J. F. Campbell Esq. of Islay
from the Author

Combustion

4

ON PUDDLING IRON,

BY

C. W. SIEMENS, F.R.S., Mem. Inst. C.E.

[PAPER READ BEFORE THE BRITISH ASSOCIATION AT NORWICH, 1868.]

LONDON:

PRINTED BY NEWBERY AND ALEXANDER, CASTLE STREET, HOLBORN.

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Of 3, Great George Street, Westminster.

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1868.

Re read December 26. 1868
after seeing Crampton's plan & Crampton himself ~~and~~ on Xmas day, and Elliot at the meeting of the Coal Commission (22d) &c

It seems that this plan of Siemens does nearly all that can be done by Crampton, but that Crampton's plan is a trifle better. <u>It might be used to burn still worse fuel in a Siemens Gas regenerating Puddling furnace</u>.

It is in short one more step in advance, but it must be made with the rest, & to follow previous steps, if it is to get the marching regiment on in the right direction. It won't do for Siemens & Crampton to stop & fight. If they march together they may step ahead & prosper.—

but after this Crampton must be content to step with Siemens who is the leader clearly.

ON PUDDLING IRON,

By C. W. SIEMENS, F.R.S.

[*Paper read before the Chemical and Mechanical Sections of the British Association at Norwich,* 1868.]

NOTWITHSTANDING the recent introduction of cast steel for structural purposes, the production of wrought iron (and puddled steel) by the puddling process ranks among the most important branches of British manufacture, representing an annual production exceeding one and a half millions of tons, and a money value of about nine millions sterling.

Notwithstanding its great national importance and the interesting chemical problems involved, the puddling process has received less scientific attention than other processes of more recent origin and inferior importance, owing probably to the mistaken sentiment that a time honoured practice implies perfect adaptation of the best means to the end and leaves little scope for improvement.

The scanty scientific literature on the subject, will be found in Dr. Percy's important work on iron and steel. Messrs. Crace Calvert and Richard Johnson, of Manchester,* have supplied most

* PHIL MAG., Sept. 1857. The following Table, from Messrs. Calvert and Johnson's Paper, includes the chief results of their investigations:

	TIME.	CARBON.	SILICON.
Pig Iron Charged	12	2.275	2.720
Sample No. 1	12.40	2.726	0.915
,, 2	1.0	2.905	0.197
,, 3	1.5	2.444	0.194
,, 4	1.20	2.305	0.182
,, 5	1.35	1.647	0.183
,, 6	1.40	1.206	0.163
,, 7	1.45	0.963	0.163
,, 8	1.50	0.772	0.168
Puddled Bar 9		0.296	0.120
Wire Iron 10		0.111	0.088

valuable information by a series of analyses of the contents of a puddling furnace, during the different stages of the process. These prove that the molten pig metal is mixed intimately, in the first place, either with a molten portion of the oxides (or Fettling) which form the lining or protecting covering to the cast-iron tray of the puddling chamber, or with a proportion of oxide of iron in the form of hammer slag or red ore thrown in expressly with the charge; that the silicon is first separated from the iron; that the carbon only leaves the iron during the "boil" or period of ebullition; and that the sulphur and phosphorus separate last of all while the metal is "coming to nature."

The investigations by Price and Nicholson, and by M. Lan, confirm these results, from which Dr. Percy draws some important general conclusions, which have only to be followed up and supplemented by some additional chemical facts and observations, in order to render the puddling process perfectly intelligible, and to bring into relief the defective manner in which it is at present put into practice, involving, as it does, great loss of metal, waste of fuel, and of human labour, and an imperfect separation of the two hurtful ingredients, sulphur and phophorus.

Silicon.—In forming (by means of the rabble) an intimate mechanical mixture between the fluid cast metal and the cinder, the silicon contained in the iron is bronght into intimate contact with metallic oxide, and is rapidly attacked, being found afterwards in the cinder in the form of silicic acid (combined with oxide of iron). The heat of the furnace is always kept low during this stage of the process, and the flame is maintained as reducing as possible.

Carbon.—The disappearance of the carbon from the metal is accompanied by the appearance of violent ebullition and the evolution of carbonic oxide, which rises in innumerable bubbles to the surface of the bath, and burns (in an ordinary puddling furnace) with the blue flame peculiar to that gas. In puddling in a Regenerative Gas Furnace this blue flame cannot be observed, because the flame of this furnace is strictly neutral, and there is no free oxygen present to burn the carbonic oxide rising from the fluid mass, a circumstance which by itself explains the superior results obtained from the Gas Furnace.

It is popularly believed that the oxygen acting upon the silicon and carbon of the metal is derived directly from the flame, which should, on that account, be made to contain an excess of oxygen, but the very appearance of the process proves that the combination between the carbon and oxygen does not take place on the surface, but throughout the body of the fluid mass, and must be attributed to reaction of the carbon upon the fluid cinder in separating from it metallic iron; while as the removal of the silicon is still more rapid, and is effected under a reducing flame, there is strong evidence that it also is oxidized rather by the oxygen of the cinder than by the flame.*

But it has been argued that, although the reaction takes place below the surface, the oxygen may, nevertheless, be derived from the flame, which may oxidize the iron on the surface, forming an oxide or cinder, which is then transferred to the carbon at the bottom, in consequence of the general agitation of the mass.

This view I am, however, in a position to disprove by my recent experience in melting cast steel upon the open flame bed of a furnace, having invariably observed that no oxidation of the unprotected *fluid metal* takes place so long as it contains carbon in however slight a proportion.

But being desirous to ascertain by positive proof, what is the behaviour of Silicon, and Carbon, in fluid cast iron, when contact with the atmosphere, or the flame of the furnace, is strictly prevented; I instituted the following experiment at my Sample Steel Works, at Birmingham:—

Ten cwts. of Acadian Pig Metal, and one cwt. of broken glass, were charged upon the bed of a Regenerative Gas Furnace, (usually employed for melting steel, upon the open hearth).

The bed of this furnace was formed of pure silicious sand, and one object in view was to ascertain whether any reaction takes place between Silica and fluid cast metal, it being generally supposed that metallic silicon is produced under such circumstances by the reducing action of the carbon in the metal upon the Silica or Silicates present. The cast metal employed in this experiment was Acadian Pig, containing

Silicon, 1.5 per cent.
Carbon, 4.0 per cent.

In the course of an hour, the metal and glass were completely melted. A sample was taken out, containing

Silicon, 1.08 per cent.
Carbon, 2.90 per cent. { 0.6 per cent. combined carbon, 2.3 „ graphite. }

At the end of the second hour, another sample was taken out and tested, the result being

Silicon, .96 per cent.
Carbon, 2.40 per cent., combined.

The physical condition of the metal had now undergone a decided change. The carbon having wholly combined with the iron, rendered it extremely hard.

The amount of Silicon having steadily diminished, these results prove that *no Silicon is taken up by fluid cast metal in contact with Silica or Silicates.*

* At the end is appended a Table showing the comparative quantities of carbon in various kinds of iron and steel.

The reduction of the amount of Silicon in the metal might be accounted for by the presence of minute quantities of oxides of iron, produced in melting the pig metal, which oxides were now increased by the addition of haematite ore in small doses.

At the end of the third hour, another sample was taken, containing

Silicon, .76 per cent.
Carbon, 2.4 per cent, combined.

the metal being *extremely* hard, as before.

