XXXIII.—*On the Regenerative Gas Furnace as applied to the Manufacture of Cast Steel.*

[A Lecture delivered before the Fellows of the Chemical Society, May 7th, 1868.]

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

IN responding to your call to deliver a lecture to your Society, on a subject of applied chemistry, I feel that I have undertaken a very responsible task, a responsibility which is only balanced by the honorary distinction conferred by your call.

It is a hopeful sign of the advancement of science that your

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* The greater part of the excess of the experimental over the theoretical percentage of CuO is due to the partial replacement of As_2O_5 by P_2O_5 in this mineral; of course cupric phosphate contains a much higher percentage of CuO than the arseniate.

† The water in the experiment is rather high; in other and subsequent determinations the percentages obtained were 7·45 and 8·16.

Society puts itself into intellectual communication with engineers and others, whose mission it is to apply and practise that pure science cultivated within your body. It would be presumptuous on my part to reason with you upon a purely chemical subject, for although many years ago I had the advantage of receiving instruction from Wöhler and Himly, I can in no way lay claim to be a chemist of the present day. Yet I can safely affirm that of all the instructions I received in early life, there is none that has been a more useful guide to me in my professional pursuits.

The subject to which I wish to call your attention this evening is one that has occupied my mind for many years, and which I hope may engage your interest, involving as it does the generation of intense heat by means essentially differing from those in general use, and the application of that heat to the production of cast steel in large masses, and directly from the ore or scrap metal.

The regenerative gas furnace, which is the joint production of my brother, Frederick Siemens, and myself, is already known through its application to nearly all those branches of industry in which furnace heat is employed. It was described by Faraday, to the members of the Royal Institution, in the last public lecture delivered by that great philosopher in 1862, and has since been the subject of several publications. I need not, therefore, bring before you all the features of this mode of producing intense heat for the various purposes to which it has been applied, but shall confine myself to its description as applied only to the production of cast steel in large masses, which is the principal subject of my present communication.

Nature of Steel.—Before proceeding with this description I shall briefly remark upon the nature of steel and the methods by which it has hitherto been produced.

Steel.—Steel is generally regarded as a *compound of iron and carbon, possessing the remarkable quality of becoming exceedingly hard when heated and suddenly cooled.* The proportion of carbon determines the degree of hardness of which the steel is capable, or what is termed its *temper.*

The following table of the percentage of carbon in steel suited to different purposes, is prepared from analyses made in my laboratory by Mr. A. Willis, unless another authority is mentioned.

Description.	Carbon per cent.	Authority.
Wootz......................	1·34	T. H. Henry
Steel for flat files	1·2	A. Willis
„ for turning tools	1·0	„
„ (Huntsman's) for cutters	1·0	„
„ for cutters............	·9	„
„ for chisels	·75	„
Die steel (welding)	·74	„
Double shear steel..........	·7	„
Welding steel	·68	„
Quarry drills	·64	„
Mason's tools	·6	„
Ramrods	·6	,·
Common steel for stamping..	·42	„
Steel for magnets (containing tungsten)	·4	„
„ spades	·32	„
„ hammers..........	·3	„
Bessemer steel for rails......	·25 to ·3	various
Homogeneous metal armour plates	·23	Percy
Very mild steel from open furnace	·18	A. Willis
Sample before Spiegel was applied	·05	„
Bessemer iron (pure)	trace	Abel

Cast-steel containing less than 0·3 per cent. of carbon is no longer capable of being hardened, and should be classed rather as homogeneous or melted iron than as steel, while on the other hand an excess of carbon above 1·4 per cent. again deprives the metal of the quality of taking a temper, and it must then be regarded as approaching in character rather to white cast-iron.

It is, however, a contested question between chemists whether the presence of a third substance may not be necessary to produce steel. Frémy, in his celebrated controversy with M. Caron before the French Academy, maintains that nitrogen or cyanogen is a necessary constituent of steel; the investigations of other chemists appear to confirm this theory and the old Sheffield practice of mixing leather and other animal substances with the charcoal used in the converting

furnace would also seem to corroborate it. M. Frémy's theory probably admits of great extension, and it may be that we should regard steel as a triple combination of iron with carbon and with another substance, taken from a series comprising nitrogen, sulphur, phosphorus, silicon, manganese, tungsten, titanium, tin, silver, and probably many other elementary bodies, each of which entering, in an exceedingly small proportion, into combination with the iron and carbon is capable of imparting to the steel distinctive physical properties.

Nitrogen.—Nitrogen has been found invariably in the steel produced by the ordinary processes.

Sulphur and Phosphorus.—Sulphur and phosphorus are commonly regarded as the worst enemies to steel, the one rendering it "*red-short*," or incapable of being forged, and the other "*cold-short*," or brittle at ordinary temperatures. It is owing to the presence of these impurities in nearly all British irons, that the highest qualities of tool steel are still made entirely from Swedish or other charcoal-iron of high quality, produced from the purest ores. If phosphorus exists in steel in quantities exceeding 0·1 per cent., its presence is indicated, on breaking the sample, by peculiarly bright and distinct faces of crystallisation on the fractured surface, but the steel admits of being forged and welded, and though somewhat brittle when cold, it is remarkable for hardness. It would, therefore, not be safe to maintain that phosphorus in small quantities is objectionable in steel under all circumstances. Steel containing above 0·2 per cent. of *sulphur* breaks under the hammer at a low red heat, and is, therefore, only applicable to the production of *steel castings :* for this purpose the presence of a small amount of sulphur is unquestionably a positive advantage imparting increased fluidity to the molten metal and toughness to the casting when cold. This effect is so well understood in Sweden as regards cast-iron, that in casting ordnance sulphur is added to the metal.

Manganese.—Manganese possesses the remarkable property of counteracting to a great extent the effect of sulphur (or red-shortness) in steel. Its application for this purpose is due to Josiah Marshall Heath (1839), and must be classed among the most important discoveries in modern times ; for it is only in consequence of the addition of manganese (in the form of oxide, mixed with carbon) to the steel melted in pots,

that the Sheffield melters have been enabled to use English puddled iron for the commoner qualities of steel in place of the purer and more costly Swedish iron; and again it is only in consequence of the addition (by Mushet) of manganese in the form of ferro-manganese or *spiegeleisen* to the liquid bath produced in the Bessemer converter that the better qualities of English pig-iron have been made available for the production of malleable Bessemer metal.   It is distressing to think that the author of this invaluable discovery was deprived of the fruits of his labour by an unjust combination among the manufacturers chiefly benefited by him, who contested the validity of Heath's patents upon trivial grounds, relying for their success upon their financial power to crush his unquestionable claims.   The specific chemical action of manganese has never been clearly demonstrated.   It is certain that only traces of metallic manganese are ever found in cast-steel, and that the bulk of the manganese added is found combined with oxygen, silica, and alumina, in the form of slag; yet it follows, from experiments which I have had occasion to make, that on adding manganese to a bath of liquid steel in an open reverberatory furnace, its beneficial action ceases if the metal is retained in the furnace, exposed to the flame for any length of time, say more than half-an-hour.   This is the case quite independently of any sensible reduction in the proportion of carbon in the steel, and indicates that the effect of manganese is not due to the removal of sulphur or other substances with which it may enter into combination, but it is inseparable from the presence of metallic manganese in the steel, in however small a quantity.   A further confirmation of the view, that the addition of manganese removes no impurity from the steel, is supplied by the fact, that if cast-steel from English iron which has been rendered perfectly malleable at a red-heat, by the addition of manganese, is re-melted *without* adding manganese, it becomes as red-short as ever.   According to Parry, the presence of manganese in sensible quantity in steel tends to render it brittle when cold.

