THE MANUFACTURE OF BESSEMER STEEL AND INGOT
IRON FROM PHOSPHORIC PIG.

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Before entering upon the subject of our paper it might not be out of place to consider for a moment what is steel and what is ingot iron. Steel has been defined as "an alloy of iron and carbon which is capable of being cast whilst in a fluid state into a malleable ingot," and all other elements usually found in the steel of commerce, such as silicon, sulphur and phosphorus, may be regarded as impurities, and are more or less hurtful. In like manner, ingot iron may be defined as an iron which is capable of being cast whilst in a fluid state into a malleable ingot, and other elements found in it (including carbon) may in this case also be regarded as impurities. It follows, then, that those steels and ingot irons are the best and purest which contain the noxious elements in the least quantities, no matter whether they be produced from the finest brands of Swedish and hematite, or from common iron containing from $1\frac{1}{4}$ to 2 per cent. of phosphorus. And we think all will agree, if it can be shown that steel and ingot iron can be produced from the latter kind of pig of the same chemical composition, and capable of standing the same mechanical tests as that produced from the purer irons, that one is as good as the other for all purposes. It is not our intention to occupy the time of the Institute by referring to any of the numerous papers that have been written, and the theories that have been propounded, during the last eighteen months, on the dephosphorization of iron by the Thomas and Gilchrist process, interesting and instructive as many of them are. It will be sufficient to say that notwithstanding the great strides that had been made in the development of the process at the works of Messrs. Bolekow, Vaughan & Co., under the able direction of Mr. Richards (who must always be regarded as one of its earliest pioneers), and the very satisfactory results obtained by that company in the manufacture of steel from Cleveland pig-iron up to the early part of November last, before we had seen the process in operation, there appeared to us certain difficulties which we feared would greatly retard its successful

working from a commercial point of view. The first of these may be regarded as a technical one, and had reference to that part of the operation now well known as the "after-blow." Assuming, as we did, all the metalloids, with the exception of phosphorus and sulphur, to be oxidized before the commencement of this period, it seemed doubtful to us whether this would be practicable (having no definite point at which we could safely stop blowing corresponding to the drop of the carbon flame in the ordinary process) to burn out the whole of the phosphorus regularly, without sometimes carrying the operation too far, and thereby oxygenating the charge. And this, as all steelmakers will agree, is very apt to give trouble. Again, we had our misgivings about the gathering at the nose, concerning which we had heard so much, and the delays which we thought must necessarily result from the indispensable and repeated turning down of the converter for sampling. It was at this time (early in November last year) that we were invited to see the process at the Hörde Works in Westphalia, and through the courtesy of Mr. Pink, the manager of the Steel Works, our representative was not only shown the process in operation, but every information respecting the difficulties that had been experienced up to that time, and the means which had been employed to overcome them, was very kindly given to him by that gentleman. From the working at Hörde it was apparent that the phosphorus was eliminated with regularity—there were no violent reactions on the addition of the spiegel, showing that the metal was not oxygenated to any great extent, and the steel made was of a mild quality, and very malleable. On November 20th we commenced to work the process in Sheffield, using a mixture of White Lincolnshire and No. 4 forge irons. By sampling during the after-blow, we were enabled not only to remove the phosphorus in a very satisfactory manner, but also to make good and malleable steel; but the gathering of the slag and metal at the nose of the converter at first proved such an obstacle to rapid working, that although we employed men with long bars to fettle after each operation, at the end of from twelve to eighteen blows we were compelled to stop, allow the converter to cool down, and cut out the accumulation. At this early stage we were of opinion that by increasing the area of the nose we should get a decreased pressure of gases, and consequently the slag and metal would not be carried up so high, and that this would remedy the evil. Our experiment proved to us conclusively the fallacy of this, for after altering the shape of our con-