Additional doses of red ore were added gradually without agitating the bath, and the effect upon the fluid metal was observed from time to time.

At the end of the fifth hour, the samples taken from the fluid bath assumed a decidedly mild temper; when the addition of ore was stopped, and exactly six hours after being charged, the metal was tapped and run into ingots; it now contained

Silicon, 0.046 per cent.
Carbon, .25 per cent.

thus both the Silicon and the Carbon had been almost entirely removed from the pig metal by mere contact with metallic oxide under a protecting glass covering.

The quantity of red ore added to the bath amounted to two hundred-weight, and the weight of metal tapped to ten hundred-weight five pounds, being slightly in excess of the weight of pig metal charged.

But the pig metal had contained

Silicon, 1.5 per cent.
Carbon, 4.0 per cent.

Total, 5.5

whereas the final metal contained collectively only .296 of Silicon and Carbon, showing a gain of metal of

$$5.5—.296=5.204 \text{ per cent},$$

or including the five pounds of increased weight, a total gain of 5.7 per cent. of metallic iron.

Supported by these observations, I venture to assert that *the removal of the Silicon and Carbon from the pig iron in the ordinary puddling or "boiling" process is due entirely to the action of the fluid oxide of iron present, and that an equivalent amount of metallic iron is reduced and added to the bath*, which gain, however, is generally and unnecessarily lost again in the subsequent stages of the process. The relative quantity of metal thus produced from the fluid cinder admits of being accurately determined.

The cinder may be taken to consist of $Fe^3 O^4$, (this being the fusible combination of peroxide and protoxide), together with more or less tribasic silicate, ($3FeO, SiO^3$), which may be regarded as a neutral admixture, not affecting the argument, and silicic acid or silica is represented by $Si\ O^3$, from which it follows that for every four atoms of silicon leaving the metal, nine atoms of metallic iron are set free, and taking the atomic weights of iron=28, and of silicon 22.5, it follows that for every

$$4 \times 22.5 = 90.0$$

grains of silicon abstracted from the metal,

$$9 \times 28 = 252$$

grains of metallic iron are liberated from the cinder.

Carbonic oxide, again, being represented by $C\ O$, and the cinder by $F\ e^3\ O^4$, it follows that for every four atoms of carbon removed from the metal, three atoms of iron are liberated; and taking into account the atomic weights of carbon=6 and of iron=28, it follows that for every

$$6 \times 4 = 24$$

grains of carbon oxidized,

$$28 \times 3 = 84$$

grains of metallic iron are added to the bath.

Assuming ordinary forge pig, after being remelted in the Puddling Furnace, to contain about 3 per cent of carbon and 2 per cent. of silicon, it follows from the foregoing that in removing this silicon

$$\tfrac{252}{90} \times 2 = 5.6$$

per cent., and in removing the carbon

$$\tfrac{84}{24} \times 3 = 10.5$$

per cent. of metallic iron is added to the bath, making a total increase of

$$5.6 + 10.5 - 5 = 11.1$$

per cent., or a charge of 420 lbs. of forge pig metal, ought to yield 466 lbs. of wrought metal, whereas from an ordinary puddling furnace the actual yield would generally amount to only 370 lbs. (or 12 per cent. less than the charge), showing a difference of 96 lbs. between the theoretical and actual yield in each charge.

This difference, amounting to fully 20 per cent., is due to the enormous waste by oxidation to which the iron is exposed after it has been "brought to nature" (by the removal of the carbon); when it is in the form of a granular or spongy metallic mass and during the process of forming it into balls. So great a waste of metal by oxidation seems at first sight almost incredible, but considering the extent of surface exposed in the finely divided puddled mass, it is not at all exceptional, and is in fact almost unavoidable in a furnace of the ordinary construction, maintained as a puddling furnace is, at a welding heat. Many attempts have been made, for example, by Chenot, Clay, Renton, and others, to produce iron directly from the purer ores, by reducing the ore in the first instance to a metallic sponge, and balling up this sponge, which is a loose porous mass, somewhat similar to spongy puddled iron, on the bed of a furnace, but all these attempts have failed, simply on account of the great waste of iron, a waste amounting to from 25 to 50 per cent., in balling up the sponge. Indeed, the loss in an ordinary puddling furnace would probably be greater than 20 per cent. if the metal were not partly protected from the flame by the bath of cinder in which it lies; for in one instance in which the cinder accidentally ran out of a puddling furnace during the balling up of the charge, leaving the iron exposed to the flame, I found the yield reduced from the average of 413 lbs. down to 370 lbs., showing an increased waste of 43 lbs., or over 10 per cent., due to the more complete exposure of the metal to the oxidizing action of the flame.

In order to realize the theoretical result, a sufficient amount of oxides must have been supplied to effect the oxidation of the silicon and carbon of the pig iron, and to form a tribasic silicate of iron (3 Fe O, Si O^3) with the silicic acid produced.

The amount of oxide required may be readily ascertained.

In taking the expression, $Fe^3 O^4$, the atomic weight of which is

$$3 \times 28 + 4 \times 8 = 116,$$

while that of the three atoms of iron alone is

$$3 \times 28 = 84$$

it follows that

$$\tfrac{116}{84} \times 46 = 63.5 \text{ lbs.}$$

of cinder or oxide of iron are requisite to produce the 46 lbs. of reduced iron, which were added to the bath There must, however, remain a sufficient quantity of fluid cinder in the bath to form with the silicon (extracted from the iron), a tribasic silicate ofi ron, or about 60 lbs., making in all 124 lbs. of fettling which would have to be added for each charge, a quantity which is generally exceeded in practice notwithstanding the inferior results universally obtained.

There remain for our consideration the sulphur and phosphorus, which being generally contained in English forge pig in the proportion of from ·2 to ·6 per cent. each, can hardly affect the foregoing quantitative results although they are of great importance as affecting the quality of the metal produced.

It has been suggested by Percy that the separation of these ingredients may be due to *liquation*. This I understand to mean that the crystals of metallic iron, which form throughout the boiling mass when the metal "comes to nature," exclude foreign substances in the same way that the ice formed upon sea water excludes the *salt*, and yields sweet water when re-melted.

According to this view, pig metal of inferior quality will really yield iron almost chemically pure, to which foreign ingredients are again added by mechanical admixture with the surrounding cinder, or semi-reduced metal.

It may be safely inferred that the freedom of the metal from impurities thus taken up will mainly depend upon the *temperature*, which should be high, in order to ensure the perfect fluidity, and complete separation of the cinder.

The following was the result of an analysis of an inferior English pig iron before and after being puddled:

PIG METAL.		PUDDLED BAR.	
Sulphur	·08	Sulphur	·017
Phosphorus	1·16	Phosphorus	·237
Silicon	1·97	Silicon	·200
Iron and Carbon (by difference)	96·79	Iron (by difference) ...	99·546
	100·00		100·000

showing the extent to which foreign matters are actually removed by the process of puddling.

These analyses were made a few days since by Mr. A. Willis in my laboratory at Birmingham.

Led by these chemical considerations, and by practical attention to the subject, extending over several years, I am brought to the conclusion *that the process of puddling, as practised at present, is extremely "wasteful in iron and fuel, immensely laborious, and yielding a metal only imperfectly separated from its impurities."*

How nearly we shall be able to approach the results indicated by the chemical reasoning here adopted, I am not prepared to say, but that much can be accomplished by the means actually at our doors is proved by the result of the working of a puddling furnace erected eighteen months since to my designs by the Bolton Steel and Iron Company in Lancashire.