Silicon.—Silicon in small quantity seems to increase the hardness of steel without taking away from its malleability or toughness when cold, and the presence of a trace of silicon appears to have the singular effect of preventing that violent evolution of gas from fluid steel at the moment of solidifica-

tion, which renders the ingot so frequently unsound. Steel containing above 0·5 per cent. of silicon breaks up under the hammer if heated above low redness.

Titanium, &c.—The effect of titanium, tin, arsenic, silver, and other metals upon steel, is stated to produce *increased hardness*, but I have not myself made any experiments upon this subject, nor been able to find very reliable observations of others.

Tungsten has a very remarkable effect upon steel, first observed by Dr. Werner Siemens, in 1853, in increasing its power of retaining magnetism when hardened. Being specially interested in this question, I have determined, by careful experiments, the extent of the increase; and the practical result is, that whereas a horse-shoe magnet of ordinary steel, weighing 2 lbs., is considered of good quality when it bears *seven times* its own weight, and the famous Haarlem magnet of the same weight, supports about 13 times its weight, I am now able to produce a similar horse-shoe magnet carrying 20 times its weight, suspended from its armature.

The chief difficulty besetting experiments on the effects of these various admixtures upon the quality of steel, consists in the unavoidable presence of other substances in variable proportions; but the effects of these other substances could be eliminated if the experiments were accompanied by exhaustive analyses, and it is impossible to over-estimate the advantages that would result from such a course.

Processes.— Dr. Percy, in his truly invaluable metallurgical work, has made us acquainted with the various known processes for obtaining steel which have been followed from the earliest times; but no method of producing steel can be considered admissible at the present day which does not pass the metal through the condition of entire liquefaction, for it is only by fusion that foreign admixtures can be thoroughly separated, and that flaws and fissures can be avoided; inasmuch however as the steel obtained by them may be subsequently fused, I shall briefly refer to them. The principal processes of this class are :—

1. The *direct process* of making steel, or steely iron, from the ore in the Catalan forge, by employing a large excess of charcoal. The steel is obtained without fusion in the form of a ball of spongy metal, and is drawn out into bars.

2. The *cementation process*, in which bar-iron is converted into

steel by prolonged contact at a comparatively low temperature either with liquid cast-iron, as formerly practised in Styria and elsewhere,* or with crushed charcoal—a method extensively employed in Sheffield at the present day for the manufacture of steel for railway and carriage springs, and for the production of bar-steel from Swedish iron, which, when subsequently melted in pots, makes the finest quality of steel for tools and cutlery.

3. The *decarburization process*, in which steel is made from cast-iron by the removal of part of the carbon in the puddling furnace, or by the partial application of any of the older methods of decarburetting cast iron in an open hearth in direct contact with the fuel. A modified form of the decarburization process has been recently introduced to some extent by Messrs. Heaton and Hargreaves. They remove the carbon of the pig-iron by the action of oxydizing salts, principally nitrate of soda, and either fuse the crude metal obtained, producing cast steel, or work it up into blooms under the hammer.

The Bessemer process, now so well known, is also a method of producing steel by the decarbonization of cast iron ; but it presents a vast advantage over those just named, in the fact that the steel is obtained in the liquid state, and may be cast, free from flaws, into homogeneous ingots of any size. As Bessemer steel is produced much more cheaply than the cast steel obtained by any other process yet extensively in use, its introduction has opened out a vast field for the application of steel where iron alone could formerly be thought of. Thus many parts of steam and other machinery, railway plant, boiler-plates, and even rails, are now made of Bessemer steel, and are found to be cheaper in the end when made of that material rather than when made of iron, although their absolute cost is fully twice as great.

Cast Steel.—The remaining methods of producing cast steel, are those in which it is obtained by the fusion either of steel already made by other processes, or of its component materials, iron or iron-ore, on the one hand, and carbon, either as charcoal or already combined in the form of cast iron, on the other.

The oldest known steel of high quality, the Indian Wootz, is obtained by the fusion of compact iron and carbonaceous substances in small crucibles, but it is only in the course of the last century that the manufacture of cast-steel was first introduced in Europe.

* Percy, Metallurgy, II, 790, 807.

Réaumur states, in his work on the conversion of forged iron into steel, published in 1722, that he had succeeded in producing steel by the fusion together of cast and wrought iron in a common forge; but steel melting was first practically carried out in the latter half of the century by Huntsman, of Sheffield; the process he employed consisting in "*the fusion in closed crucibles of steel already made by cementation in charcoal*," is still universally in use for the production of the finest qualities of steel for tools and cutlery. The Hindoo process has, however, been revived within the last twenty years, by Heath, Price and Nicholson, Gentle Brown, Attwood, and others, and large quantities of steel are now made in Sheffield and elsewhere, by the fusion of puddled iron or puddled steel with charcoal, or with pure pig-iron (Canadian or Spiegeleisen), in such proportions as to form steel of the required quality. The Uchatius process is somewhat similar to these in principle; it consists in effecting the partial decarburization of granulated pig-iron by fusing it in contact with iron-ore, but the temper obtained is said to be irregular, and, together with the process just mentioned, it labours under the disadvantage of involving the expensive operation of *fusion in pots*.

Open Hearth.—Some method of effecting the fusion of steel more cheaply than in crucibles, as well as in larger masses, has long been a desideratum. Heath, the discoverer of the beneficial action of manganese, was the first (in 1845) to conceive that cast-steel might be produced in large quantities by fusing wrought and cast-iron together upon the open hearth of a reverberatory furnace. The *modus operandi* he proposed, consisted in melting pig-metal in a cupola, and running it into the heated furnace. The wrought-iron was introduced into another part of the furnace, forming a bank between the bath of fluid metal and the chimney, to be there heated by the waste heat of the flame, previously to its being pushed forward into the liquid in order to be dissolved. Fearing the effect of the ashes from a common fire-place, Heath proposed to heat his furnace by jets of gas, and there is every probability that his experiments would have been crowned with success, if he had possessed the means of imparting to his flame the intensity of heat and, at the same time, the absence of cutting draught, which are essentially necessary. Since the date of Heath's patent, the fusion of steel in an open furnace has formed the subject of an

extensive series of experiments, by Sudre, in France. The experiments of M. Sudre were made at the Montataire Iron Works, at the expense of the Emperor of the French, and were superintended, on his behalf, by three members of the French Institute; MM. Sainte-Claire Deville, Treuille de Beaulieu, Colonel of Artillery, and Caron, Captain of Artillery, who have made an able report on the subject, showing that it is just possible to raise the heat of an ordinary furnace by means of a fan-blast, sufficiently to effect the fusion of tool-steel upon the open hearth in protecting the metal by a layer of glass, but that the rapid destruction of the furnace, the cost of fuel, and other difficulties attending the operation, were such as to render the process, commercially, of doubtful value.

Regenerative Gas Furnace.—The regenerative gas furnace is so manifestly suitable for the operation of melting steel, both in pots and on the open hearth, that my attention was directed from the first towards this object. The early experiments conducted by my brother and myself at Sheffield failed, however, partly on account of certain irregularities, arising from defects in the furnace which have since been removed, but chiefly in consequence of the want of determination on the part of the manufacturers and their workmen to persevere with us to the attainment of the proposed results.

Attwood.—In 1862, Mr. Charles Attwood took a licence to apply the regenerative gas furnace to the melting of steel upon the open hearth in connection with certain chemical processes or mixtures of his own. I supplied the design of a furnace which answered the purpose, except that the quality of steel produced was not such as Mr. Attwood desired. This circumstance decided him to carry out his process in closed pots heated in the same furnace.

