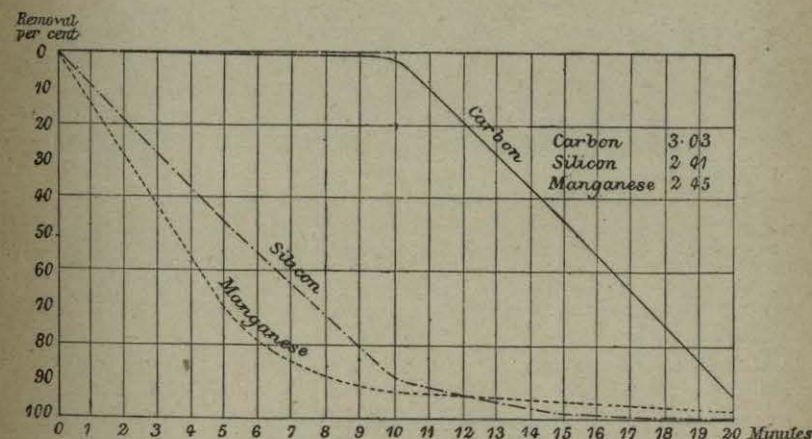


Fig. 85.—Elimination of Carbon, Silicon, and Manganese in Acid Bessemer. High Silicon and High Manganese. (Kessler.)

In carefully examining the various diagrams, it will be noticed that although the removal of the impurities is similar in many cases, yet the composition of the metal and conditions of working have very considerable effect on such removal, the Carbon being attacked much earlier in the blow, in some cases, than in others. Such differences may be due in part to errors arising from the difficulty of obtaining representative samples of the bath of metal during the different periods of the blow, and consequently the results must not be regarded as in any sense absolute, but simply as giving a general indication of the oxidising reactions which take place in the converter under a certain set of conditions.