This furnace consists of a puddling chamber of very nearly the ordinary form, which is heated however by means of a Regenerative Gas Furnace, a system of which the principle is now sufficiently well established to render a very detailed description here unnecessary.

The general arrangement of the furnace is shown in the accompanying illustrations. It consists of two essential parts:

The Gas Producer, in which the coal or other fuel is converted into a combustible gas; and

The Furnace, with its "regenerators" or chambers for storing the waste heat of the flame, and giving it up to the in-coming air or gas.

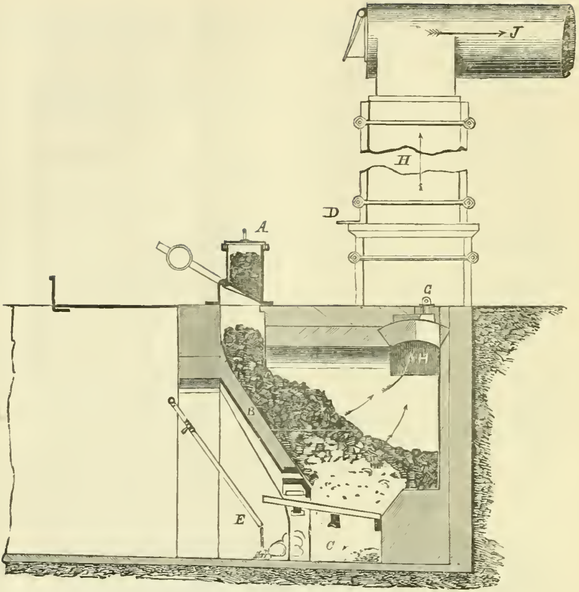

Fig. 1.---SECTION OF GAS PRODUCER.
Scale 3/16 to a foot.

The Gas Producer is shown in Fig. 1; it is a rectangular fire-brick chamber, one side of which, B, is inclined at an angle of from 45° to 60°, and is provided with a grate, C, at its foot. The fuel, which may be of any description, such as coal, coke, lignite, peat, or even sawdust, is filled in through a hopper, A, at the top of the incline, and falls in a thick bed upon the grate. Air is admitted at the grate, and in burning, its oxygen unites with the carbon of the fuel, forming carbonic acid gas, which rises slowly through the ignited mass, taking up an additional equivalent of carbon, and thus forming carbonic oxide. The heat thus produced distils off carburetted hydrogen and other gases and vapours from the fuel as it descends gradually towards the grate, and the carbonic oxide already named diluted by the inert nitrogen of the air and by any small quantity of unreduced carbonic acid, and mixed with these gases and vapours distilled from the raw fuel is finally led off by the gas flue to the furnace. The ashes and clinkers that accumulate in the grate are removed at intervals of one or two days.

E is a pipe for the purpose of supplying a little water to the ash pit, to be decomposed as it evaporates and comes in contact with the incandescent fuel, thus forming some hydrogen and carbonic oxide, which serve to enrich the gas; G is a small plug hole by which the state of the fire may be inspected, and the fuel moved by a bar if necessary; and D is a sliding damper by which the Gas Producer may be shut off at any time from the flue.

It is necessary to maintain a slight outward pressure through the whole length of the gas flue leading to the furnaces, in order to prevent the burning of the gas in the flue through the indraught of air at crevices in the brickwork.

Where the furnaces stand much higher than the gas producers, the required pressure is at once obtained; but more frequently the furnaces and gas producers are placed nearly on the same level, and some special arrangement is necessary to maintain the pressure in the flue. The most simple contrivance for this purpose is the "elevated cooling tube." The hot gas is carried up by a brick stack, H, to a height of eight or ten feet above the top of the gas producer, and is led through a horizontal sheet-iron cooling tube, J, (Fig. 1), from which it passes down either directly to the furnace, or into an underground brick flue.

The gas rising from the producer at a temperature of about 1000° Fahr., is cooled as it passes along the overhead tube, and the descending column is consequently denser and heavier than the ascending column of the same length, and continually over-balances it. The system forms, in fact, a syphon in which the two limbs are of equal length, but the one is filled with a heavier gaseous fluid than the other.

In erecting a number of gas producers and furnaces I generally prefer to group the producers together, leading the gas from all into one main flue, from which the several furnaces draw their supplies.

The puddling furnace, proper, is shown in Figures 2, 3, and 4.

Fig. 2, is a front elevation of the furnace, showing the gas reversing valve and flues in section.

Fig. 3, is a longitudinal section at A, B, C, D, (Fig. 4).

Fig. 4 is a sectional plan at L, M, (Fig. 3.)

The peculiarity of the Regenerative Gas Furnace, as applied either to puddling, or to any other process in which a high heat is required, consists in the utilization *in the furnace* of nearly the whole of the heat of combustion of the fuel, by heating the entering gas and air by means of the waste heat of the products of combustion, after they have left the furnace, and are of no further use for

FIG. 2.

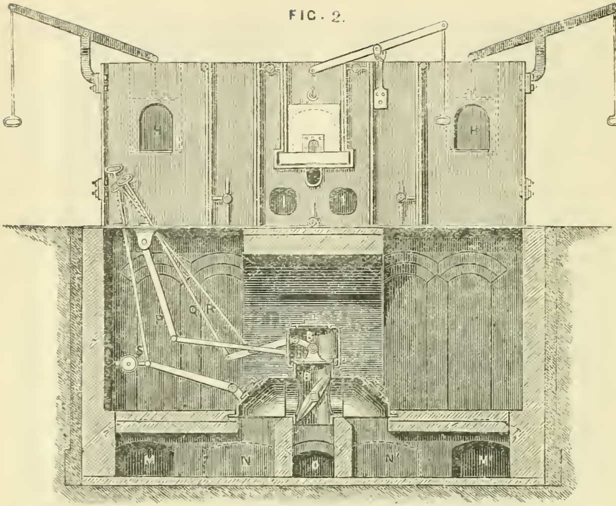

Fig 2.---FRONT ELEVATION OF PUDDLING FURNACE.
Scale 3/16 to a foot.

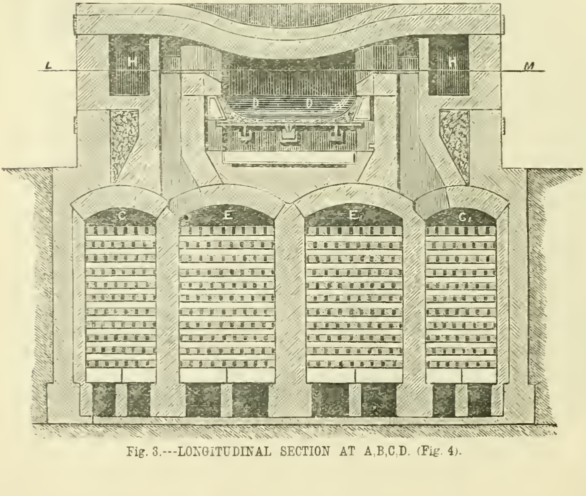

Fig. 3.---LONGITUDINAL SECTION AT A,B,C,D. (Fig. 4).

the operation being carried on. The waste heat is, so to speak, intercepted on its passage to the chimney, by means of masses of fire-brick stacked in an open or loose manner in certain chambers, called "Regenerator Chambers," C, E, E^1, C^1, (Fig. 3).