Le Chatelier.—In 1863, my friend, M. Le Chatelier, Ingénieur en Chef des Mines, elaborated a process for producing steel from cast-iron by puddling, and melting the hot puddled blooms in a bath of cast-iron prepared in a regenerative gas furnace, upon a bed of *bauxite* of the following composition:—

Silica..............	13 to 17 per cent.	
Alumina	60 to 65	,,
Peroxide of iron....	4 to 8	,,
Water in combination	15 to 17	,,

This material presents the advantage of being exceedingly infusible and of containing no materials that could impart hurtful ingredients to the steel.   A furnace of great heating power was constructed by Messrs. Boigue, Rambour, and Co., at their works near Montluçon, in France, under my superintendence and would certainly have accomplished the desired object if the company had displayed the least determination to succeed.   The furnace-bottom of bauxite did not succeed, as it was not solidified by the heat, and rose to the surface of the liquid bath,—but this defect was soon rectified by the substitution of a white sand bottom.   Through some carelessness, however, the covering arch of the furnace was damaged by excess of heat ; and this slight accident, which proved nothing except an ample sufficiency of heating power, sufficed to deter he company from pressing on to the attainment of that success which was so nearly within their reach.   In the meantime I had granted a licence to Messrs. Emile and Pierre Martin, of the Sireuil Works, to melt steel, both in pots and on the open hearth, and a furnace was erected by them in 1864 which was chiefly intended for a heating furnace, but was at the same time constructed of such materials (Dinas brick) and in such a form as to be also applicable for melting steel.

With this furnace, which was really less suitable than those previously erected, MM. Martin have succeeded in producing cast-steel of good quality and of various tempers, and their produce was awarded a gold medal at the great French Exhibition of last year.   MM. Martin have since patented various arrangements of their own, such as the employment of particular *fluxes* to cover the surface of the molten metal, the application of a *separate furnace* for heating the iron before charging it into the melting furnace, and the employment of particular brands of cast and wrought-iron, which may be useful under special circumstances, but which form no essential part of the general solution of the problem.

Having been so often disappointed by the indifference of manufacturers and the antagonism of their workmen, I determined, in 1865, to erect experimental or "Sample Steel Works" of my own at Birmingham, for the purpose of maturing the details of these processes, before inviting manufacturers to adopt them.   The first furnace erected at these works, is one for melting the higher qualities of steel in closed pots, and

contains 16 pots of the usual capacity. The second, erected in 1867, is an open bath furnace, capable of melting a charge of 24 cwt. of steel every 6 hours. Although these works have been carried on under every disadvantage, inasmuch as I had to educate a set of men capable of managing steel furnaces, the result has been most beneficial, in affording me an opportunity of working out the details of processes for producing cast-steel from scrap-iron of ordinary quality and also directly from the ore, and in proving these results to others.

I shall now proceed to describe the construction and working of the regenerative gas furnaces (similar to those at Birmingham) which are now at work, or in course of erection, in this country and abroad for the production of cast-steel, both by the old method of fusion in pots, and by the new system of making cast-steel on a large scale and on an open furnace bed, from *scrap iron* and from the *ore.*

The regenerative gas furnace consists of two essential parts;

The Gas Producer, in which the coal or other fuel used 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 and gas.

Any combustible gas might be burned in the regenerative furnace; I have used ordinary lighting gas very successfully on a small laboratory scale, but it is far too costly to be employed in larger furnaces, and the only gas generally available is that generated by the complete volatilisation of coal, wood, or other fuel, with admission of air in a special "gas producer." Any description of carbonaceous matter may be worked in a suitable gas producer, and will afford gas sufficiently good for the supply of even those furnaces in which the highest heat is required. Coal is the fuel chiefly used for gas furnaces in England; small coke has been employed in some cases, as in gas-works, where it is to be had at a cheap rate; wood is used in France, Bohemia, and Spain; sawdust in Sweden, furnishing gas for welding and other high-heat furnaces; lignite in various parts of Germany; and peat in Italy and elsewhere; this last being applicable with the greatest relative advantage.
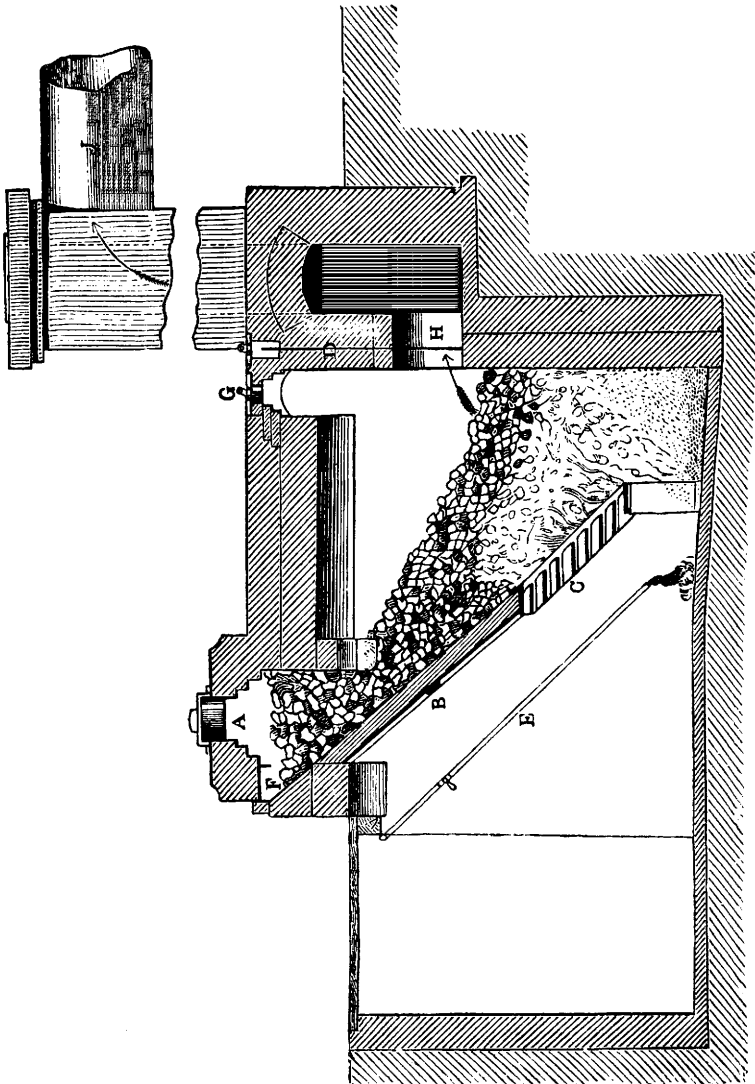
The accompanying illustration represents a gas-producer suitable for burning non-caking slack.

In form 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 is filled in

SECTION OF GAS PRODUCER.

(Scale $\frac{1}{4}$ inch to a foot.)

at the top of the incline at A, and falls in a thick bed upon the grate.   Air is admitted at the grate, and as it rises slowly through the ignited mass, the carbonic acid, first formed by the combination of the oxygen with the carbon of the fuel, takes up an additional equivalent of carbon, forming carbonic oxide, which diluted by the inert nitrogen of the air and by a little unreduced carbonic acid, and mixed with the gases and vapours distilled from the raw fuel during its gradual descent towards the grate, is led off by the gas flue to the furnace. The ashes and clinkers that accumulate on the grate are removed at intervals of one or two days.