verter so that the area of the mouth was doubled, and lining up with basic brick as before, although we worked under precisely the same conditions, this converter was completely slagged up to the nose, and was unfit for further work after ten blows, simultaneously with the other converter and with the mouth of usual size, lined with basic bricks. We tried admitting blast at the throat, with the view of burning the carbonic oxide, and so increasing the temperature at this point, but the results were not sufficiently encouraging to justify our following up the experiment. In the succeeding week we lined our converter nose with brick made of silicate of soda and limestone, the other with ordinary fireclay bricks, contracting both at this point to a diameter of about 20 inches, or to about one-half the original area. In both cases we perceived at once a great improvement through the reduced size, the converters retaining their heat very much better than before. The slag still adhered to the first-mentioned slightly. It was easily removed by bars, but, unfortunately, usually carried a portion of the very brittle silicate of soda and limestone brick with it, and this form was abandoned on that account. The other converter with the fireclay bricks gave better results, and we have since used them regularly. What little slag adhered could be removed without any material injury to the lining. Although the common fireclay bricks then used wasted considerably, numerous experiments proved that the amount of silica carried down into the bath from them was too small to do any harm, and as the lining at this part was about 15 inches in thickness, we were able to get regularly from 30 to 40 blows before it got too thin. Thus, as far as the immediate nose was concerned, the difficulty seemed at an end, but we soon found that a great accumulation took place just below the junction of the fireclay bricks with those of the basic material, and also along the sides of the converter, in the form of a ridge of slag and metal left little by little on each turning down for the purpose of sampling. It seemed to us that to remedy this evil the simplest plan was to avoid testing as much as possible, if not altogether. All our results had shown that notwithstanding the after-blow the fully blown metal was not nearly so much oxygenated as at the end of the ordinary blow in the hematite process. Numerous analyses gave us the impression that this was due to the presence of manganese in the mixture we were then using, containing as it did about .75 per cent. of this metal, and we found invariably

that when we started with this quantity there always remained from $\cdot 1$ to $\cdot 2$ at the expiration of the after-blow.

The following analyses show how much more readily (during this part of the operation) the phosphorus is attacked than the manganese.

	At the drop of the carbon flame.	At the end of the after-blow.
Blow 108 Phosphorus, . . .	$\cdot 883$ per cent.	$\cdot 062$ per cent.
“ Manganese, . . .	$\cdot 443$ “	$\cdot 111$ “
Blow 136 Phosphorus, . . .	$1\cdot 090$ “	$\cdot 044$ “
“ Manganese, . . .	$\cdot 183$ “	$\cdot 147$ “
Blow 166 Phosphorus, . . .	$\cdot 890$ “	$\cdot 081$ “
“ Manganese, . . .	$\cdot 435$ “	$\cdot 194$ “

These, amongst other results of a similar kind, led us for a time to think that it might be possible to eliminate the whole of the phosphorus by increasing the amount of manganese in the charge, and blowing with the spectroscop until the absorption bands—which one of our greatest authorities, Mr. Watts (see Roscoe's *Chemistry*, vol. ii, part 2, page 77), on the use of this instrument has attributed to the oxides of this metal—had disappeared, for although our previous experience with mixtures containing $\cdot 75$ manganese had shown us that the bands always disappeared from the spectrum at the drop of the carbon flame, at which from $\cdot 2$ to $\cdot 4$ still remained, we thought it likely (assuming the above theory to be correct) that with a larger quantity we should be able to get rid of the phosphorus before these bands vanished. Accordingly, by means of ferro-manganese we increased the proportion of manganese in charge No. 165 to about $1\cdot 75$ per cent. At the drop of the carbon flame, when the bands disappeared, we found the composition to be :

Sulphur,	$\cdot 118$ per cent.
Phosphorus,	$\cdot 955$ “
Manganese,	$\cdot 817$ “

The sample taken at this period hammered well, but, on testing in the usual way, proved very brittle indeed, and the fracture did not show the characteristic appearance indicating the presence of phosphorus, but resembled that of a very hard steel. On turning up the converter again for a further blow of thirty seconds certain bands reappeared in the green portion of the spectrum for three or four seconds only; the composition at the end of this period was found to be :

Sulphur,	$\cdot 155$ per cent.
Phosphorus,	$\cdot 831$ “
Manganese,	$\cdot 612$ “

The sample taken and treated in the same way as before was still exceedingly brittle, and resembled the former one. Again the converter was turned up, and for the space of one or two seconds only these bands again flashed across the spectrum, after which they were not observed during the remainder of the after-blow, although most carefully looked for. At the end of this period the test made was still hard, though much milder than before, and had the following composition :

Sulphur,		. 132 per cent.
Phosphorus,		. 460 “
Manganese,		. 576 “

The charge was then blown for a further sixty seconds, and as the sample, which was very malleable, did not harden, thinking that the fine crystalline appearance of the fracture on breaking was due to manganese, the heat was cast without the addition of spiegel or ferro-manganese. It showed no disposition to rise in the open-top ingot moulds in which it was cast, and a tire 2 feet 8 inches inside diameter, made from one of the ingots, all of which hammered very well indeed, deflected 8 inches before breaking. Analysis of this steel or ingot iron, which showed that we had not carried the process quite far enough, gave the following composition :