On first lighting the furnace the gas passes in through the gas regulating valve, B, (Fig. 2), and the gas reversing valve, B^1, and is led into the flue, M, and thence into the bottom of the Regenerator Chamber, C, (Fig. 3); while the air enters through a corresponding "air reversing valve," behind the valve B^1, and passes thence through the flue, N, into the Regenerator Chamber, E.

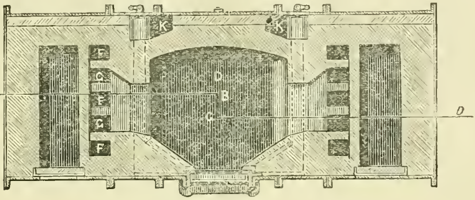

Fig. 4.---SECTIONAL PLAN AT L,M. (Fig. 3).

The currents of gas and air, both quite cold, rise separately through the Regenerator Chambers, C and E, and pass up through the flues, G, G, and F, F, F, (Fig. 4) respectively, into the furnace above, where they meet and are lighted, burning and producing a moderate heat. The products of combustion pass away through a similar set of flues at the other end of the furnace into the Regenerator Chambers, C^1, E^1, and thence through the flues, M^1, N^1, and through the gas and air reversing valves, into the chimney flue, O. The waste heat is thus deposited in the upper courses of open fire-brick work filling the chambers, C^1, E^1, so heating them up, while the lower portion, and the chimney flue, are still quite cool; then after about an hour, the reversing valves, B^1, (through which the air and gas are admitted to the furnace) are reversed, by means of the levers, P, and the air and gas enter through those Regenerator Chambers, E^1, C^1, that have just been heated by the waste products of combustion, and in passing up through the open brickwork they become heated, and *then* on meeting and entering into combustion in the furnace, D, D, they produce a very high temperature, probably 500° Fahr. higher than when admitted cold; the waste heat from such *higher temperature of combustion* heating up the previously cold Regenerator Chambers, C, E, to a correspondingly higher heat. After about an hour's work the reversing valves, B^1, are again reversed, and the air and gas enter the first pair of Regenerator Chambers, C, E, but which are now very hot, and therefore the air and gas become very hot, and enter the furnace in this state, meeting and entering into combustion, and thus producing a still higher temperature, *probably* 500° *higher still*, and again heating the second pair of Regenerator Chambers, C^1, E^1, *so much higher*, which enables them to again heat the air and gas to a still higher degree, when the valves, B^1, are again reversed. Thus an *accumulation* of heat and an accession of Temperature is obtained, step by step, so to speak, until the Furnace is as hot as is required; for unless cold materials are put in to be heated, and thus abstract heat, the temperature rises as long as the Furnace holds together, and the supply of gas and air is continued. The heat is at the same time so thoroughly abstracted from the products of combustion by the Regenerators that the chimney flue remains always quite cool. The command of the temperature of the furnace and of the quality of the flame is rendered complete by means of the gas and air regulating valves shown at B in Fig. 2, and by the chimney damper. These are adjusted to any required extent of opening by the notched rods Q, R, and S, (Fig. 2,) respectively, so that having the power of producing as high a temperature as can be desired, there is also the power of varying it according to the requirements in each case.

The bed of the furnace, D, D, is of the ordinary construction, formed of iron plates, and is provided with water bridges at the ends, as shown, to protect the "Fettling," (or Oxide of Iron used for lining the furnace) from being melted away. The overflow from one of the water bridges is led into a sheet iron tank below the bed, and then away. The evaporation from this tank keeps the bottom plates cool and preserves the cinder covering them from melting off, and the steam is carried away by a draught of air entering through two holes I, I, (Fig. 2,) below the tap hole, and passing off by small ventilating shafts K, K, (Fig. 4,) at the back of the furnace.

A heating chamber, H, is arranged at each end of the furnace, in which the charge of pig iron may be heated to redness before it is introduced into the puddling chamber, D, D.

The advantages of this furnace, for puddling, are that the heat can be raised to an almost unlimited degree; that the flame can be made at will oxidizing, neutral, or reducing, without interfering with the temperature; that in-draughts of air and cutting flames are avoided; and that the gas fuel is free from ashes, dust, and other impurities, which are carried into an ordinary Puddling Furnace from the grate. In this last respect the new furnace presents the same advantages as puddling with wood.

The following tables give the working results which were obtained from this furnace, as compared with the results obtained at the same time in an ordinary furnace from the same pig (the ordinary forge mixture):

REGENERATIVE GAS FURNACE.

Table No. 1.

Date.	Nos. of Heats.	Time charged.	First Ball out.	Metal charged.	Yield.
1867.			*First Shift.*		
				lbs.	lbs.
May 27	1	5.25	6.32	410	392
	2	6.45	7.50	433	396
	3	8.8	9.9	430	410
	4	9.15	10.7	425	426
	5	10.20	11.22	426	430
	6	11.40	12.46	412	412
			Second Shift.		
,,	1	1.48	2.47	428	410
	2	2.50	3.47	420	414
	3	3.56	4.53	426	418
	4	5.0	6.3	432	417
	5	6.5	7.12	425	407
	6	7.20	8.15	420	422
			Third Shift.		
,,	1	9.10	10.15	423	414
	2	10.25	11.30	422	412
	3	11.35	12.40	420	420
	4	12.45	2.0	430	410
	5	2.10	3.10	424	418
	6	3.16	4.20	420	400
			First Shift.		
28	1	5.38	6.45	423	402
	2	6.50	8.0	422	400
	3	8.6	9.8	430	390
	4	9.15	10.25	426	407
	5	10.35	11.45	426	420
	6	11.55	1.8	430	416
			Second Shift.		
,,	1	2.0	3.1	422	422
	2	3.6	4.0	424	415
	3	4.5	5.18	423	424
	4	5.23	6.27	423	415
	5	6.33	7.46	427	420
	6	7.49	8.50	420	406

TABLE No. 1.—*continued.*

Date.	Nos of Heats.	Time charged.	First Ball out.	Metal charged.	Yield.
1867.			*Third Shift.*		
				lbs.	lbs.
May 28	1	10.0	11.20	420	424
	2	11.25	11.33	420	410
	3	12.40	1.45	423	412
	4	1.50	2.58	425	420
	5	3.13	4.20	430	418
	6	4.30	5.35	422	426

	Cwt.	qrs.	lbs.
Total charge...	136	1	2
,, yield	132	3	7
Being at the rate of	20	2	2

of pig iron per ton of puddled bar.

ORDINARY FURNACE.

TABLE No. 2.

Date.	Time.	Weight of Metal charged.	Weight of Puddled Bar produced.
1867.	These times were not taken for each charge but six heats were produced every 12 hours.	Mean 484 lbs.	lbs.
May 17			424
			425
			405
			430
			430
			438
			416
			456
			410
			432
			426
			420
			422
			422
			425
			430
			450
			410

	lbs.
Mean charge	484
,, yield	426

or 22 cwt. 2 qrs. 20 lbs. of pig iron per ton of puddled bar.

It will be observed that the ordinary furnace received charges of 484 lbs. each, and yielded on an average 426 lbs., representing a loss of 12 per cent., whereas the gas furnace received charges averaging 424 lbs., and yielded 413 lbs., representing a loss of less than 2·6 per cent.

It is important to observe, moreover, *that the gas furnace turned out eighteen heats in three shifts per twenty-four hours*, instead of only twelve heats per twenty-four hours, which was the limit of production in the ordinary furnace.