The composition of the gas varies with the nature of the fuel used, and the management of the gas producer.   That of the gas from the producers at the Plate Glass Works, St. Gobain, France, burning a mixture of $\frac{3}{4}$ caking coal and $\frac{1}{4}$ non-caking coal is as follows, by an analysis dated July, 1865:—

	Volumes.
Carbonic oxide	23·7
Hydrogen	8·0
Carburetted hydrogen	2·2
Carbonic acid	4·1
Nitrogen......................	61·5
Oxygen	0·4
	99·9

The trace of oxygen present is no doubt due to carelessness in collecting the gas, or to the leakage of air into the flue, and allowing for this, the corrected analysis will stand as under:—

	Volumes.	
Carbonic oxide	24·2 ⎤	
Hydrogen	8·2 ⎬ 34·6	
Carburetted hydrogen	2·2 ⎦	
Carbonic acid	4·2 ⎤ 65·4	
Nitrogen	61·2 ⎦	
	100·0	

Only the first three of these constituents, say 35 per cent. of the whole, are of any use as fuel, the nitrogen and carbonic acid present only diluting the gas.   It is the presence of this

large proportion of inert gases, which must be heated to the full temperature of the flame, that renders it so difficult to maintain a high heat by gas of this description burned in the ordinary way. In using such gas in a regenerative furnace the presence of so large an amount of nitrogen is not objectionable, as the heat it carries off is given up again to the air and gas coming in.

The gas as it passes off from the fuel contains also more or less aqueous vapour, which is got rid of by cooling it, with some tar and other impurities, and a small quantity of suspended soot and dust.

Any air drawing in unburned through a hole in the mass of fuel, reduces the value of the gas, by burning the carbonic oxide again to carbonic acid. To prevent the indraught of air in this way at the side of the grate, I have found it very advantageous to set the side walls of the gas producer back, forming a broad step, about nine or ten inches above the grate; any air creeping up along the wall is thus thrown into the mass of fuel and completely burned. The effect of this feature in the form of the producer on the quality of the gas has been very striking.

Three-tenths of the total heat of combustion of solid carbon are evolved in burning it to carbonic oxide; but in the gas producer, a small portion only of this heat is really lost, because it is in a great measure taken up and utilized in distilling the tar and hydrocarbon gases from the raw fuel; and it may be still further economised, especially in burning a fuel, such as coke or anthracite, which contains little or no volatile matter, by introducing a regulated supply of steam with the air entering at the grate. This is effected very simply by keeping the ash-pit always wet. The steam is decomposed by the ignited coke, and its constituents, hydrogen and oxygen are rearranged as a mixture of hydrogen and carbonic oxide, with a small variable proportion of carbonic acid. Each cubic foot of steam produces nearly two cubic feet of the mixed gases, which, being free from nitrogen have great heating power and form a valuable addition to the gas. The proportion of steam that can be advantageously introduced into the gas producer is, however, limited, as it tends to cool the fire, and if this is at too low a heat, much carbonic acid is produced instead of carbonic oxide, causing waste of fuel.

From the high temperature of the gas, as it rises from the

fuel (1000° F to 1300° F.), and from its comparatively low specific gravity, it is considerably lighter than atmospheric air, and ascends into the upper part of the producer with a slight outward pressure. It is necessary to maintain this pressure through the whole length of the gas flue, in order to ensure a free supply of gas to the furnaces, and to prevent its deterioration in the flue, through the indraught of air at crevices in the brickwork. The slight loss of gas by leakage, which results from a pressure in the flue, is of no moment, as it ceases entirely in the course of a day or two, when the crevices become closed by tar and soot.

Where the furnace stands so much higher than the gas producer, that the flue may be made to rise considerably, the required plenum of 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 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, of not less than 60 square feet of surface per gas producer, 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 1100° F., 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 fluid than the other. The height of cooling tube required to produce as great a pressure in the flue as would be obtained by placing the gas producers, say *ten feet* deeper in the ground may be readily calculated. The temperature of the gas as it rises from the producers has been taken as 1100° F., and we may assume that it is cooled in the overhead tube to 100° F., an extent of cooling very easily attained. The calculated specific gravity, referred to hydrogen, of the gas of which I have quoted the analysis, being 13·14, we obtain the following data:—

		lb.
Weight of the gas per cube foot at 1100° F.	=	·022
,, ,, ,, 100° F.	=	·061
Weight of atmospheric air per cube foot at 60° F.	=	·076

and from these we have, on the one hand, the increase of pressure per foot of height, in a flue rising directly from the gas producer,

$$= \cdot 076 - \cdot 022 = \cdot 054 \text{ lb. per square foot;}$$

and on the other hand, the excess of pressure at the foot of the downtake from the cooling tube, over that at the same level in the flue, leading up from the gas producer (for each foot in height of the cooling tube)

$$= \cdot 061 - \cdot 022 = \cdot 039 \text{ lb. per square foot.}$$

The height of the cooling tube above the level of the flue that will be sufficient to produce the required pressure, equal to 10 feet of heated gas column, is therefore,

$$\frac{\cdot 054}{\cdot 039} . 10 \text{ ft.} = 13' 10'', \text{ or say 14 feet.}$$

This method of obtaining a pressure in the gas-flue by cool-ing the gas, has been objected to as throwing away heat that might be employed to more advantage in the furnace, but this is not the case, because the action of a regenerator is such, that the initial temperature of the gases to be heated has no effect on the final temperature, and only renders the cooling of the hotter fluid more or less complete. The only result, therefore, of working the furnace with gas of high temperature is to increase the heat of the waste gases passing off by the chimney flue. The complete cooling of the gas results, on the other hand, in the great advantage of con-densing the steam that it always carries with it from the gas producer; and in the case of iron and steel furnaces, in burning wet fuel, it is absolutely necessary to cool the gas very thoroughly, in order to get rid of the large amount of steam that it contains, which, if allowed to pass on to the furnace, would oxidize the metal.

There is, undoubtedly, a certain waste of heat, which might

be utilized by surrounding the cooling tube with a boiler, or by otherwise economising the heat it gives off, as, for instance, in drying the fuel; but the saving to be effected is not very great, for as 100 volumes of the gas require for combustion about 130 volumes of air, including 20 per cent. above that theoretically required, the heat given off in cooling the gas 1000° is no more than would be lost in discharging the products of the complete combustion of the fuel, at a temperature 435° in excess of the actual temperature of 200°, and this loss is greatly diminished if a richer gas is obtained.

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 advantages of this are saving of labour and convenience of management, from the gas producers being all close together, and greater regularity in working, as the furnaces are seldom all shut off at once ; nor is it likely that all will require at the same time an exceptional amount of gas.

From the fact that the gas producers may be at any distance from the furnaces that they supply, if they are only at a lower level, it would be perfectly practicable to erect them in the very coal mine itself, burning the slack and waste coal *in situ* (in place of leaving it in the workings as is now often done), and distributing the gas by culverts to the works in the neighbourhood, instead of carrying the coal to the different works and establishing special gas producers at each. In rising to the mouth of the pit, the gas would acquire sufficient pressure to send it through several miles of culvert.