Sulphur,		. 114 per cent.
Phosphorus,		. 146 “
Manganese,		. 440 “

From these results we drew the following conclusions: That the absorption bands usually seen in the spectrum of the Bessemer flame are due to carbon, and that manganese bands (very similar in appearance to those of carbon) are apparent only when that metal exists in quantities of about 5 per cent. ; and further, that we could not hope, through the agency of this metal to determine upon any fixed point indicated by the spectroscope at which we could safely stop blowing, satisfied that the whole of the phosphorus was removed. But we had before noticed that with regular charges and conditions the after-blow was of very constant duration, and the results of the blow showed us not only that with 1.75 per cent. of manganese in the charge, in order to be quite sure of eliminating the whole of the phosphorus, we might safely blow rather longer (without risk of oxygenating) than the time actually required to effect this purpose, and thus avoid sampling ; and afterwards, for rails, add a low spiegel or plate iron to carbonize ; but

also that, if an ingot iron were required, it could be readily produced by the means described, without any such addition. Want of an iron containing anything like the amount of manganese prevented us from following up these results for some time, but meanwhile, with mixtures such as we had, containing $\cdot 75$ per cent., we tried the effect of blowing after the addition of the spiegel, until the carbon bands, as seen through the spectroscope, had nearly vanished. The chemical analyses and results of a rolled bar from each of three such blows, tested, gave the following results :

Blows.	C. Carbon by combustion.	Sulphur.	Phosphorus.	Manganese.	Breaking Strain. Tons.	Elongation in 10 in. Per cent.	Reduction of area. Per cent.
·314	·040	·065	·030	·356	24·20	26·875	51·78
·329	·050	·045	·051	·240	26·48	29·375	65·59
·330	·038	·069	·035	·266	24·18	26·250	59·04

Three more blows made, amongst others, in the same manner, some weeks afterwards, gave the following results :

Blows.	C. Carbon by combustion.	Sulphur.	Phosphorus.	Manganese.	Breaking strain. Tons.	Elongation in 10 in. Per cent.	Reduction of area. Per cent.
·689	·061	·096	·051	·345	Not tested.		
·703	·073	·091	·027	·370	24·49	31·25	49·79
					24·62	27·50	56·06
·705	·101	·070	·047	·468	Not tested.		

The metal in all cases gave no trouble in casting into ingots (some, indeed, were cast in open-top moulds from the top), and it was very malleable. Specimens of bars from blows 314, 329, 330 and 703 plunged into cold water at a red heat—some of which were afterwards bent and some twisted, cold—are exhibited. Having at length obtained some iron containing about 2 per cent. of manganese, a charge of this was blown alone, and at the end of the after-blow of 130 seconds' duration, as the test taken was very malleable, and would not harden, the charge was cast into ingots without any addition whatever. The chemical composition of this charge and the results of the mechanical tests are as follows :

Blows.	C. Carbon by combustion.	Sulphur.	Phosphorus.	Manganese.	Breaking strain Tons.	Elongation in 10 in. Per cent.	Reduction of area. Per cent.
748	—	·075	·030	·235	23·49	30·00	72·04
					23·49	28·25	70·01
					23·37	27·50	74·12

The heat as before gave no trouble in casting, and the steel was very malleable when worked at a high heat. Samples of the pieces submitted to tensile strains, together with bars plunged into cold water at a red heat, and afterwards twisted and bent cold, as well as ordinary cold bends, are exhibited.