This rate of working was attained without the employment of any arrangement for heating the pig iron before charging it into the furnace, the heating chambers at the ends not having been used. The adoption of the plan of heating the metal beforehand, a system already extensively in use both in this country and on the Continent, effects a further saving of ten to fifteen minutes in the time required for working each charge, as well as a considerable economy in fuel.

The quality of the iron produced from the gas furnace was proved decidedly superior to that from the ordinary furnace, being what is technically called "*best best*" in the one, and "*best*" in the other case, from the same pig.

The economy of fuel was also greatly in favour of the gas furnace, but could not be accurately ascertained, because some mill furnaces were worked from the same set of producers. Still, judging from the experience of several years' in the working of Regenerative Gas Furnaces as Re-heating or Mill Furnaces, and as Glass Furnaces, the saving of fuel in puddling, cannot be less than 40 to 50 per cent. in quantity, while a much cheaper quality may be used.

The consumption of "Fettling" was, however, greater in the gas furnace, and the superior yield was naturally attributed by the forge managers to that cause, although the writer held a different opinion.

The gas furnace, however, had *not* been provided with water bridges, these were subsequently added, and the furnace put to work again in February last, since which time it has been worked continuously.

The result of the water bridges has been that the amount of "Fettling" required is reduced to an ordinary proportion, the average quantity of red ore used being 92·6 lbs. per charge, besides the usual allowance of bull dog, while the yield per charge of 483·3 lbs. of grey forge pig has been increased to 485 lbs. of puddled bar, as shown by the following return of a series of eighty consecuti[ve] charges in June last :

REGENERATIVE GAS FURNACE,

Table No. 3.

Date.	No. of Heats.	Total Charges and Yields.	LBS.	CWT.	QRS.	LBS.	Average per Heat. LBS
June, 1868	80	Pig Iron charged	38668	=345	1	0	483.3
		Puddled Bar returned ..	38808	=346	1	25	485
		Red Ore for "Fettling"	7406	= 66	0	14	92.6

proving that the *yield of puddled bar slightly exceeds the charge of pig metal,* (representing a saving of fully 12 per cent. over the ordinary furnace), while *the superiority of quality in favour of the gas furnace is fully maintained.*

It is also worthy of remark that these results are obtained regularly by the ordinary puddlers of the works, and that no repairs have been necessary to the gas puddling furnace since November last, the roof being reported to be still in excellent condition.

In these investigations I have confined myself to the puddling of ordinary English forge pig in order to avoid confusion, but it is self-evident that the same reasoning also applies in a modified degree to white pig metal or refined metal, the use of which I should not, however, advocate.

Water Bridges.—Regarding the water bridges, I was desirous to ascertain the expenditure of heat at which the saving of "Fettling" and greater ease of working was effected. The water passing through the bridges was accordingly measured by Mr. W. Hackney (who has also furnished me with the other working data) and found to amount to 25 lbs. per minute, heated 40° Fahr. This represents 60,000 units of heat per hour, or a consumption not exceeding 8 lbs. to 10 lbs. of solid fuel per hour, an expenditure very much exceeded by the advantages obtained where water or cooling cisterns are available.

The labour of the puddler and of his underhand being very much shortened and facilitated by means of the furnace, I should strongly recommend the introduction of three working shifts of 8 hours each per 24 hours, each shift representing the usual number of heats, by which arrangement both the employer and the employed would be materially benefitted. The labour of the puddler may be further reduced with advantage by the introduction of the mechanical "Rabble" which has already made considerable progress on the Continent.

By working in this manner, a regenerative gas puddling furnace of ordinary dimensions would produce an annual yield of about 940 tons of bar iron, of superior quality, from the same weight of grey pig metal and the ordinary proportion of "Fettling."

In conclusion, I may state that a considerable number of these puddling furnaces have been erected by me abroad, and that, in this country, they are also being taken up by the Monkbridge Iron Co., Leeds, and a few other enterprising firms.

The construction of these furnaces has been still further improved lately by the application of horizontal Regenerators, to save deep excavations, and by other arrangements whereby the first cost is diminished and the working of the furnace facilitated.

Table No. 4.

Percentage of Carbon and Silicon contained in various kinds of Cast and Wrought Iron and Steel.

Description.	Carbon.	Silicon.	Authority.
	per cent.	per cent.	
Spiegeleisen (New Jersey, U.S.) ...	6.900	0 100	Henry.
,, (German)	5.440	0.179	Schafhäutl.
,, (Müsen)	4.323	0.997	Fresenius.
Löfsta Pig Iron (Dannemora, Sweden)	4.809	0.176	Henry.
Grey Pig Iron, No. 1 (Tow Law)...	2.795	4.414	Riley.
Grey Pig Iron, No. 1 (Acadian Iron Co.	3.500	4.840	Tookey.
Grey Foundry Pig Iron, No. 1 (Netherton, South Staffordshire ...	3.07	1.48	Woolwich Arsenal.
Ditto ditto, No. 2, ditto ...	3.04	1.27	,,
Grey Forge Pig Iron, ditto ...	3.12	1.16	,,
Forge Pig Iron, ditto ...	3.03	0.83	,,
Strong Forge Pig Iron, ditto ...	2.81	0.57	,,
Grey Pig Iron (Dowlais)	3.14	2.16	Riley.
Mottled ditto, ditto	2.95	1.96	,,
White ditto, ditto	2.84	1.21	,,
Mottled Pig Iron (Wellingborough)	2.10	2.11	Woolwich Arsenal.
White Pig Iron (Blaenavon) ...	2.31	1.11	Percy.
Refined Iron (Bromford, S. Staffordshire	3.070	0.630	Dick.
Puddled Steel, hard, (Königshütte)	1.380	.006	Brauns.
Ditto ditto, mild, (South Wales)	.501	.106	Parry.
Cast Steel, Wootz	1.34		Henry.
,, for Flat Files	1.2		A. Willis.
,, (Huntsman's) for Cutters	1.0		,,
,, for Chisels	.75		,,
,, Die Steel (welding) ...	.74		,,
,, Double Shear Steel ...	.7		,,

TABLE No. 4.—*continued.*

Description.	Carbon.	Silicon.	Authority.
	per cent.	per cent.	
Cast Steel, Quarry Drills	.64		,,
,, Masons' Tools	.6		,,
,, Spades	.32		,,
,, Railway Tyres	32 to 27		,,
,, Rails	26 to 24		,,
,, Plates for Ships ...	.25		Various.
,, very mild, ... ,, (melted on open hearth)	.18		A. Willis.
Hard Bar Iron (South Wales) ...	.410	.080	Schafhäutl.
,, ,, (Kloster, Sweden) ..	.386	.252	Henry.
,, ,, (Russia)	.340	Trace	,,
,, ,, ,, ...	.272	.062	,,
Boiler Plates (Russell's Hall, South Staffordshire)	.190	.144	,,
Armour Plates (Weardale Iron Co.) too steely	.170	.110	Percy.
Bar Iron (Löfsta, Sweden)	.087	.115	Henry.
,, (Gysinge, Sweden) ...	.087	.056	,,
,, (Österby, Sweden) ...	.054	.028	,,
Armour Plates (Beale & Co.) ...	.044	.174	Percy.
,, ,, (Thames Iron Co.) ...	.033	.160	,,
,, ,, (Low Moor) ...	.016	.122	Tookey.