In the regenerative furnace the gas and air employed are separately heated by the waste heat of the flame, by means of what are termed " regenerators," placed beneath the furnace. These are four chambers, filled with fire-bricks, stacked loosely together, so as to expose as much surface as possible ; the waste gases from the flame are drawn down through two of the regenerators, and heating the upper rows of bricks to a temperature little short of that in the furnace itself, pass successively over cooler and cooler surfaces and escape, at length, to the chimney flue nearly cold. The current of hot gases is continued down through these two regenerators until a considerable depth of brickwork, near the top, is uniformly heated

to a temperature nearly equal to that of the entering gas, the heat of the lower portion decreasing gradually downwards, at a rate depending on the velocity of the current, and the size and arrangement of the bricks. The direction of the draught is then reversed; the current of flame or hot waste gases is employed to heat up the second pair of regenerators; and the gas and air entering the furnace are passed in the opposite direction through the first pair, and coming into contact, in the first instance, with the cooler brickwork below, are gradually heated as they ascend, until, at some distance from the top, they attain a temperature nearly equal to the initial heat of the waste gases, and, passing up into the furnace, meet and at once ignite, producing a strong flame, which, after passing through the heating-chamber, is drawn down through the second pair of regenerators to the chimney-flue. The temperature attained by the ascending gas and air remains nearly constant, until the uppermost courses of the regenerator brickwork begin sensibly to cool; but by this time the other two regenerators are sufficiently heated, and the draught is again reversed, the stream of waste gases being turned down through the first pair of regenerators, re-heating them in turn, and the gas and air which enter the furnace being passed up the second.

By thus reversing the direction of the draught at regular intervals, nearly all the heat is retained in the furnace that would otherwise be carried off by the products of combustion, the temperature in the chimney-flue rarely exceeding 300° F., whatever may be the heat in the furnace. The proportion of heat carried off in an ordinary furnace by the products of combustion is generally far greater than that which can be utilized, as all the heat of the flame below the temperature of the work to be heated is absolutely lost. The economy of fuel effected in the regenerative gas furnace, by removing this source of loss, and making all the heat of the waste gases, however low its intensity, contribute to raise the temperature of the flame, amounts in average practice to fully 50 per cent. on the quantity used in an ordinary furnace, and the saving is greater the higher the heat at which the furnace is worked. In addition to this economy in the amount of fuel used, a much cheaper quality may generally be burned in the gas producer than could be used in a furnace working at the same heat, and in which the fuel is burned directly upon the grate in the ordinary way.

When the heat of the furnace is not abstracted continually by cold materials charged into it, the temperaturne necessarily increases after each reversal, as only a very small fraction of the heat generated is carried off by the waste gases.   The gas and air, in rising through the regenerators, are heated to a temperature nearly equal to that at which the flame had been passing down, and when they meet and burn in the furnace the heat of combustion is added to that carried up from the regenerators, and the flame is necessarily hotter than before, and raises the second pair of regenerators to a higher heat.   On again reversing, this higher heat is communicated to the gas and air passing in, and a still hotter flame is the result.

The temperature that may be attained in this way by the gradual accumulation of heat in the furnace and in the upper part of the regenerators appears to be quite unlimited, and the heat at which a suitably designed furnace can be worked is limited in practice only by the difficulty of finding a material sufficiently refractory of which it can be built.

Welsh Dinas brick, consisting of nearly pure silica,* is the only material, of those practically available on a large scale, that I have found to resist the intense heat at which steel-melting furnaces are worked; but though it withstands perfectly the temperature required for the fusion of the mildest steel, even this is melted easily if the furnace is pushed to a still higher heat.

As the gas flame is quite free from the suspended dust which is always carried over from the fuel by the keen draught of an ordinary furnace, the brick-work exposed to it is not fluxed on the surface and gradually cut away, but fails, if at all, only from absolute softening and fusion throughout its mass.   A Stourbridge brick, for example, exposed for a few hours to the heat

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* Analysis of Dinas "clay" from Pont-Neath-Vaughan, Vale of Neath (Percy's Metallurgy, vol. i, p. 237).

Silica	98·31
Alumina	0·72
Protoxide of iron	0·18
Lime	0·22
Potass and soda	0·14
Water combined.	0·35
	——
	99·92

The "clay" is mixed with 1 per cent. of lime in making the bricks.

of the steel-melting furnace, remains quite sharp on the edges, and is little altered even in colour; but it is so thoroughly softened by the intense heat, that on attempting to take it out, the tongs press into it and almost meet, and it is often pulled in two, the half-fused material drawing out in long strings.   It results from this perfect purity of the flame, that where the heat is not sufficient to effect the absolute fusion of the bricks employed, the length of time is almost unlimited, during which a gas furnace will work without repairs.

Another advantage in employing the fuel in the manageable form of gas is that the rate of combustion may be regulated at pleasure to produce an active heating flame of any length, from little more than two feet, as in the pot steel-melting furnaces, to thirty feet in the largest furnaces for the fusion of plate glass ; and the most intense heat may be thrown exactly upon the charge, the ends of the furnace and the apertures through which the gas and air are introduced being actually protected from the heat by the currents of unburned and comparatively cool gases flowing through them, and only mixing and burning at the very point at which the heat is required, and where it is taken up at once by the materials to be fused or heated.   This is of especial importance in the case of those furnaces in which a very intense heat is employed.

The amount of brickwork required in the regenerators to absorb the waste heat of a given furnace is a matter of simple calculation.   The products of the complete combustion of one pound of coal have a capacity for heat equal to that of nearly 17 pounds of firebrick,* and (in reversing every hour) 17 pounds of regenerator brickwork at each end of the furnace per pound

* Taking the analysis by Vaux of the celebrated ten-yard coal of South Staffordshire (Watts' Dictionary of Chemistry, i, 1081), the exact calculation is as follows :—

Composition of the coal.			Oxygen required.
Carbon	·7857	× $\frac{8}{3}$ =	2·0952
Hydrogen........	·0529	× 8 =	0·4232
Sulphur..........	·0039	× 1 =	0·0039
			2·5223
Nitrogen	·0184		
Oxygen	·1288 .... less......		0·1288
Ash	·0103		
		net oxygen required	2·3935
	1·0000	20 per cent. excess	0·4787
		Total Oxygen	2·8721

of coal burned in the gas-producer per hour would be theoretically sufficient to absorb the waste heat, if the whole mass of the regenerator were uniformly heated at each reversal to the full temperature of the flame, and then completely cooled by the gases coming in; but in practice by far the larger part of the depth of regenerator chequer-work is required to effect the gradual cooling of the products of combustion, and only a small portion near the top, perhaps a fourth of the whole mass, is heated uniformly to the full temperature of the flame; the heat of the lower portion decreasing gradually downwards nearly to the bottom. Three or four times as much brickwork is thus required in the regenerators, as is equal in capacity for heat to the products of combustion.

The best size and arrangement of the bricks is determined by the consideration of the extent of opening required between them to give a free passage to the air and gas, and by the rule, deduced from my experiments on the action of regenerators in 1851–2,* that a surface of six square feet is necessary in the regenerator to take up the heat of the products of combustion of one pound of coal in an hour.

By placing the regenerators vertically and heating them from the top, the heating and cooling actions are made much more uniform throughout than when the draught is in any other direction, as the hot descending current on the one hand passes down most freely through the coolest part of the mass, while the ascending current of air or gas to be heated, rises chiefly

	Corresponding Nitrogen ..		9·616
	Nitrogen in the fuel		·018
	Total Nitrogen		9·634

Gases produced from 1 lb. of coal.			Specific heats.	Equivalent weight of water.
Carbonic acid	=	2·881	·217	·625
Water (Steam)	=	0·476	·480	·228
Sulphurous acid	=	0·004	·154	·001
Oxygen in excess	=	0·479	·218	·104
Nitrogen	=	9·634	·244	2·350

Total equivalent weight of water.................... 3·308

„ „ firebrick (sp. heat = 0·2) .... 16·540

* Proceedings of the Institution of Civil Engineers, 1852–3, page 571, On the Conversion of Heat into Mechanical Effect.

through that part which happens to be hottest, and cools it to an equality with the rest.