A second charge was treated in exactly the same way, except that at the end of the after-blow 15 cwt. of white hematite pig-iron were added in lieu of spiegel. The resulting steel gave no trouble in casting, and an ingot, hammered to test its malleability, worked very well. Analysis of the steel produced gave the following results:

C. C.	Si.	S.	P.	Mn.
·55	Not estimated.	·107	·151	·612 per cent.

It will be noticed that the phosphorus and manganese are higher—the former than it ought to be, the latter than one would have expected to find, after the addition of a non-manganiferous pig; but as the charge of white hematite was melted in a cupola which had only just before contained a 20 per cent. spiegel charge, we think it likely that a small quantity of this must have remained behind and come out with the white iron. With respect to the phosphorus, the mixture was one with which we had little experience. It was also the last charge from the cupola, and, unfortunately, nearly a ton heavier than it should have been, which circumstance was not observed until it was poured into the ladle. And, although it was blown for 130 seconds after the disappearance of the carbon bands, exactly the case as blow 748, there is no doubt that it was underblown, as the metal, before the addition of the white iron, contained as follows:

S.	P.	Ma.
·125	·147	·360 per cent.

For some time past, except in the case of the first two or three blows from a new mixture, when samples have been taken to determine the length of the after-blow, we have blown to time, and all

testing during the operation has been dispensed with. It is true that our early results were not all satisfactory, but latterly since we have used a mixture containing about C.C. 4.0 per cent., Si .5 per cent., S .2 per cent., P 1.4 per cent., Mn 1.0 per cent. in the converter, we have succeeded very well, as the results below will show. During the week ending April 10th, twelve test pieces, taken at random from the week's work, contained of phosphorus as follows:

	Per cent.		Per cent.		Per cent.
No. 1,	.103	No. 5,	.065	No. 9,	.111
" 2,	.067	" 6,	.074	" 10,	.054
" 3,	.040	" 7,	.073	" 11,	.074
" 4,	.051	" 8,	.052	" 12,	.048

And in the week ending April 17th, when not a single sample was taken during the operation, except in the case of the experimental blow 748, the average amount of phosphorus contained in 36 blows, all of which were analyzed, was .056 per cent., the highest being .101 per cent., and the lowest .019 per cent. The composition of this quality of steel has been in other respects very regular, the analyses and results of a test piece, 2 inches long and .533 inches in diameter, being as follows:

Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Breaking strain. Tons.	Elongation. Per cent.	Reduction of area. Per cent.
.40	—	.40	.085	.662	39.75	20.25	31.84

Since the sampling during the operation has been dispensed with there has been comparatively little trouble with the slag adhering to the sides of the converter, and the wear of the lining has been practically uniform. As many as eighty-seven blows, representing about 630 tons of steel, have been produced from one lining without any repairs whatever, except, after the fiftieth blow, new fireclay bricks to the nose. Thirty-seven more blows, equal to about 270 tons of steel, were converted in the same lining after renewing the front or blowing side and putting in a third fireclay nose. At the end of our last week's work (April 17th), during which bricks made of the best pot clay were used for this purpose, instead of being scoured away as had been invariably the case with the commoner ones, they were little the worse

for wear, and would, we feel sure, have run for a second week. The vessel bottoms (all made with a mixture of tar and lime rammed round pins) during this same week, averaged eight blows each, the maximum being twelve and the minimum four; but this bottom was taken out on completion of the week's work, and was very little worn. With respect to output, during the eight weeks ending April 17th (omitting Easter week, which was a broken one), 3380 tons of steel were made, or an average of 422 tons per week, the largest week being that ending March 27th, when 541 tons 7 cwt. were produced. In conclusion, we think it will be apparent to all that there are no difficulties in the working of the process. We are satisfied that as good steel can be produced by it from phosphoric pig, and quite as regularly as that obtained from hematite in the ordinary gannister-lined converter. We have shown that it is an easy matter to produce a malleable ingot iron, containing practically no carbon and very little manganese by this method, which, to say the least, it is rather difficult to do from hematite pig-iron by the old process; and although our only experiment (results of which we have laid before you) to produce a harder quality of steel from phosphoric pig high in manganese, without the addition of any manganimiferous pig, at the end of the operation did not turn out as satisfactorily as we could have wished, there appears to us little doubt but that this too will be accomplished, as well as the production of soft steels, suitable for boilers and ships' plates, etc., in a similar manner. It is true that our production from one pair of converters has never yet exceeded 541 tons 7 cwt. in one week, but it must not be forgotten that the process is still a new one, and that the plant at our disposal is not of modern construction, nor well adapted to its requirements. These requirements are, in our opinion (on account of the lining), either additional fixed converters, or duplicates with proper facilities for changing, as well as suitable arrangements for the speedy removal of the large quantity of slag. Under these conditions, in a well-arranged shop, we feel sure that not only as great an output can be obtained by the process as is now being produced in the best English practice in the conversion of hematite, but also that it may be made to equal anything that has ever been accomplished by our friends on the other side of the Atlantic.