DISCUSSION.

BEFORE SECTION G.

Mr. F. J. BRAMWELL said he had heard this paper with much pleasure; as it related to an important improvement in the most essential operation in the manufacture of wrought iron, and as it not merely stated the bare fact of the improvement and economy Mr. Siemens had effected, but also gave an intelligible theory to account for that economy. He (Mr. Bramwell) believed that when persons considered the subject of puddling iron, they did so, if not universally, at all events most generally, with the view before them that the red ore and other "Fettling" were merely materials for lining the walls of the furnace, and that the pig iron put into the furnace was the only metallic substance to be taken into consideration, and then they looked to the atmosphere as the sole means by which the Carbon, Silicon, and other foreign matters were to be burnt out, so to speak, from the pig iron. Of course, when viewing the puddling process in this way, there must inevitably be, even with perfection of manipulation, a difference between the weight of the wrought iron made and that of the pig iron charged into the furnace, such difference being a decrease and being equal to the weight of the Caıbon and other foreign matters expelled in the process. But he begged to be allowed to express his acquiescence in Mr. Siemens' proposition that this was not the true view of the theory of the puddling process.

He (Mr. Bramwell) regretted that his chemical knowledge was but slight, but he believed it was sufficient to enable him to appreciate the fact that the red ore, "bull dog," and other "Fettling" were all of them mainly composed of oxide of iron, and that such oxide of iron was competent to decarburize the pig iron by the union of the oxygen of the "Fettling" with the carbon of the pig iron, thus setting free metallic iron from the oxide, and he might mention that so long back as the year 1858 he had built an experimental furnace with the object of making steel by mixing together in crucibles molten cast iron and oxide of iron obtained from mill or reheating furnaces, and although, owing to the impurities in the iron, and to the difficulty of getting crucibles to stand the action of the oxide he never succeeded in obtaining a piece of steel that would thoroughly bear the hammer, he nevertheless constantly succeeded in getting a metallic mass of a greater weight than that of the pig iron put into the crucible. He might add that the action which ensued when the liquid pig iron and the oxide came into contact was most intense. He thought this experiment made with a totally different object to that which Mr. Siemens had in view, went nevertheless to corroborate, the soundness of Mr. Siemens' theory as to the reduction of metallic iron out of the "Fettling." He might perhaps be allowed to add that a practice of puddlers when they could not get the iron to come to "nature" readily, went also to support Mr. Siemens' views, the practice to which he alluded was that of putting a small quantity of water on the molten iron which thus became oxidized, and then with the "rabble" the workman thrust down the oxide, and found the beneficial effect of oxygen administered in this form of an oxide of iron by the speedy bringing the molten metal to "nature," which he had failed to do by the mere exposure of that metal to the oxygen of the air. Another evidence that the decarburization of the iron was effected below the surface (and if below the surface then not by the oxygen of the air but by the oxygen of a submerged oxide) was this, that the blue flames which burnt on the surface of the iron proceeded from the Carbonic oxide which shot up through the fluid iron from such a depth as to be capable of driving particles of iron before it, and to give the well known appearance of boiling.

In conclusion on this point of the decarbonization being effected by the oxygen of the oxide and not by that of the air, he would allude to the process of making malleable cast iron where the brittle castings being packed in iron ore and then subjected to heat were decarbonized by the iron ore, and were thus rendered tough and malleable. He thought that an operation like this in which both the iron to be decarburized and the oxide which decarburized it were in a solid state, and were not raised to more than comparatively a low heat, was a good test of the ability of the oxide to act to decarburize the pig iron in a puddling furnace, under the much more favourable conditions of the fluidity of the materials and of the heat necessary to maintain that fluidity.

Assuming Mr. Siemens' theory to be established (which he, Mr. Bramwell, believed it must be), then there was no paradox in the statement that a weight of puddled iron might be obtained equal to or indeed exceeding that of the pig iron charged into the furnace. He held in his hands returns of the actual working of 17 puddling furnaces, with the working of which he had had ample opportunity of being acquainted, and he found that there, where every care was taken, and where an almost unlimited amount of "Fettling" was allowed, the weight of the puddled iron produced was from 8 to 9 per cent. less than that of the pig iron used; he believed that in ordinary cases the deficiency was fully 12 per cent. and he had known it stated by many competent authorities as even more than this.

Now it might be asked how it was that if according to Mr. Siemens' theory, the reduction of metallic iron from the "Fettling" was effected, and inevitably effected, there could possibly be in the ordinary process so great a waste. He believed this waste mainly arose from the burning of the iron at the time of "balling up." It was well known that the process of "bringing to nature" was done at a comparatively low heat, a heat too low to enable the particles of wrought iron of which the balls are composed to be properly welded together, and it therefore was necessary so soon as the iron was made, to endeavour to considerably increase the heat of the furnace and of the puddled balls, and he had no hesitation in saying as the result of frequent observation, that at this part of the process a fierce combustion of the iron of the balls themselves took place, a combustion so great as fully to account for all the deficiency. The amount of the combustion would no doubt vary considerably, according as more or less care was taken to prevent there being free oxygen in the flame of the furnace. He was by no means sure, however, that in a common puddling furnace it would be desirable to stop altogether the burning of the puddle balls, because he believed that in such furnaces it was due to the thus using a portion of the iron as fuel that there was obtained with sufficient rapidity the higher heat requisite to weld the puddle balls.

Hitherto, he (Mr. Bramwell) had only spoken as to Mr. Siemens' theory of puddling, and as to the waste and the cause of that waste in the ordinary proces, but he would now ask their permission to say a few words on the cause of the improvement effected by Mr. Siemens. This cause lay in the adaptation of Mr. Siemens' Regenerative Gas Furnace to the process of puddling.

By the use of these Furnaces it was possible to obtain an intensity of heat limited only by the endurance of the materials of which the furnace was composed. This heat was also under the most absolute control and was not accompanied by fierce currents of air in the furnace, on the contrary, the heat though when required most intense was (if he might use the term) a tranquil heat, and the flame could be made instantaneously, and at will, either oxidizing neutral, or de-oxidizing; and thus, when puddling was conducted in a "Siemens' Furnace," it was perfectly practicable to heat up the puddle balls by the heat of the furnace itself, and not by the combustion of the particles of iron in the balls. This one fact was quite sufficient to account for the saving in the iron, and as regarded the improvement in its quality, he could well understand it would arise from one or both of two causes, the one the extreme cleanliness of the fuel, which being gaseous, brought no impure earthy matter into contact with the iron; the other, and he believed the principal cause, that the puddle balls could be thoroughly heated up throughout, and that thus they were got into the best possible condition, for being welded together under the shingling hammer and also for having the cinder expelled from them by it, because the high heat had rendered that cinder thoroughly fluid.

He might be allowed to add that from the first introduction of these furnaces he had been much struck with their extraordinary value, especially for those purposes where great heats were required. By his advice these furnaces had been adopted about five years ago by one of the largest Plate Glass Companies in England, the result had been most satisfactory, effecting a large saving not only in the fuel consumed but also in the number of melting pots used, this latter saving being undoubtedly due to the cleanliness of the gas flame. At the present time, and for some years past, these Works were using to the exclusion of all others, the "Siemens Furnace" for Glass Melting.

At an Iron Works where these furnaces had been erected, not for the purpose of puddling but for the purpose of heating iron for other processes in the manufacture, the proprietor of the Works had informed him that while to heat a given weight of iron had by the old process cost 6/6, by the "Siemens Furnace" it only cost 2/6.