The regenerators should be always at a lower level than the heating chamber; as the gas and air are then forced into the furnace by the draught of the heated regenerators, and it may be worked to its full power, either with an outward pressure in the heating chamber, so that the flame blows out on opening the doors, or with the pressure in the chamber just balanced, the flame sometimes blowing out a little, and sometimes drawing in. The outward pressure of the flame prevents that chilling of the furnace, and injury to the brickwork, from the in-draught of cold air through crevices, which is otherwise unavoidable in any furnace worked without blast.

The action of the furnace is regulated by the chimney damper, and by valves governing the supply of gas and air, and the draught is reversed by cast-iron reversing valves, on the principle of the common four-way cock.

Fusion of Steel in Crucibles.—In the application of the system to the fusion of steel in closed pots or crucibles, the melting chamber, containing generally 24 pots, is constructed in the form of a long trench, 3 feet 6 inches wide at the bottom, and gathered in to under 2 feet at the top. The sides of the melting-chamber are arched both horizontally and vertically, to keep them from sinking together in working, and the work is strengthened by cross walls at intervals. The pots are set in a double row along the centre of the melting-chamber, and the flame passes from side to side, the gas and air from the regenerators being introduced alternately from one side and from the other, opposite to each pair of pots. The melting chamber is closed above by loose firebrick covers, which are drawn partly off in succession by means of a lever suspended from a pulley above the furnace, when the pots are to be charged or drawn out. The pots stand in a bed of finely ground coke-dust, resting on iron plates. The coke dust burns away only very slowly, if it is made of hard coke and finely ground, and it presents the great advantage of remaining always in the form of a loose dry powder, in which the pots stand firmly, while every other material that I have tried either softens at the intense heat, or sets after a time into a hard, uneven mass, in which the pots do not stand well.

The process of melting carried out in this form of gas furnace

is the same in all respects as that in the small air furnaces or melting-holes fired with coke which are commonly employed, but a great saving is effected in the cost of fuel, and in the number of crucibles required.

The ordinary consumption of hard coke, costing 22s. per ton in Sheffield, is between three and four tons per ton of steel fused, while in the gas furnace the same work may be done by the expenditure of 15 to 20 cwt. of common coal slack (worth only 5s. to 8s. per ton), at a cost that is of only 5s. against 75s. per ton of steel melted. There is a further saving in the number of crucibles required, as they may be used in the gas furnace four or five, and sometimes even ten times, while in furnaces heated by coke, two or three casts are as much as are ever obtained. The lining of the furnace lasts at least 15 to 20 weeks without repair (in working day and night), while 4 to 5 weeks is the longest duration of the ordinary coke-fired holes.

Fusion of Steel on the Open Bed.—The furnace employed for the fusion of steel on the open bed is similar in shape to a reheating or puddling furnace; the direction of the flame is from end to end; and the regenerators are placed transversely below the bed, which is supported on iron plates, kept cool by a current of air. The air enters beneath the bed plates in front, and escapes by two ventilating shafts at the back of the furnace near the ends. This cooling of the bed is very necessary to keep the slag or melted metal from finding its way through into the regenerator chambers. The upper part of the furnace is built entirely of Dinas brick.

There are three doors in the front of the furnace, one in the centre immediately over the tap-hole, and two near the bridges, through which the bed can be repaired when necessary, and ingot ends or other heavy scraps may be charged in. Sloping shoots are provided at the back of the furnace, through which long bars, such as old rails, may be conveniently charged, and beneath these are openings for charging the pig-iron. The upper end of the shoots is on a level with an elevated charging platform behind the furnace.

The bottom of the furnace is formed of siliceous sand, which answers exceedingly well if properly selected and treated.

Instead of putting moist sand into the cold furnace, as is usually done in preparing the bottoms of furnaces for heating or melting iron or copper, I dry the sand, and introduce it into the hot

furnace, in layers of about 1″ thickness.   The heat of the furnace must be sufficient to fuse the surface of each layer, that is to say, it must rather exceed a welding heat to begin with, and rise to a full steel-melting heat at the end of the operation, in order to impart additional solidity to the uppermost layers. Care must be taken that the surface of the bath assumes the form of a shallow basin, being deepest near the tap-hole.   Some white sands, such as that from Gornal, near Birmingham, will set under these circumstances into a hard impervious crust, capable of surviving from 20 to 30 charges of liquid steel, without requiring material repairs.   If no natural sand of proper quality is available, white sand, such as Fontainebleau sand, may be mixed intimately with about 25 per cent. of common red sand, to obtain the same results.

In tapping the furnace, the loose sand near the tapping-hole is removed, when the lower surface of the hard crust will be reached.   The lowest point of this surface is thereupon pierced by means of a pointed bar, upon the withdrawal of which the fluid metal runs out from the hottest and deepest portion of the bath into the ladle in front of the furnace.

M. Le Chatelier now proposes to mix the natural Bauxite, of which the bottom of the experimental furnace at the works of MM. Boignes, Rambourg and Co., near Montluçon was first made, with about 1 per cent. of chloride of calcium in solution, to calcine the mixture, and to form it into moulded masses of highly refractory material.

A hard bottom being thus prepared, and the heat of the furnace being raised to whiteness, it is ready to receive the materials to be melted.

If these materials consist of bar iron, or of old iron and steel rails, they are cut into lengths of about six feet, and are introduced into the furnace through slanting hoppers from the elevated platform at the back, so that their ends rest upon the sand bottom forming the bath.

If the capacity of the furnace is such, that charges of 3 tons can be formed, about 6 cwt. of grey pig-iron is introduced through the ports or short hoppers, below the main charging hoppers before-mentioned.   As soon as a bath of pig metal is formed, the heated ends of the rails or bars begin to dissolve, causing the bars gradually to descend.   By partially closing the mouths of the charging hoppers, a regulated quantity of

THE REGENERATIVE GAS FURNACE AS APPLIED TO THE PRODUCTION
OF CAST STEEL DIRECTLY FROM THE ORE.

FIG 2
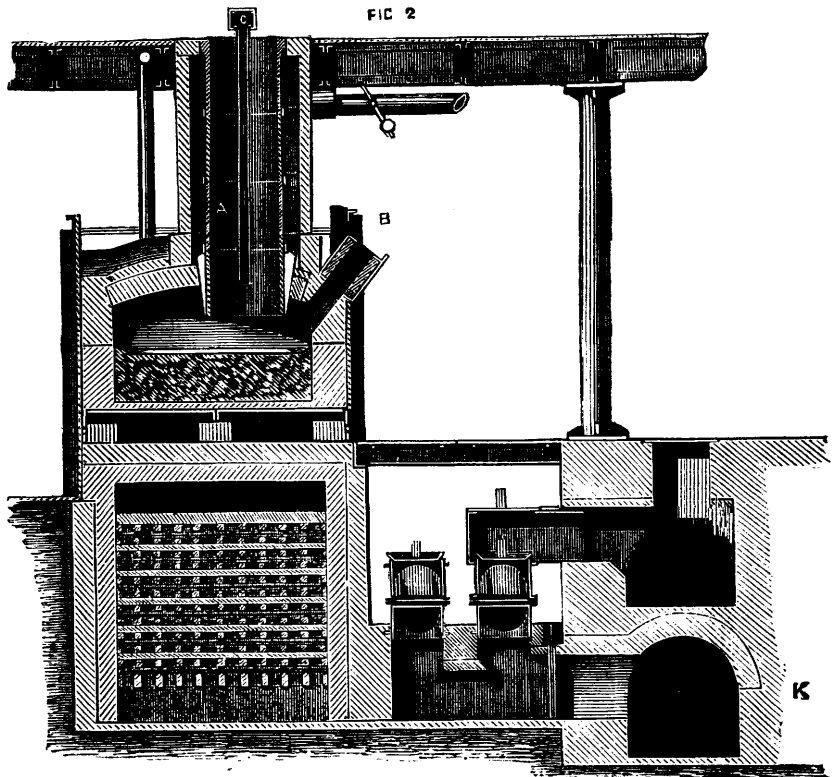
Transverse section on line C D.
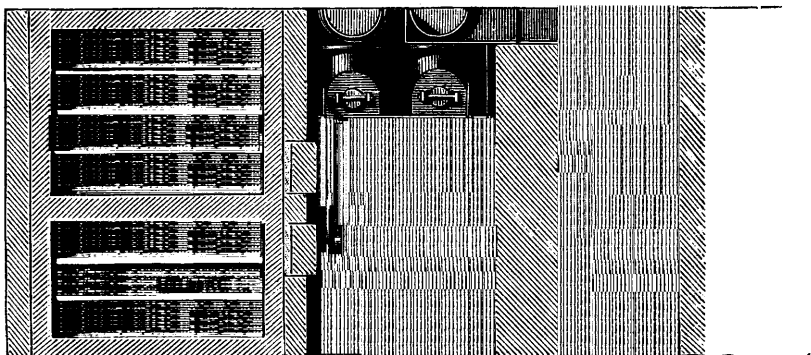
Half plan through the regenerator chamber and main gas flue.
Scale $\frac{1}{8}$ inch to a foot.