He looked upon these furnaces as being an invention of even more than National importance, for it was undoubted that in all operations requiring great heat they performed their work in the most efficient manner and with a very large saving of fuel, and there could be no question as to the vital importance of checking the great waste that had too long prevailed in the employment of coal—while by the application of the furnace for the operation of puddling, it was not too much to say that the Iron Master would obtain a better quality of iron accompanied by a saving of from 10 to 12 per cent. of the iron itself, such saving in these days of keen competition being enough to represent a profit. He had observed that Mr. Siemens had omitted to state that it was by no means necessary to use coal in the Gas Producers, and he, Mr. Bramwell, thought it well to call the attention of the Meeting to this point, as one's ideas of gas were associated with the distillation of coal, and thus the fact might be overlooked that the gas made in the producers was principally, and might be entirely, carbonic oxide, and that for the production of this gas, coke or even peat was just as efficient as coal.

In conclusion he felt justified in saying that the " Siemens Furnace," whether used for puddling, or heating, in the process of iron making, or whether for the direct manufacture of steel in the furnace as alluded to in a previous paper, or for the melting of steel in crucibles in steel manufacture, seemed to put within the reach of the metallurgist everything that could reasonably be hoped for in the way of economy of fuel, purity of flame, and easy regulation of the quality and temperature of that flame.

Mr. R. Mallet being called upon by the Chairman, said he had no special light which individually he could add to the luminous statements which had been laid before the Meeting by Mr. Siemens, nor was it necessary that he should add any endorsement to the wide-spread and rapidly extending reputation which the "Siemens-Regenerative-Furnaces" had so justly acquired.

Without undertaking to follow the Author through the whole of his chemical reasoning which would have to be studied at leisure, the fact did not admit of question that immense advantages and great economy must attend the employment of the " Siemens-Furnace " for Puddling, not alone in fuel, but from the command over the process which it gave, in the iron itself, by avoiding its needless or injurious oxidation.

But although these were great results, he was amongst those who thought that the applications of the "Siemens-Furnace" could scarcely be said to have more than commenced, and that within the next quarter century perhaps it would be found to have revolutionised almost every branch of metallurgy. as well as many processes of art and *manufacture*, dependant on high temperatures. He spoke under correction, but he believed as an illustration, that as yet the "Siemens-Furnace" had not been applied to copper smelting at all, and this alone was a great branch of metallurgy, and probably more wasteful of fuel than any other within the entire range of the metallurgic arts.

Mr. Jones, Secretary to the Iron Masters' Association, thought there might be some difficulty if Caking or Bituminous Coal were attempted to be used in the Gas Producers. With regard to the question of heating the Boilers, it was well known that in some works, part of the waste heat from the Puddling Furnaces was used for the purpose, and he thought that as this could not be done with Mr. Siemens's Furnace great loss would arise in such cases.

He had heard that it was very possible that Mr. Menelaus's plan of puddling in a revolving chamber might come into use, and if so, he did not see how Mr. Siemens's plan could be applied. He understood that Mr. Siemens's Puddling Furnace cost an excessive amount, viz., about £3,000. The men were very difficult to deal with, and did not like new things.

Mr. Kohn understood Mr. Siemens preferred Pig Iron rich in Silicon, (Mr. Siemens at once dissented) at all events if he *could* use it, and make good iron, he thought it would be only common sense to do so. He thought Silicon might perhaps burn out on the surface of the metal in the Puddling Furnace, or become oxidized there while the iron still contained carbon.

Mr. W. Hackney remarked that the improved quality of the puddled iron from the gas furnace, was to be attributed no doubt to a large extent, to the greater purity of the gas flame, but it was due also to the greater heat at which the furnaces might be worked. Any practical puddler knew well that when the iron had fully come to the "boil" the furnace should be kept as hot as possible, both to obtain the best quality of iron, and to render the cinder more liquid, so that it might not be lapped up in the wrought iron when made into bars.

In the gas puddling furnace, the puddler had an unlimited command of heat, without any extra labour in firing, or in clearing the grate bars, but when the furnace had been first put to work, this very facility for obtaining any temperature required, had brought with it a new train of difficulties. The puddler naturally worked his furnace much hotter than a common one, with little care for the quantity of "Fettling" he employed, and the result was, that with ordinary iron sides to the puddling chamber, the "Bulldog" or calcined tap hole cinder that was used as "Fettling" was melted down rapidly, and it was necessary to fettle the furnaces chiefly with "Red Ore," (the natural red oxide of iron) a material much less fusible, but at the same time costing fully three times as much. The greater yield of the furnace had been attributed to this large consumption of red ore, but it had been proved that this was not the true cause of the larger yield, as the waste of "Fettling" had been completely overcome many months since, by the introduction of water bridges at the ends of the furnace, as mentioned by Mr. Siemens in his paper, and this without any diminution in the yield of puddled bar. The quantity of "Red Ore" now used, was less than that in the common Puddling Furnace at the same works, and the remainder of the "Fettling" was made up of the cheap "Bulldog," so that the total cost of "Fettling" was about the same as in the common furnaces, while the yield of iron was fully twelve per cent. greater.

The peculiar soundness and freedom from flaws of the "Gas Iron," as it had been called, was not entirely to be attributed to the greater heat at which the furnace was worked; it might be also to some extent due to the fact that the puddled iron was less cut away in the furnace after it had "*come to nature*," so that the cinder approached more nearly to the composition of the fusible tribasic silicate, and was more liquid, and more easily squeezed out of the puddled balls, than the cinder richer in iron, which resulted from the oxidation in an ordinary puddling furnace of a great part of the spongy metallic iron just produced.

He might mention one fact in illustration of the improved quality of the iron puddled in the gas furnace; a very high quality of iron was required for what were termed "flys" in cotton spinning machinery, as the iron must not only be perfectly free from flaws, but must also stand very severe treatment, both hot and cold without cracking. "Fly iron," he believed, had never hitherto been made in an ordinary puddling furnace, except from fine charcoal pig iron, but he had examined a few days before, a perfect "fly" made of iron puddled in the "Siemens-Furnace" from coke pig; though as yet this quality of iron had only been made as an experiment.

The regularity in yield, and in quality of successive heats, puddled in the gas furnace, was very remarkable as compared with the results from an ordinary furnace, and was due to the facility with which the furnace might be regulated, so as to obtain at all times the exact temperature and quality of flame that might be required.

It appeared from the particulars that had been given of the working of Mr. Siemens's puddling furnaces, that the waste of iron from oxidation, below the yield required by theory, was reduced from twenty-four per cent. to twelve; the weight of puddled bar obtained being as nearly as possible equal to that of the pig iron put in. This fact was in itself a striking confirmation of the accuracy of Mr. Siemens's view; as a saving of 50 per cent. of the *waste* corresponded exactly with the results that had been obtained in the working of Regenerative Gas Heating Furnaces, during a number of years.

At the works of the Monkbridge Iron Co., Leeds, for example, the waste in heating and forging wrought-iron blooms for tyres, had been in the ordinary furnace 6 per cent., in the gas furnace $2\frac{1}{2}$ to 3 per cent.; and in heating piles of very small and dirty scrap, the waste had been in the ordinary furnace 20 per cent., and in the gas furnace between 11 and 12 per cent. Again at the Govan Bar Iron Works, Glasgow, the loss in welding and forging axles had been with the ordinary furnace 14 per cent., with the gas furnace 7 per cent.; and so on in a number of similar cases.