AA Charging shoots for the ore.
BB Charging shoots for the pig iron.
C Tube conveying reducing gas into the mass of ore.

flame is allowed to escape from the furnace, in order to heat the descending bars of metal previous to their entry into the melting-chamber, the object being to maintain the high temperature of the furnace, notwithstanding the constant introduction of cold metal. The escaping products of combustion, which are thus withdrawn from the regenerators, are a positive gain to the heat of the furnace, because, having been in contact with comparatively cold metal, they would be at a heat inferior to that of the upper portions of the regenerators, and would therefore only lower their temperatures.

As the bars sink in the hoppers by their gravity, they are followed up by additional bars until the metal charged amounts to about three tons, all of which will be rendered fluid within about four hours from the time of commencing the charge. The metallic bath is tested from time to time by the introduction of a bar through one of the front doors of the furnace, and if the bath should become thick before the end of the operation, although the heat has been maintained, it will be necessary to introduce an additional quantity of pig-metal. All the metal being liquid, a sample is taken out by means of a small iron ladle, and plunged into cold water while still red-hot. In breaking this sample upon an anvil, the temper and quality of the metal may be fairly judged. Its fracture should be bright and crystalline, betokening a very small proportion of carbon (not exceeding ·1 per cent.), and the metal should be tough and malleable, notwithstanding its sudden refrigeration. From 5 to 8 per cent. of Spiegeleisen (containing not less than 9 per cent. of manganese), is thereupon charged through the side openings upon the bank of the furnace, and allowed to melt down into the bath, which is then stirred and made ready for tapping in the manner before described.

The amount of carbon introduced with the Spiegeleisen determines the temper of the steel produced, the manganese being necessary to prevent redshortness, unless Swedish or Styrian iron is used.

When old iron rails or scrap of inferior quality are charged, the addition of manganese does not suffice to effect the necessary purification of the steel produced; but the perfectly liquid condition of the bath, together with the unlimited time available for chemical reaction, offer extraordinary advantages for the introduction of such materials as may be found to combine with

sulphur, phosphorus, silicon, or arsenic, which are the usual antagonists to be dealt with.

The experiments which I have been able to institute in this direction, are by no means complete;—nevertheless, I have obtained most beneficial results from the introduction into the bath of litharge, in conjunction with oxidising salts containing strong bases, such as the alkaline nitrates, chromates, chlorates, stannates, titanates, &c.

The choice of the reagents and the quantity to be employed depend, naturally, upon the quality and quantity of objectionable matter to be removed.

By the aid of the process just described, it will be possible to convert old iron rails into steel rails of sufficiently good quality at a cost scarcely exceeding that of re-rolling them into fresh iron rails. The non-expensive nature of the process may be judged by the fact that extremely little labour is required in conducting it; that the loss of metal does not exceed from 5 to 6 per cent., and that from 10 to 12 cwt. of coal suffices to produce a ton of cast steel.

Ore.—Although I have succeeded in producing malleable steel from ordinary English iron by this process, it would be unreasonable to expect steel of really high quality, in using those materials which are already contaminated in the blast-furnace; and I am sanguine in the expectation of producing cast steel superior in quality, and at a low cost, directly from the better description of ores, such as the hæmatites, magnetic oxides, and the spathic carbonates. My experiments in this direction extend over several years; and last year I sent a few bars of steel produced from hæmatite ore, to the French Exhibition, which had stood a high test in Kirkcaldy's machine. A "grand prix" was awarded for this and other applications of the regenerative gas furnaces.

Having tried various modifications of the furnace, I have arrived at a form of apparatus not dissimilar to the one just described. The furnace and tapping arrangements are, indeed, the same, except that for the slanting hoppers, vertical hoppers over the middle of the bath, are substituted, in which the ore gradually descends. Each hopper is formed of a cast iron pipe, supporting a clay-pipe, which is attached to it by means of a bayonet-joint, and reaches down into the furnace, while the cast-iron pipe rests with its flange on the charging platform.

THE REGENERATIVE GAS FURNACE AS APPLIED TO THE PRODUCTION
OF CAST STEEL DIRECTLY FROM THE ORE.
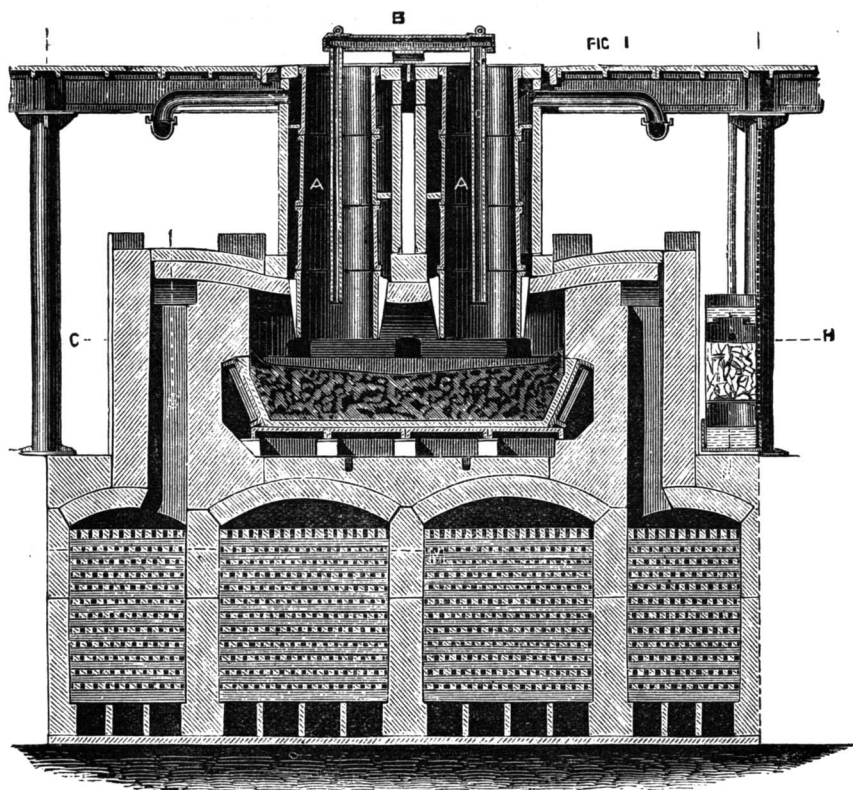
Longitudinal section on the line G H.
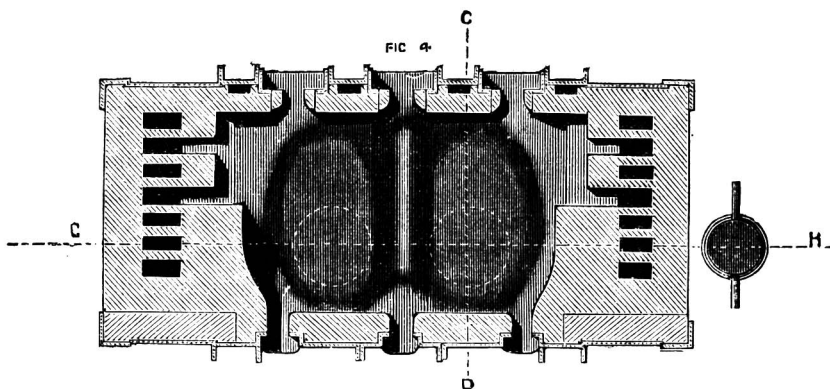
Section of plan through the melting chamber.
Scale $\frac{1}{8}$ inch to a foot.