Mr. Cowper could quite confirm the great success that Mr. Siemens's Glass Furnaces had met with, as referred to by Mr. Bramwell. The Glass Pots were found to wear away, or *wash away*, from the inside *only*, and not also from the outside, as they used to do in the old furnaces, neither did they break nearly as often as formerly, hence it was found to be true economy to make them thicker than they used to be made, and they lasted a much longer time; he only mentioned this to show that the flame was much purer, and the draught very much less; in fact, there was no necessity at all for any thing beyond a quiet slow passage of the very highly heated gases, in a state of *most vivid combustion* through the furnace, making it (as Dr. Faraday once said in describing it at the Royal Institution) *naturally hot*, or a real "Glory-hole," as the glass blowers call the heating holes. It had been asked what fuels would suit the Gas Producers, and he might state, that it was no question of *experiment*, but that everything from North Country Caking Coal, free-burning Coal, Coke, Slack, Brown Coal, and Peat were being used day and night in hundreds of "Producers" with excellent effect.

North Country Coal had been used in Producers for supplying his own patent Hot Blast Stoves for years, and these perhaps had the largest Regenerators in the world, one pair being 21 feet diameter and 20 feet high, and another pair 26 feet diameter and 23 feet high, giving Blast for a Blast Furnace at 1250° Fahrenheit. The purer flame of Mr. Siemens's Puddling Furnace produced better iron, and its higher temperature caused the cinder or melted oxide to be much more fluid than is usual, so that it not only ran out more freely from each ball of wrought iron as it was made up in the furnace, but being so liquid it was much more thoroughly expressed from the bloom when squeezed, hammered, and rolled; thus iron of first-rate quality for purposes such as Drawing Rolls and Flyers for Cotton Frames could be made, and indeed when any special piece of iron was required in the works, where the furnace was at work, as for instance a piston rod for a steam hammer, the job was always sent to the " Siemens Furnace."

The name of " Gas Iron " given by the workmen to the metal made at this furnace, he thought ought to be changed (before it was too widely spread in the trade) to " *Siemens-Iron* " in justice to the Inventors of the Furnace, just as they called his steel " *Siemens-Steel*." He understood that Mr. Siemens had found the greatest practical advantage in having constant chemical analyses carried on at his own works by Mr. Willis, whose name would at once be a guarantee for accuracy.

He might perhaps be allowed to mention a rather interesting circumstance that he had observed, connected with the working of the furnace, that he confessed rather puzzled him the first moment; it was, that contrary to all his experience in Puddling, either of iron or steel, there were no *blue flames* apparent on the surface of the boiling mass, as the gas escaped from it, but the phenomenon was soon explained by Mr. Siemens, as arising from the fact, of there being either no free oxygen, or so little in the furnace, that the carbonic oxide gas, formed by the union of the carbon of the Pig Iron, with the oxygen of the Cinder, simply bubbled out and did not burn; this very clearly proved the freedom of the furnace from uncombined oxygen. The blue flames were at once produced, if oxygen were let in on purpose. To the total absence of all solid fuel from the furnace might chiefly be attributed the fact of the roof of the furnace standing so well, it having lasted the whole of this year, or seven months and a half, and being still in good condition; this alone to any one acquainted with ordinary Puddling Furnace repairs, would at once appear on the credit side of the account.

Then the saving in coal was considerable, even after allowing for the loss of heat through not heating the Boilers by the waste heat of the ordinary Puddling Furnaces, this alone paying the interest of money on the whole cost of the furnace over and over again.

The greater savings were however, in the greater value of the iron from the *improved quality*, and the much *greater yield;* he had taken the trouble to extract from the regular Books of the Works, the weights of iron charged in, and weights taken out, over a length of time, and not merely the results of any experiment, and he found that 122,643 lbs. of pig had been charged, in and 122,632 lbs. of wrought iron had been taken out and worked up, thus there was practically no loss of iron; in another case he had taken out the weights 14,538 lbs. charged in, and 14,673 lbs. taken out, showing a gain of ·9 per cent.

And as the usual waste in puddling was at least 12 per cent., there was clearly that saving without any expense for Iron, " Fettling," or Plant. But taking it only at 10 per cent., and 18 beats per 24 hours, the actual money saving would be at least £390 per annum, a sum considerably greater than the whole cost of the Furnace and Producers, the actual cost of a *pair of* Puddling Furnaces and Producers being only £450, and not £3,000 as had been erroneously supposed by some one.

Mr. Siemens said he quite agreed with most of the remarks that had been made.

Mr. Bramwell's way of putting the loss of iron was quite correct, and if ever the puddling process was brought to an absolute state of perfection the saving would in some cases be 20 per cent. instead of only 12 per cent. as at present. Undoubtedly what was saved in weight, was due to the improved chemical action, as named by Mr. Hawksley and Mr. Mallet, and he was glad to find that his explanation of the theory of puddling was so readily appreciated, both by Chemists, in Section B, where his paper had also been read, and by Engineers. In working it out he admitted at once that he had had the benefit of special advantages, by being able to exclude nearly all free oxygen whilst he was working with a very high temperature, much higher indeed than usual.

In answer to Mr. Mallet's remark as to the use of the new furnace for other metals, he might say it was now being used for zinc, lead, and other ores, with great success.

He was happy to be able to relieve Mr. Jones's mind of the impression that the furnace cost £3,000; the cost of a pair of puddling furnaces and their gas producers was £450, or £225 per puddling furnace complete.

Caking Coal, Brown Coal, Free burning Coal, and Peat, &c., &c., had been in daily use for years in the gas producers with excellent effect, indeed the arrangement offered a means of utilizing for operations requiring high temperatures, several descriptions of fuel that had never been used for the purpose before.

He certainly did not heat the boilers in a mill, with the waste heat from the puddling furnaces, simply because he had no " waste heat " to throw away, all he made he used, and for the highest or best paying purposes. With regard to the last objection that had been raised, he was happy to say he had not found any difficulty with the workmen, they had in fact after a few days' work at the furnace, taken to it very well indeed, he was sorry to say that it was with the masters only that he had any trouble, and he simply mentioned it, as the contrary had been stated, but without the intention of finding fault with iron-masters, who would no doubt soon see that what was chemically right, and practicable, must also prove remunerative to themselves.

He would only add one word in explanation of the quality obtained, in reference to the remarks made by Mr. Cowper, Mr. Kohn, and Mr. Hackney; Mr. Kohn said the Silicon might burn out on the surface of the melted metal, but he thought that the experiments he had produced clearly indicated that both the Silicon and the Carbon in the cast metal were oxidized by the oxygen contained in the Fettling. He begged to say that he had not the slightest idea of suggesting that Pig Iron containing large quantities of Silicon was preferable, he preferred the best, as every Iron Master did, but had given the effects of the furnace on a bad sample of iron as a severe test of its powers. There was no doubt that the practical improvement in the quality of the iron produced in his furnace was due as Mr. Cowper had stated, partly to a mechanical cause and partly to a chemical one, for the purer flame of the furnace did far less injury to the iron, and the higher temperature at which the metal was balled up without being burned, caused the cinder to be so much more fluid, as to run out better from the iron when squeezed, hammered, or rolled, thus excluding more thoroughly those bad welds, "blacks" and "greys" so plentiful in ordinary iron.