A fire space is provided surrounding each hopper, through which flame ascends from the furnace, and is allowed to escape in regulated quantities near the upper extremity of the retort, the object being to heat the latter and the ore contained in it to a red heat. A wrought iron pipe descends into each hopper from a general gas-tube above, through which a current of ordinary producer gas is forced in amongst the heated ore. The propulsion of the gas is effected most conveniently by means of a steam-jet in the gas-tube leading from the main gas-channel to the top of the furnace, care being taken to effect a total condensation of the steam by passing the gas finally through a small scrubber, in which water trickles over pieces of coke. In this way the gas is at the same time purified from sulphurous acid, the sulphur of which might otherwise combine with the reduced ore.

The furnace is charged in the following manner:—

The hoppers and gas-pipes being placed in position, about $\frac{1}{4}$ cwt. of charcoal is charged through each hopper to form a basis for the ore with which these are afterwards filled.

About 10 cwt. of pig-metal is charged through the ports at the back or front of the furnace, which, upon being melted, forms a metallic bath below the hoppers. In the meantime, the ore in the lower parts of the hoppers, being heated in an atmosphere of reducing gas, has become partially reduced into metal sponge, which, in reaching the metallic bath, is readily dissolved in it, making room for the descent of the superincumbent ore, which is likewise reduced in its descent and dissolved in due course, fresh ore being continually supplied on the charging platform. The dissolution of the reduced ore proceeds with extraordinary rapidity, but is practically limited by the time necessary to effect the reduction of the ore in the hopper which occupies several hours. It is, however, not essential that the ore should be thoroughly reduced before reaching the bath, because the carbon contained in the cast metal serves also to complete the operation.

I prefer to employ a mixture of hæmatite and spathic ore, containing the elements for forming a fusible slag, which will accumulate on the surface of the metallic bath, and may be from time to time removed through the centre door. If the ore contains any silica, it is necessary to add some lime or other fluxing materials, but it is desirable to employ ores containing

little gangue, in order not to encumber the furnace with slag, reserving the poorer ores for the blast furnace.   The ore should moreover, be in pieces ranging from the size of a pea to that of a walnut, in order to be pervious to the reducing gases.   If ores in the form of powder are employed, it is necessary to mix them with about 10 per cent. by weight of light carbonaceous materials, such as dry peat, wood, or charcoal.

The metallic bath having sufficiently increased in the course of from three to four hours, the supply of ore is stopped, and that contained in the hoppers is allowed to sink.   Before the hoppers are empty, a false cover of cast iron, lined with clay at its under side, is introduced, being suspended from above by a strong wire, in order to prevent the access of flame to the interior of the empty hoppers.   Charcoal and ore are filled in upon the top of this false cover, and, on cutting the wire, afterwards form the commencement of the succeeding charge.

When all the ore has disappeared, the metallic bath is tested as before described in reference to the melting of scrap.   If it should be partially solidified, cast iron is added to re-establish complete liquefaction ; but if, on the other hand, the bath contains an excess of carbon, oxidising agents may be added as before described, in requisite proportion.   From 5 to 8 per cent. of Spiegeleisen is then added, and the furnace is tapped as already described.

The quality of the steel produced is chiefly dependent upon the quality of the ore, but considering that ores of great freedom from sulphur, phosphorus, or arsenic can be had in large quantities, this process contains all the elements for producing steel of high quality.

Having tried a variety of ores, I do not attach much importance to their precise composition, so long as they are comparatively free from gangue, and from sulphur and phosphorus, the heat being sufficient to reduce the most refractory.   My experience is, however, as yet limited to experimental working.

I hoped to have been in a position to have given you the temperature of this furnace, as determined by an electric resistance pyrometer, which I have constructed for this purpose, but have not yet been able to obtain satisfactory results, owing to the destruction of the coil of platinum wire, which has to be exposed to the heat.   My efforts were baffled moreover by the fact, interesting in itself, that platinum wire produced by fusion

in Deville's furnace, does not increase in electrical resistance, with increase of temperature in the same ratio as that produced by the old process, owing probably to the presence of carbon or other alloy in fractional quantities.

Avoiding the use of fused platinum wire, I have measured temperatures by electrical resistance up to a full welding heat, which I estimate at 1,600° C. = 2,900° F.; and in judging the heat of the steel-melting furnace by comparison of effects, I should put it at not less than 2,200° C. = 4,000° F. The effect of this degree of heat may be judged by the following:—

An ingot of rather hard cast-steel, weighing 6 cwt., was introduced into the furnace to be incorporated with the bath of steel. The ingot was nearly cold, and was allowed to remain fifteen minutes upon the bank before it was pushed into the bath, where it was completely dissolved in fifteen minutes, the time occupied in heating and melting the ingot being thirty minutes. A cube of wrought metal of nearly 8 inches, weighing 130 lbs., was also introduced cold into the furnace, and allowed to remain upon the bank during ten minutes to be heated externally to whiteness, before being pushed into the metallic bath, when twelve minutes sufficed to render it completely liquid. It must be borne in mind that these results are produced without a strong draught, the flame being indeed so mild, as not to oxidize the unprotected metal, which can be maintained for several hours as liquid steel in the furnace without adding carbon in any form.

It may be matter for surprise, that the material composing the furnance can be made to resist such a heat, and it must be admitted that best Dinas brick is the only brick capable of resisting for four to five weeks, by which time the thickness of the arch is reduced to about 2 inches, by the absolute fusion of the inner surface; but this excessive heat is confined to the heated chamber only, the regenerators being at such a moderated heat, that the chequerwork will stand for months, and the arches for years of constant working.

In conclusion, I wish to express to you my sense of the disproportion that exists between the magnitude of the task I have brought before you, and my ability to accomplish it in all its ramifications. It may be granted that the Regenerative Gas Furnace itself has passed beyond its experimental stage, but much is yet to be done in working out the applications of the

system to the useful arts, and the modifications and improvements in processes which it frequently involves.

Much, also, is yet to be done before the method of producing cast steel, in one direct process from the ore, can take its place as the recognized system of making steel on a large scale from the purer iron ores, a position that I firmly believe it will assume, sooner or later. It is my earnest hope that, in bringing the subject before your Society, I may induce some of its members to forward this result, by taking up particular branches of the scientific inquiries upon which I have only been able to touch lightly in my present communication. I have much pleasure in acknowledging the assistance I have received in working out this subject from Mr. William Hackney, my principal superintendent, and Mr. Willis, the chemist in charge at my experimental works,